

**A STUDY OF STATISTICAL ARBITRAGE OPPORTUNITIES
IN INDIAN SECURITIES MARKET**

Dissertation

**Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of**

**DOCTOR OF PHILOSOPHY
in
BUSINESS ADMINISTRATION
(Minor Subject: Economics)**

By

**Geetu Aggarwal
(L-2015-BS-76-D)**

**School of Business Studies
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CERTIFICATE I

This is to certify that the dissertation entitled “**A Study of Statistical Arbitrage Opportunities in Indian Securities market**” submitted for the degree of **Ph.D.**, in the subject of **Business Administration** (Minor subject: **Economics**) of Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Geetu Aggarwal (L-2015-BS-76-D)** under my supervision and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE II

This is to certify that the dissertation entitled “**A Study of Statistical Arbitrage Opportunities in Indian Securities market**” submitted by **Geetu Aggarwal (L-2015-BS-76-D)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **Ph.D.**, in the subject of **Business Administration** (Minor subject: **Economics**) has been approved by the Student’s Advisory Committee after an oral examination on the same in collaboration with an External Examiner.

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ABSTRACT

Statistical arbitrage is a trading strategy that employs time series methods to identify relative mispricing between securities based on expected values of these assets. This study is undertaken to study statistical arbitrage opportunities present in Indian securities market through pairs trading, one of the most popular techniques of statistical arbitrage. Specifically, the study focuses on the profitability of pairs trading to common investors and attribution of returns to different risk factors. The study is conducted across three asset classes and under different scenarios of the underlying assets involved, viz., stock futures market, stock spot market, stock spot-future market, commodity futures market, currency futures market, currency spot market and currency spot-future statistical arbitrage. Daily prices of securities traded and listed on their respective exchanges over 2011–2017 are used on rolling basis to compute the performance of pairs trading based on the selection of pairs of securities through minimizing the sum of squared deviation (distance method) and cointegration tests (cointegration method). Pairs trading strategy is executed in two stages: the pairs formation period and the pairs trading period. The strategy is executed by taking long position in one security and short position in other security of the identified security pairs. To examine the risk of pairs trading and the drivers of returns, the portfolio returns are risk-adjusted using Fama and French (1993) three factor asset pricing model. The study reveals that pairs trading in stock futures is significantly profitable with average annualized profitability of up to 34% including transaction costs. At the same time, statistical arbitrage opportunities present in stock spot market and stock spot-future scenario are not profitable. On the other hand, pairs trading in commodities is significantly profitable, with average annualised profitability of up to 59 percent, including transaction costs. While currency spot and currency future market do present statistical arbitrage opportunities, they are not profitable enough to cover the underlying risk. Meanwhile, the currency spot-future statistical arbitrage generates annualized return of 10.52% in a near riskless arbitrage scenario. The evidence of pairs trading profits supports the view that these profits reflect compensation to arbitrageurs for enforcing the law of one price in similarly related markets to ensure market efficiency. Indian financial markets are maturing and are attracting sizable retail and institutional investments. Advanced applications like the one presented in this study are of significance for the investors and investment consultants so that they can benefit from such trading strategies.

Keywords: Statistical arbitrage; Pairs trading; Market neutral; Financial assets; Stock futures; Commodity futures; Currency futures; Distance method; Cointegration; Fama and French (1993)

Signature of Major Advisor

Signature of the Student

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ਸਾਰ-ਅੰਸ਼

ਸਟੈਟਿਸਟਿਕਲ ਆਰਬਿਟਰੇਜ ਇੱਕ ਅਜਿਹੀ ਵਪਾਰਕ ਰਣਨੀਤੀ ਹੈ ਜੋ ਇਹਨਾਂ ਸੰਪਤੀਆਂ ਦੇ ਅਨੁਮਾਨਤ ਮੁੱਲਾਂ ਦੇ ਅਧਾਰ 'ਤੇ ਸਮਾਂ ਅੰਤਰਾਲਾਂ ਦੀ ਵਰਤੋਂ ਕਰਕੇ ਸਕਿਊਰਟੀਸ ਦਰਮਿਆਨ ਗਲਤ ਮੁੱਲਾਂ ਦਾ ਪਤਾ ਲਗਾਉਂਦੀ ਹੈ। ਮੌਜੂਦਾ ਅਧਿਐਨ ਦੌਰਾਨ, ਸਟੈਟਿਸਟਿਕਲ ਆਰਬਿਟਰੇਜ ਦੀ ਸਭ ਤੋਂ ਮਸ਼ਹੂਰ ਵਿਧੀ, ਪੇਅਰਸ ਟ੍ਰੇਡਿੰਗ, ਦੀ ਵਰਤੋਂ ਕਰਕੇ ਇੰਡੀਅਨ ਸਕਿਊਰਟੀਸ ਮਾਰਕੀਟ ਵਿੱਚ ਪਾਏ ਜਾਣ ਵਾਲੇ ਸਟੈਟਿਸਟਿਕਲ ਆਰਬਿਟਰੇਜ ਅਵਸਰਾਂ ਦਾ ਪਤਾ ਲਗਾਇਆ ਗਿਆ। ਇਸ ਅਧਿਐਨ ਦੌਰਾਨ ਮੁੱਖ ਤੌਰ ਤੇ ਸਧਾਰਨ ਨਿਵੇਸ਼ਕਾਂ ਲਈ ਪੇਅਰਸ ਟ੍ਰੇਡਿੰਗ ਦੀ ਲਾਭਦਾਇਕਤਾ ਅਤੇ ਵੱਖੋ-ਵੱਖਰੇ ਜੋਖਿਮਾਂ ਦਾ ਪਤਾ ਲਗਾਇਆ ਗਿਆ। ਅਧਿਐਨ ਤਿੰਨ ਸੰਪਤੀ ਵਰਗਾਂ ਵਿੱਚ ਅਤੇ ਇਹਨਾਂ ਸੰਪਤੀਆਂ ਦੇ ਵੱਖੋ-ਵੱਖਰੇ ਪਰਿਪੇਕਸ਼ਾਂ ਜਿਵੇਂ ਕਿ ਸਟਾਕ ਫਿਊਚਰਸ ਮਾਰਕੀਟ, ਸਟਾਕ ਸਪੋਟ ਮਾਰਕੀਟ, ਸਟਾਕ ਸਪੋਟ-ਫਿਊਚਰਸ ਮਾਰਕੀਟ, ਕੋਮੋਡਿਟੀ ਸਟਾਕ ਫਿਊਚਰਸ ਮਾਰਕੀਟ, ਕਰੰਸੀ ਸਪੋਟ ਮਾਰਕੀਟ ਅਤੇ ਕਰੰਸੀ ਸਪੋਟ-ਫਿਊਚਰਸ ਮਾਰਕੀਟ ਸਟੈਟਿਸਟਿਕਲ ਆਰਬਿਟਰੇਜ ਦਰਮਿਆਨ ਕੀਤਾ ਗਿਆ। ਵਰਗ ਵਿਚਲਣ ਦੀ ਰਾਸ਼ੀ ਨੂੰ ਘੱਟ ਕਰਕੇ (ਡਿਸਟੇਂਸ ਵਿਧੀ) ਅਤੇ ਕੋਇੰਟੀਗ੍ਰੇਸ਼ਨ ਟੈਸਟ (ਕੋਇੰਟੀਗ੍ਰੇਸ਼ਨ ਵਿਧੀ) ਦੀ ਵਰਤੋਂ ਕਰਕੇ ਸਕਿਊਰਟੀਸ ਦੇ ਪੇਅਰਸ ਦੀ ਚੋਣ ਦੇ ਅਧਾਰ ਤੇ ਪੇਸਰਸ ਟ੍ਰੇਡਿੰਗ ਦੀ ਕਾਰਜ-ਸਮਰੱਥਾ ਦਾ ਆਂਕਲਣ ਕਰਨ ਲਈ ਟਰੇਡ ਕੀਤੀਆਂ ਗਈਆਂ ਸਕਿਊਰਟੀਸ ਦੇ ਰੋਜ਼ਾਨਾ ਦੇ ਮੁੱਲ ਅਤੇ ਸੰਨ 2011-17 ਦੌਰਾਨ ਇਹਨਾਂ ਦੇ ਐਕਸਚੇਂਜ ਦੀ ਵਰਤੋਂ ਕੀਤੀ ਗਈ। ਪੇਅਰਸ ਟ੍ਰੇਡਿੰਗ ਰਣਨੀਤੀ ਨੂੰ ਦੋ ਪੜਾਵਾਂ ਵਿੱਚ ਚਲਾਇਆ ਗਿਆ: ਪੇਅਰਸ ਫਾਰਮੇਸ਼ਨ ਅੰਤਰਾਲ ਅਤੇ ਪੇਅਰਸ ਟ੍ਰੇਡਿੰਗ ਅੰਤਰਾਲ। ਰਣਨੀਤੀ ਦੀ ਪਛਾਣ ਇੱਕ ਸਕਿਊਰਟੀ ਵਿੱਚ ਲੰਬੀ ਸਥਿਤੀ ਅਤੇ ਪਛਾਣੀ ਗਈ ਸਕਿਊਰਟੀ ਪੇਅਰਸ ਦੀ ਦੂਸਰੀ ਸਕਿਊਰਟੀ ਵਿੱਚ ਛੋਟੀ ਸਥਿਤੀ ਨਾਲ ਕੀਤੀ ਗਈ। ਪੇਅਰਸ ਟ੍ਰੇਡਿੰਗ ਵਿੱਚ ਜੋਖਿਮਾਂ ਅਤੇ ਵਾਪਸੀ ਦੇ ਡ੍ਰਾਇਵਰਸ ਦਾ ਪਤਾ ਲਗਾਉਣ ਲਈ, ਫਾਮਾ ਅਤੇ ਫ੍ਰੈਂਚ (1993) ਦੁਆਰਾ ਸੁਝਾਏ ਗਏ ਤਿੰਨ ਕਾਰਕੀ ਐਸਟ ਪ੍ਰਾਈਸਿੰਗ ਮਾਡਲ ਦੀ ਵਰਤੋਂ ਕਰਕੇ ਪੋਰਟਫੋਲੀਓ ਰਿਟਰਨਸ ਨੂੰ ਜੋਖਿਮ ਅਨੁਕੂਲ ਕੀਤਾ ਗਿਆ। ਅਧਿਐਨ ਤੋਂ ਪਤਾ ਚੱਲਿਆ ਕਿ ਸਟਾਕ ਫਿਊਚਰਸ ਵਿੱਚ ਪੇਅਰਸ ਟ੍ਰੇਡਿੰਗ ਅਰਥਪੂਰਨ ਤੌਰ ਤੇ ਲਾਭਕਾਰਕ ਹੈ ਅਤੇ ਇਸ ਤੋਂ ਟ੍ਰਾਂਜੈਕਸ਼ਨ ਖਰਚੇ ਸਣੇ ਸਾਲ ਵਿੱਚ ਔਸਤਨ 34% ਮੁਨਾਫਾ ਮਿਲਦਾ ਹੈ। ਇਸੇ ਸਮੇਂ, ਸਟਾਕ ਸਪੋਟ ਮਾਰਕੀਟ ਅਤੇ ਸਟਾਕ ਸਪੋਟ-ਫਿਊਚਰ ਵਿੱਚ ਮੌਜੂਦ ਸਟੈਟਿਸਟਿਕਲ ਆਰਬਿਟਰੇਜ ਅਵਸਰ ਵਧੇਰੇ ਮੁਨਾਫੇ ਵਾਲੇ ਨਹੀਂ ਸਨ। ਦੂਜੇ ਪਾਸੇ, ਕੋਮੋਡਿਟਿਸ ਵਿੱਚ ਪੇਅਰਸ ਟ੍ਰੇਡਿੰਗ ਅਰਥਪੂਰਨ ਤੌਰ 'ਤੇ ਲਾਭਕਾਰੀ ਹੈ, ਇਸ ਤੋਂ ਇਸ ਤੋਂ ਟ੍ਰਾਂਜੈਕਸ਼ਨ ਖਰਚੇ ਸਣੇ ਸਾਲ ਵਿੱਚ ਔਸਤਨ 59% ਮੁਨਾਫਾ ਮਿਲਦਾ ਹੈ। ਭਾਵੇਂ ਕਰੰਸੀ ਸਪੋਟ ਅਤੇ ਕਰੰਸੀ ਫਿਊਚਰ ਮਾਰਕੀਟ ਵੀ ਸਟੈਟਿਸਟਿਕਲ ਆਰਬਿਟਰੇਜ ਅਵਸਰ ਦਿੰਦੀ ਹੈ, ਪਰ ਇਹ ਜੋਖਿਮਾਂ ਦੇ ਲਿਹਾਜ਼ ਨਾਲ ਜ਼ਿਆਦਾ ਫਾਇਦੇਮੰਦ ਨਹੀਂ ਹੈ। ਇਸੇ ਸਮੇਂ ਦੌਰਾਨ, ਕਰੰਸੀ ਸਪੋਟ-ਫਿਊਚਰ ਸਟੈਟਿਸਟਿਕਲ ਆਰਬਿਟਰੇਜ ਨੇ ਨੇੜਲੇ ਜੋਖਿਮ ਰਹਿਤ ਸਟੈਟਿਸਟਿਕਲ ਪਰਿਪੇਕਸ਼ ਵਿੱਚ ਸਲਾਨਾ 10.52% ਮੁਨਾਫਾ ਦਿੱਤਾ। ਪੇਅਰਸ ਟ੍ਰੇਡਿੰਗ ਲਾਭ ਦੇ ਮੁਨਾਫਿਆਂ ਦੇ ਸਬੂਤ ਇਸ ਗੱਲ ਦਾ ਸਮਰੱਥਨ ਕਰਦੇ ਹਨ ਕਿ ਇਹ ਮੁਨਾਫਸ ਆਰਬਿਟਰੇਜਰਾਂ ਦੇ ਮੁਆਵਜ਼ੇ ਨੂੰ ਉਸੇ ਤਰ੍ਹਾਂ ਨਾਲ ਸਬੰਧਤ ਬਾਜ਼ਾਰਾਂ ਵਿੱਚ ਇੱਕ ਕੀਮਤ ਦੇ ਕਾਨੂੰਨ ਨੂੰ ਲਾਗੂ ਕਰਨ ਲਈ ਦਰਸਾਉਂਦਾ ਹੈ ਤਾਂ ਜੋ ਮਾਰਕੀਟ ਦੀ ਕੁਸ਼ਲਤਾ ਨੂੰ ਯਕੀਨੀ ਬਣਾਇਆ ਜਾ ਸਕੇ। ਭਾਰਤੀ ਵਿੱਤੀ ਬਾਜ਼ਾਰ ਵੱਧ-ਫੁੱਲ ਰਹੇ ਹਨ ਅਤੇ ਵੱਡੇ ਪ੍ਰਚੂਨ ਅਤੇ ਸੰਸਥਾਗਤ ਨਿਵੇਸ਼ਾਂ ਨੂੰ ਆਕਰਸ਼ਿਤ ਕਰ ਰਹੇ ਹਨ। ਵਿਕਸਤ ਐਪਲੀਕੇਸ਼ਨਾਂ, ਜਿਹਨਾਂ ਵਿੱਚੋਂ ਇੱਕ ਜੋਕਿ ਮੌਜੂਦਾ ਅਧਿਐਨ ਵਿੱਚ ਦਰਸਾਈ ਗਈ ਹੈ, ਨਿਵੇਸ਼ਕਾਂ ਅਤੇ ਨਿਵੇਸ਼ ਸਲਾਹਕਾਰਾਂ ਲਈ ਮਹੱਤਵਪੂਰਨ ਹਨ ਤਾਂ ਜੋ ਉਹ ਇਹਨਾਂ ਟ੍ਰੇਡਿੰਗ ਰਣਨੀਤੀਆਂ ਦਾ ਲਾਭ ਉਠਾ ਸਕਣ।

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TABLE OF CONTENTS

Chapter	Contents	Page No.
	ABSTRACT	
	LIST OF TABLES	
	LIST OF FIGURES	
	LIST OF ABBREVIATIONS	
I	INTRODUCTION	1-20
1.1	Background and Introduction	1
1.2	Types of Statistical Arbitrage Strategies	5
1.3	Working of Statistical Arbitrage Strategy	6
	1.3.1 Pairs Trading	6
	1.3.2 Working of Pairs Trading	8
1.4	Advantages and Risks in Pairs Trading	12
1.5	Use of Cointegration Theory in Statistical Arbitrage (with reference to pairs trading)	12
1.6	The Bottom Line	14
1.7	Preliminary Literature Review and Research Gap	15
1.8	Research Aim, Approach and Methodology	17
	1.8.1 Aim	17
	1.8.2 Approach	17
	1.8.3 Methodology	17
1.9	Research Objectives	17
1.10	Need and Significance of Study	18
1.11	Scope of Study	19
1.12	Outline of the Thesis	19
II	REVIEW OF LITERATURE	21-38
2.1	Introduction	21
2.2	Review of Literature	21
	2.2.1 Statistical Arbitrage	21
	2.2.2 Pairs Trading	23
	2.2.3 Fama and French Three Factor Model	26

Chapter	Contents	Page No.
	2.2.4 Statistical Arbitrage in Indian Securities Market	28
	2.3 Summary of Studies and their Empirical Findings	28
	2.4 Observations and Research Gap	38
III	RESEARCH METHODOLOGY	39-71
	3.1 Conceptual Framework of the Study	39
	3.2 Objectives, Scope and Hypotheses	40
	3.2.1 Objectives of the Study	40
	3.2.2 Saunders Research Onion	41
	3.2.3 Nature and Scope of the Study	42
	3.2.4 Statement of Hypotheses	43
	3.3 Population and Sampling	45
	3.3.1 Stock Markets	45
	3.3.2 Commodities	47
	3.3.3 Currencies	47
	3.4 Time Period	48
	3.5 Sources of Data	49
	3.6 Framework of Analysis	50
	3.6.1 Identification of Pairs	50
	3.6.1.1 Distance Method	51
	3.6.1.2 Cointegration Method	52
	3.6.1.3 Formation of Pairs with and without Sector Restriction	52
	3.6.2 Implementation of Pairs Trading Strategy	55
	3.6.3 Illustrating Pairs Trading Strategy	57
	3.6.4 Risk-Adjusted Returns and Attribution of Returns	68
	3.6.4.1 Sharpe Ratio	68
	3.6.4.2 Single Index Model	69
	3.6.4.3 Fama-French Three-Factor Model	69
	3.7 Risks and Limitations	71
IV	RESULTS AND DISCUSSION	72-158

Chapter	Contents	Page No.
4.1	Statistical Arbitrage in Stock Futures	74
	4.1.1 Pairs Trading Without Sector Restriction	74
	4.1.1.1 Profit and Loss Approach (Stop Loss and Take Profit)	74
	4.1.1.2 Standard Deviation Approach	78
	4.1.1.3 Combined Approach	81
	4.1.2 Pairs Trading With Sector Restriction	86
	4.1.2.1 Profit and Loss Approach (Stop Loss and Take Profit)	86
	4.1.2.2 Standard Deviation Approach	89
	4.1.2.3 Combined Approach	92
	4.1.3 Returns' Attribution of Pairs Trading Strategies (Risk Characteristics of Pairs Trading)	95
4.2	Statistical Arbitrage in Stock Spot/ Cash Market	99
	4.2.1 Pairs Trading Without Sector Restriction	99
	4.2.1.1 Profit and Loss Approach (Stop Loss and Take Profit)	99
	4.2.1.2 Standard Deviation Approach	
	4.2.1.3 Combined Approach	106
	4.2.2 Pairs Trading With Sector Restriction	109
	4.2.2.1 Profit and Loss Approach (Stop Loss and Take Profit)	109
	4.2.2.2 Standard Deviation Approach	112
	4.2.2.3 Combined Approach	115
	4.2.3 Returns' Attribution of Pairs Trading Strategies	118
4.3	Spot-Future Statistical Arbitrage in Indian Stock Market	121
	4.3.1 Profit and Loss Approach (Stop Loss and Take Profit)	121
	4.3.2 Standard Deviation Approach	123
	4.3.3 Combined Approach	125
	4.3.4 Returns' Attribution of Spot-Future Pairs Trading Strategies	128
4.4	Statistical Arbitrage in Commodity Futures	130
	4.4.1 Pairs Trading Without Sector Restriction	130
	4.4.1.1 Profit and Loss Approach (Stop Loss and Take Profit)	130
	4.4.1.2 Standard Deviation Approach	134

Chapter	Contents	Page No.
	4.4.1.3 Combined Approach	136
	4.4.2 Pairs Trading With Sector Restriction	140
	4.4.2.1 Profit and Loss Approach (Stop Loss and Take Profit)	140
	4.4.2.2 Standard Deviation Approach	143
	4.4.2.3 Combined Approach	146
	4.4.3 Returns' Attribution of Pairs Trading Strategies (Risk Characteristics of Pairs Trading)	149
4.5	Statistical Arbitrage in Currencies Market	152
	4.5.1 Statistical Arbitrage in Currencies Futures	152
	4.5.2 Statistical Arbitrage in Currencies Spot	154
	4.5.3 Spot-Future Statistical Arbitrage in Indian Currencies Market	156
V	SUMMARY	159-167
	REFERENCES	168 – 176
	ANNEXURE	i – vii
	PAPERS SUBMITTED/ACCEPTED/ PUBLISHED	
	VITA	

LIST OF TABLES

Table No.	Title	Page No.
1	Study Objectives and Rationale for Selection	18
2	Scope of the Study	19
3	Definitions of Statistical Arbitrage (SA)	22-23
4	Empirical Evidences on Pricing Efficiency of Futures Markets	29
5	Summary of Literature Review in terms of quantified results	30-37
6	Saunders Research Onion Framework for the Study	41-42
7	Scope of the Study	43
8	Proposed Hypotheses	43-45
9	Population and Sample selection	45
10	List of stocks taken in the sample	46
11	List of commodities taken in the sample	47
12	List of currencies pairs available for trading in India	48
13	Formation Period and respective Trading Period on rolling basis	49
14	Portfolio of stock future pairs formed with and without sector restriction for 1 st formation period	54
15	Pairs Trading Strategies	55
16	Margin percentage across asset classes for pairs trading	57
17	Daily future closing prices of copper and lead (Jan 1, 2011 – Dec 31, 2011)	58
18	Input Parameters for Copper-Lead Pairs Trading Model	59
19	Trading of Copper-Lead Pair using Combined Approach	61-67
20	Output obtained from trading commodity pair Copper-Lead	68
21	Summary of Methodology for Data Analysis	70
22	Six-monthly returns of stock futures' pairs without sector restriction from profit and loss trading approach over various trading periods	75
23	Descriptive statistics for six-monthly returns of stock futures' pairs without sector restriction with profit and loss trading approach	76
24	Six-monthly returns of stock futures' pairs without sector restriction from standard deviation trading approach over various trading periods	78
25	Descriptive statistics for six-monthly returns of stock futures' pairs without sector restriction with standard deviation trading approach	79

Table No.	Title	Page No.
26	Six-monthly returns of stock futures' pairs without sector restriction from combined trading approach over various trading periods	81
27	Descriptive statistics for six-monthly returns of stock futures' pairs without sector restriction with combined trading approach	84
28	Six-monthly returns of stock futures' pairs with sector restriction from profit and loss trading approach over various trading periods	86
29	Descriptive statistics for six-monthly returns of stock futures' pairs with sector restriction with profit and loss trading approach	87
30	Six-monthly returns of stock futures' pairs with sector restriction from standard deviation trading approach over various trading periods	89
31	Descriptive statistics for six-monthly returns of stock futures' pairs with sector restriction with standard deviation trading approach	90
32	Six-monthly returns of stock futures' pairs with sector restriction from combined trading approach over various trading periods	92
33	Descriptive statistics for six-monthly returns of stock futures' pairs with sector restriction with combined trading approach	93
34	Stock futures' portfolios with risk adjusted six-monthly returns and attribution of returns	96-97
35	Six-monthly returns of stock spot pairs without sector restriction from profit and loss approach over various trading periods	100
36	Descriptive statistics for six-monthly returns of stock spot pairs without sector restriction with profit and loss trading approach	101
37	Six-monthly returns of stock spot pairs without sector restriction from standard deviation approach over various trading periods	103
38	Descriptive statistics for six-monthly returns of stock spot pairs without sector restriction with standard deviation trading approach	104
39	Six-monthly returns of stock spot pairs without sector restriction from combined trading approach over various trading periods	106
40	Descriptive statistics for six-monthly returns of stock spot pairs without sector restriction with combined trading approach	107
41	Six-monthly returns of stock spot pairs with sector restriction from profit and loss trading approach over various trading periods	109

Table No.	Title	Page No.
42	Descriptive statistics for six-monthly returns of stock spot pairs with sector restriction with profit and loss trading approach	110
43	Six-monthly returns of stock spot pairs with sector restriction from standard deviation trading approach over various trading periods	112
44	Descriptive statistics for six-monthly returns of stock spot pairs with sector restriction with standard deviation trading approach	113
45	Six-monthly returns of stock spot pairs with sector restriction from combined trading approach over various trading periods	115
46	Descriptive statistics for six-monthly returns of stock spot pairs with sector restriction with combined trading approach	116
47	Stock spot portfolios with risk adjusted six-monthly returns and attribution of returns	119-120
48	Six-monthly returns of stock spot-future pairs from profit and loss approach over various trading periods	122
49	Descriptive statistics for six-monthly returns of portfolios formed from stock spot-future pairs with profit and loss trading approach	122
50	Six-monthly returns of stock spot-future pairs from standard deviation approach over various trading periods	124
51	Descriptive statistics for six-monthly returns of portfolios formed from stock spot-future pairs with standard deviation trading approach	124
52	Six-monthly returns of stock spot-future pairs from combined approach over various trading periods	126
53	Descriptive statistics for six-monthly returns of portfolios formed from stock spot-future pairs with combined trading approach	127
54	Stock spot-future portfolios with risk adjusted six-monthly returns and attribution of returns	129
55	Six-monthly returns of commodity futures' pairs without sector restriction from profit and loss trading approach over various trading periods	131
56	Descriptive statistics for six-monthly returns of commodity futures' pairs without sector restriction with profit and loss trading approach	132
57	Six-monthly returns of commodity futures' pairs without sector restriction from standard deviation trading approach over various trading periods	134
58	Descriptive statistics for six-monthly returns of commodity futures' pairs without sector restriction with standard deviation trading approach	135

Table No.	Title	Page No.
39	Six-monthly returns of commodity futures' pairs without sector restriction from combined trading approach over various trading periods	137
60	Descriptive statistics for six-monthly returns of commodity futures' pairs without sector restriction with combined trading approach	138
61	Six-monthly returns of commodity futures' pairs with sector restriction from profit and loss trading approach over various trading periods	140
62	Descriptive statistics for six-monthly returns of commodity futures' pairs with sector restriction with profit and loss trading approach	141
63	Six-monthly returns of commodity futures' pairs with sector restriction from standard deviation trading approach over various trading periods	143
64	Descriptive statistics for six-monthly returns of commodity futures' pairs with sector restriction with standard deviation trading approach	144
65	Six-monthly returns of commodity futures' pairs with sector restriction from combined trading approach over various trading periods	146
66	Descriptive statistics for six-monthly returns of commodity futures' pairs with sector restriction with combined trading approach	147
67	Commodity futures' portfolios with risk adjusted six-monthly returns and attribution of returns	150-151
68	Six-monthly returns of currency futures' pairs over various trading periods	153
69	Descriptive statistics for six-monthly returns of currency futures' pairs traded using different strategies	153
70	Six-monthly returns of currency spot pairs over various trading periods	155
71	Descriptive statistics for six-monthly returns of currency spot pairs traded using different strategies	155
72	Six-monthly returns of currency spot-future pairs over various trading periods	157
73	Descriptive statistics for six-monthly returns of currency spot-future pairs traded using different strategies	157

LIST OF FIGURES

Fig. No.	Title	Page No.
1	Process of statistical arbitrage (pairs trading strategy)	7
2	Stock Prices of Ambuja and ACC from 2005 to 2010	8
3	Chart showing daily comparison (in percentage scale) of Ford: F (red) and General Motors: GM (green)	9
4	Graph showing 200 Day Bollinger Bands (2.5 standard deviations) and F/GM share price with 200-day moving average	10
5	Graph showing entry and exit of pairs trade of F / GM ratio	10
6	Graph showing entry, exit and stop-loss of a pairs trade	11
7	Depiction of formation period and trading period on rolling basis	49
8	Portfolio Formation Approaches for Pairs Trading	51
9	Scheme for Pairs Trading Analysis	53
10	Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock future prices without sector restriction and traded using profit and loss strategy over twelve trading periods	77
11	Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock future prices without sector restriction and traded using standard deviation strategy over twelve trading periods	80
12	Formation period and trading period example	82-83
13	Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock future prices without sector restriction and traded using combined strategy over twelve trading periods	85
14	Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock future prices with sector restriction and traded using profit and loss strategy over twelve trading periods	88
15	Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock future prices with sector restriction and traded using standard deviation strategy over twelve trading periods	91
16	Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock future prices with sector restriction and traded using combined strategy over twelve trading periods	94
17	Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock spot prices without sector restriction and traded using profit and loss strategy over twelve trading periods	102

Fig. No.	Title	Page No.
18	Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock spot prices without sector restriction and traded using standard deviation strategy over twelve trading periods	105
19	Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock spot prices without sector restriction and traded using combined strategy over twelve trading periods	108
20	Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock spot prices with sector restriction and traded using profit and loss strategy over twelve trading periods	111
21	Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock spot prices with sector restriction and traded using standard deviation strategy over twelve trading periods	114
22	Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock spot prices with sector restriction and traded using combined strategy over twelve trading periods	117
23	Graphical presentation of six-monthly returns of various portfolios formed using stock spot-future pairs and traded using profit and loss strategy over twelve trading periods	123
24	Graphical presentation of six-monthly returns of various portfolios formed using stock spot-future pairs and traded using standard deviation strategy over twelve trading periods	125
25	Graphical presentation of six-monthly returns of various portfolios formed using stock spot-future pairs and traded using combined strategy over twelve trading periods	127
26	Graphical presentation of six-monthly returns of various portfolios of pairs formed using commodity future prices without sector restriction and traded using profit and loss strategy over twelve trading periods	133
27	Graphical presentation of six-monthly returns of various portfolios of pairs formed using commodity future prices without sector restriction and traded using standard deviation strategy over twelve trading periods	136
28	Graphical presentation of six-monthly returns of various portfolios of pairs formed using commodity future prices without sector restriction and traded using combined strategy over twelve trading periods	139
29	Graphical presentation of six-monthly returns of various portfolios of pairs formed using commodity future prices with sector restriction and traded using profit and loss strategy over twelve trading periods	142

Fig. No.	Title	Page No.
30	Graphical presentation of six-monthly returns of various portfolios of pairs formed using commodity future prices with sector restriction and traded using standard deviation strategy over twelve trading periods	145
31	Graphical presentation of six-monthly returns of various portfolios of pairs formed using commodity future prices with sector restriction and traded using combined strategy over twelve trading periods	148
32	Graphical presentation of six-monthly returns of currency futures' pairs over twelve trading periods and traded using different strategies	154
33	Graphical presentation of six-monthly returns of currency spot pairs over twelve trading periods and traded using different strategies	156
34	Graphical presentation of six-monthly returns of currency spot-future pairs over twelve trading periods and traded using different strategies	158

CHAPTER I

INTRODUCTION

This chapter traces the genesis, background and growth of statistical arbitrage opportunities in securities markets across the world and places it into the context of pairs trading. It also discusses the types, working and risks of statistical arbitrage strategies apart from stating the objectives of the study and rationale for selection of these objectives. It concludes by discussing the organization of the study.

1.1 Background and Introduction

In current environment, market dynamics, geopolitical tensions and unrest, uncertain economic outlook have made investors vulnerable and many investors still feel the sting when the bull market reversed in early 2000 and recession hit the markets in late 2000s. The triple digit returns now seem unrealistic and, for many, so is a substantial percentage of the personal wealth that was created in the late 1990s and 2000s. Not surprisingly, hence, many of these same investors have taken refuge in fixed income securities, cash instruments, or in increasingly popular arbitrage strategies.

In most basic terms, **arbitrage** refers to a trade opportunity which entails exploiting an inefficiency in the securities market by simultaneously buying and selling a security for a profit (Ehrman 2006). It is an opportunity of making a profit in securities market without risk and without net investment of capital (Delbean and Schachermayer 2006). While the existence of such opportunities seems somewhat sceptical in the information age, it was once possible for a select group of individuals with superior resources to capitalize on such situations. Today, however, with a nearly unlimited level of computing power available on any desktop, simple arbitrage is mostly a thing of the past.

While certain market inefficiencies do still exist, the majority of arbitrage activity today is based on perceived or implied pricing flaws rather than on real ones. These pricing flaws are not the result of faulty or slow information, but are the result of an individual's perception that the relationship between two securities has deviated from its historical average in a statistically significant way. **Statistical arbitrage** represents statistically significant deviations from historically identified average price relationships. It is taking counteracting positions in securities that are historically or mathematically associated, but taking these positions at times when their inter-relationship has been temporarily askewed. Over time, these relationships fluctuate around an average, moving away and then back to a mathematically determined midpoint.

The concept of statistical arbitrage forms the prerequisite to understand pairs trading because it is considered essentially as the same thing or categorised as a form of pairs trading.

The foundation of pairs trading is based on the principle of prices moving/converging to the expected values. Ehrman (2006) defines pairs trading as, “a nondirectional, relative-value investment strategy that seeks to identify two companies with similar characteristics whose equity securities are currently trading at a price relationship that is outside their historical trading range. This investment strategy entails buying the undervalued security while short-selling the overvalued security, thereby maintaining market neutrality”. Thus, it is fundamentally a market neutral strategy, which obtains its returns from the inter-relation between the performance of its long position and short position. Basically, the performance of the strategy is governed by the relative performance and not by the absolute performance of the securities involved. Therefore, pairs trading is one of the several strategies collectively referred to as statistical arbitrage strategies.

While every pairs trader uses different criteria when selecting her stocks, all are drawn around the concept of mean reversion. These traders operate under the assumption that anomalies among stock valuations may occur in the short term, but that over time these anomalies will correct or mean-revert. When one stock’s price anomaly reverts back to the mean price of its group, this is known as mean reversion. The establishment of organised listed markets also led to the emergence of pairs trading and other market neutral strategies. Jesse Livermore, one of the most famous traders of all time, was the first pairs trader. He was known for using various principles of pairs trading in most of his analyses. Smitten (2004) in his book ‘Trade Like Jesse Livermore’ mentions about “Tandem Trading”. Livermore used sister stocks in his trading technique and this strategy is valid even today. He never considered a single stock in isolation but always studied pair of two stocks in a particular industry for analysis.

Statistical Arbitrage or Stat Arb for short has a history of being a highly profitable algorithmic trading strategy for many big hedge funds and investment banks. Statistical arbitrage initiated around late 1970s and early 1980s, led by Morgan Stanley and other banks. Putting the strategy into a historical context, it can be traced to Gerry Bamberger, a computer science graduate who worked for Morgan Stanley in 1980s as analytical and technical support. He observed that when the traders prepared to buy and sell big chunks of shares for clients, acquiring a few million dollars of Coca-Cola, for example, they protected themselves by selling an equal amount of something similar, like Pepsi, in what is commonly referred to as a pairs trade (Zuckerman 2019). Bamberger, watching the traders buy big blocks of shares, observed that prices often moved higher, as might be expected. Prices headed lower when Morgan Stanley’s traders sold block of shares. Each time, the trading activity altered the gap, or spread, between the stock in question and the other company in the pair, even when there

was no news in the market. An order to sell, a chunk of Coke shares, for instance, might send that stock down a percentage point or two, even as Pepsi barley moved. Once the effect of their Coke stock selling wore off, the spread between the shares reverted to the norm, which made sense, since there had been no reason for Coke's drop other than Morgan Stanley's activity.

Bamberger sensed opportunity. If the bank created a database tracking the historic prices of various paired stocks, it could profit simply by betting on the return of these price-spreads to their historic levels after block trades or other unusual activity. Morgan Stanley set him up with half a million dollars and a small staff and Bamberger began developing computer programs to take advantage of 'temporary blips' of paired shares. By 1985, he was managing USD 30 million, making profits for Morgan Stanley (Zuckerman 2019).

Morgan Stanley then appointed Wall Street quantitative analyst Nunzio Tartaglia as a new boss for Bamberger, which led Bamberger to quit. Tartaglia renamed the group 'Automated Proprietary Trading' (or APT) and by 1987, it was generating USD 50 million of annual profits. Their strategy was simply to wager on the re-emergence of historic relationships between shares. New hires, including a computer science professor named David Shaw and mathematician Robert Frey, improved profits and the Morgan Stanley traders became some of the first to embrace the strategy of **statistical arbitrage**, or stat arb. This generally meant making lots of concurrent trades, most of which were not correlated to the overall market but were aimed at taking advantage of statistical anomalies or other market behaviour. By 1988, Automated Proprietary Trading (APT) was among the largest and most-secretive trading teams in the world, buying and selling USD 900 million worth of shares each day.

Academically and in the finance world, the strategy of statistical arbitrage is accredited to Nunzio Tartaglia, who with a team of mathematicians, computer scientists and physicists wanted to establish quantitative arbitrage strategies using state-of-the-art statistical tools. This rapidly extended to general pairs trading and then in 1990s further broadened to comprise long and short market neutral portfolios composed of groups of securities selected from stocks, ETFs, options, index futures and options on index and it can also include commodities, fixed income and other derivatives. Some examples of securities for statistical arbitrage strategies include cross-listed stocks, futures and stock indexes, pairs of stocks, foreign currency, portfolio of stocks and pairs of foreign currencies (Zacks 2011). Thus, pair trading was pioneered by Gerry Bamberger and then later led by Nunzio Tartaglia's quantitative group at Morgan Stanley in the 1980s.

Pairs trading presupposes that while markets might not be in equilibrium, with time they steer towards a rational equilibrium, and trader has an opportunity to take utmost benefit

of the departure from the equilibrium (Göncü and Akyildirim 2016). The theoretical explanation for the correlated or similar movement of security prices arises from Arbitrage Pricing Theory (APT). According to this theory, if two securities have absolutely the same risk factor exposures, then the expected return of the two securities for a stated time interval is the same (Ross 1976).

Although the pairs trading technique of statistical arbitrage is commonly used by hedge funds and investment banks, empirical studies testing the profitability of this strategy are scarce, especially in Indian context. The most significant and extensive study testing the pairs trading strategy and its profitability is that of Gatev *et al* (2006) which focused on U.S. market. Their study matched stocks into pairs with minimum distance between normalized historical prices. The trading done through this strategy for the period 1962-2002 yielded annualized risk-adjusted returns of about 11%.

Many academic researches provide frameworks to carry out pairs trading. Vidyamurthy (2004) presented an implementation strategy based on cointegration by explaining the nexus between pricing theory and pairs trading theory. Many studies claimed that usage of statistical arbitrage strategies based on cointegration with optimal weight allocations would generate significant abnormal annual returns between 2.44% and 11.96% (Norden and Schaller 1993 and Grobys 2012). Pole (2007) in a comprehensive review on statistical arbitrage and cointegration stated that the portfolio was anticipated to generate a positive return as valuations converge. The mean-reversion paradigm is specifically related with securities being transiently over or under priced in connection to one or more reference securities and market over-reaction to it (Lo and MacKinlay 1990).

Elliott *et al* (2005) by using a ‘mean-reverting Gaussian Markov chain model’ provided a detailed framework for pairs trading. Huck (2010) applied multicriteria decision techniques for choosing pairs for pairs trading. The most prominent work, Gatev *et al* (2006) evaluated a large sample of U.S. stocks over the period 1962 and 2002. Despite the fact that these studies used different methods to assess the performance of the pairs trading strategy and hence are not directly comparable, pairs trading displayed a positive performance in all of them.

Bossaerts and Green (1989) and Jagannathan and Viswanathan (1988) found that the pairs trading strategy might be supported within an equilibrium asset-pricing framework with nonstationary common factors. They opined that if the long and short components fluctuated with common nonstationary factors, then the prices of the component portfolios would be cointegrated and the pairs trading strategy would be expected to work. Statistical Arbitrage denies the securities market to be in any economic equilibrium, a crucial imperative for an efficient market (Jarrow 1988).

The existence of arbitrage opportunities is a contradiction to the **efficient market hypothesis** proposed by (Fama 1970). The hypothesis states that securities are justly priced in the market and that arbitrage situations cannot prevail. Hence, it seems to be a paradox, ipso facto that the market exhibits efficiency on one hand and yet have arbitrage opportunities. The plausible explanation is that investors and traders who seek arbitrage opportunities are themselves the reason for the existence of efficient markets. By pursuing and exploiting market inefficiencies, they essentially exclude these inefficiencies in the mechanism by enabling prices to reach their appropriate level. Although the market is broadly efficient, there is generally a time lag in this efficiency which explains the existence of arbitrage opportunities. Therefore, it is not necessary to resolve the paradox.

India is a strong emerging economy. Huge investment and trading activities from all over the world are directed to Indian securities market. Global hedge funds are now prioritizing Indian securities market for their emerging market investments. Many strategies and algorithms are now implemented and tested in Indian securities market and statistical arbitrage has been a profitable quantitative strategy. There are many platforms available in India where one can trade using statistical arbitrage techniques. These platforms do not provide any documented evidence of profitability. Therefore, this research aims at studying the statistical arbitrage opportunities that are available in Indian securities market and how profitable they are for the investors. It will provide help to the investors to select best statistical arbitrage strategies for investment.

To put it in simple terms, statistical arbitrage consists of a set of quantitatively driven algorithmic trading strategies. These strategies try to exploit the relative price movements across thousands of financial instruments by analysing the price differences and price patterns between financial instruments. The outcome of such strategies is to generate alpha (higher than normal profits) for the trading firms. A point to be noted here is that statistical arbitrage is not a high-frequency trading (HFT) strategy, rather it can be classified as a medium-frequency strategy where the trading period ranges from a course of a few hours to a few days.

1.2 Types of Statistical Arbitrage Strategies

To analyse the price differences and price patterns, the strategists make use of statistical and mathematical models. The various statistical arbitrage strategies include:

- a) **Cross Asset Arbitrage:** This model is based on the price discrepancy between a financial asset and its underlying. For instance, between a stock index future and the stocks that form the index.
- b) **Market Neutral Arbitrage:** It involves assuming a long position in an undervalued asset and shorting an overvalued asset at the same time. The assets are believed to

have similar volatilities and thus, a rise in the market will lead the long position to appreciate in value and the short position will depreciate by approximately the same amount. The positions get squared off when the assets fall back to their normal value.

- c) **ETF arbitrage:** Exchange Traded Fund arbitrage can be explained as a form of cross-asset arbitrage that identifies discrepancies between the value of an Exchange Traded Fund and its underlying assets.
- d) **Cross Market Arbitrage:** Cross Market Arbitrage seeks to exploit the price discrepancy of the same asset across markets. Going by the strategy, one buys an asset in the lower-valuing market and sells it in the higher-valuing market.

1.3 Working of Statistical Arbitrage Strategy

In statistical arbitrage, which is an advanced form of pairs trading strategies, stocks are selected into pairs based on market-based or fundamental strategies. In case one stock outperforms the another stock in the pair, the another stock is purchased with the expectation that it will rise to level of its outperforming partner. Further, in order to hedge the position against market variations, short selling of the outperforming stock is done.

Since statistical arbitrage strategy involves a huge number of stocks, there is large portfolio turnover and the relatively small size of the spread. The strategy is designed in an automated manner and emphasis is given on reduction of transaction or trading costs. Statistical arbitrage strategy is significantly used by both hedge funds and investment banks. The Figure 1 represents the process of statistical arbitrage strategy in its most crude form.

1.3.1 Pairs Trading

There is usually some **correlation**—the extent to which prices move in the tandem — between any two different assets. Usually, there is a high correlation between prices for two assets which are in the same segment. For example, if government imposes new regulation on automobile industry, then it is highly probable that stock prices of both Tata Motors and Mahindra & Mahindra will decline which implies they are highly correlated. Arbitrage opportunities exist when correlations diverge from the general norm.

Suppose there are two Oil Marketing Companies with similar business model. Due to tensions in Middle East there is increase in crude oil prices and the price of company P decreases by 15%, but the price of company Q decreases only by 5%. Pairs Trading is possible in this scenario by buying the underperforming stock (company P) and selling the over-performing stock (company Q) under the assumption that prices of both the stocks will settle around a decrease of 10% on the day. **In pairs trading, it is assumed that the two assets will fall back to their equilibrium correlation levels, instead of the price level (as**

in the mean reversion model). In pairs trading two opposite positions are undertaken — buying one asset and selling one asset. As a result, one need not to worry about prices of both the assets moving in same direction i.e. both rising or falling. Rather, we need to focus on the relationship between prices of two assets since it (often but not necessarily always) is statistically more significant than any individual price level prediction. Since two positions have been taken instead of one, if the prices of the pair do actually converge as per their historical pattern, then we might be able to get double the profit unlike the mean reversion case.

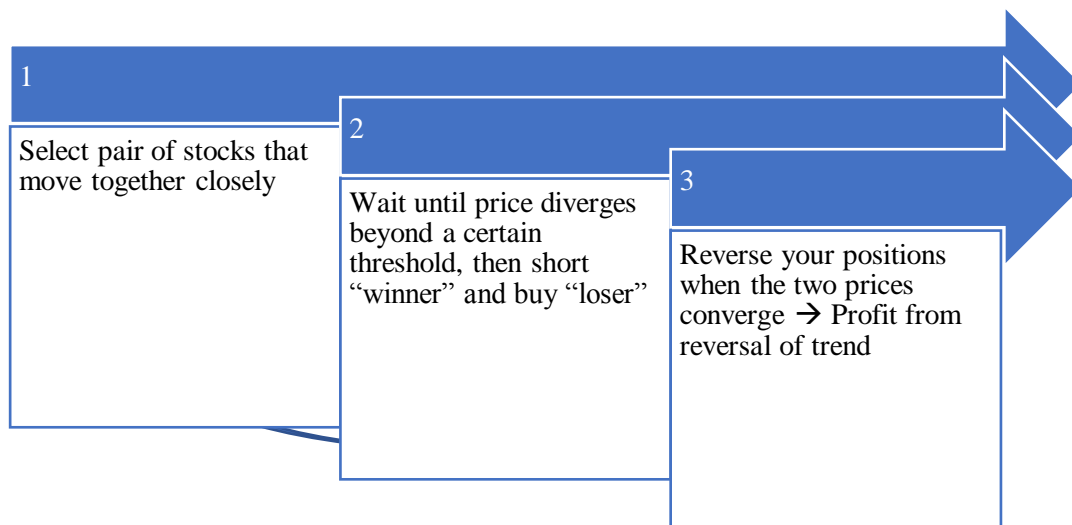


Figure 1: Process of statistical arbitrage (pairs trading strategy)

The major risk in pairs trading model is the possibility of the pair diverging instead of converging after assuming the positions. It can lead to loss on both sides of the trade. Following parameters have to be considered initially before applying this model:

- the assets of interest must be selected
- their current correlation is determined
- entry level is to be set when we have a correlation ‘break’
- manage a take profit and stop loss level for both the positions assumed.

Convergence and divergence are quite often determined by confidence intervals which can be created by using tools like standard deviations, Bollinger bands, and range trading, among others.

There is usually upward or downward trend in the prices of securities, typically stocks. A quantitative method tries to capitalize on this trend. Trends discovered are based on the frequency, volume and the price of a security at which it is traded. The Figure 2 below, represents the stock prices of Ambuja and ACC over a period of six years from 2005 to 2010.



Figure 2: Stock Prices of Ambuja and ACC from 2005 to 2010

Source: Gupta and Paradkar (2017) *Arbitrage Strategies: Understanding Working of Statistical Arbitrage* (accessed at: www.quantinsti.com/blog/statistical-arbitrage)

It can be seen that both the stocks stayed quite close to each other during the entire time span of six years, barring only a few instances of separation. It is in these separation periods that an arbitrage opportunity would arise based on the belief that the stock prices would move closer again. **The key in identifying such opportunities lies in two important factors:**

- recognizing or identifying the pairs which require advance statistical tests and time series analysis, and
- fixing the entry-exit points for the strategy to leverage the market position.

1.3.2 Working of Pairs Trading

In pairs trading, long position is held in one stock and a short position is held in another stock simultaneously. Initially, when a pairs trading strategy is to be applied it must be ensured that two stocks are correlated. These selected stocks must move in sync (tandem) at most times because whenever these selected stocks would deviate from each other, eventually, they would go back trading in sync and thus profit would be realised.

Figure 3 represents the price trend between Ford (F) and General Motors (GM) over a period of time. The prices generally move in sync with each other. When the prices' movement separate, there is an opportunity of entering into a pairs trade by short selling GM and buying Ford when it is underpriced relative to GM. Eventually, when the stock prices get back in sync, the profit is realized as in this particular case. The overall market position does

not matter as long as the stocks separated come back in sync. The profit is made irrespective of whether both stock prices fall or rise as long as they remain in tandem. This is the theoretical aspect but identifying the stocks to form a pair, controlling the risk, and when to book the profit requires careful planning, analysis and strategy.

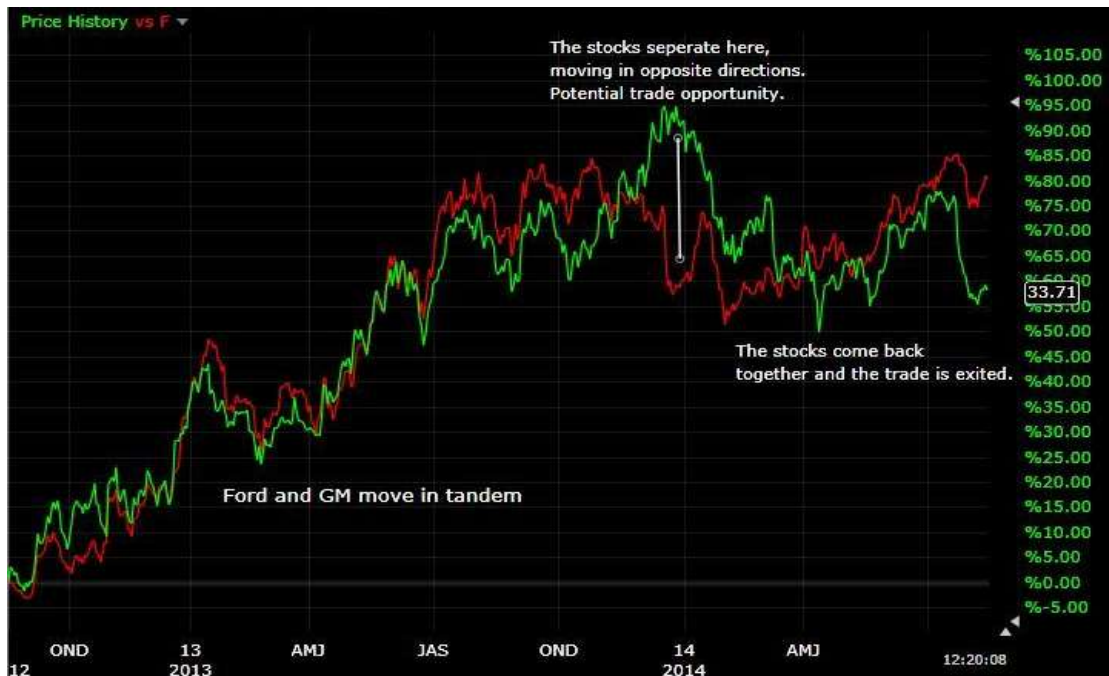


Figure 3: Chart showing daily comparison (in percentage scale) of Ford: F (red) and General Motors: GM (green)

Source: <https://stockcharts.com/>

Ratio of one stock to another can be plotted on a chart on StockCharts.com. Figure 4 represents the ratio of share prices between Ford and GM. The ratio at present is 0.51 which means GM is almost twice the price of Ford.

“Normal” ratio is calculated by applying 200-day period moving average which is 0.45. To identify the times when ratio has deviated significantly from the norm (normal ratio), Bollinger Bands are also employed (200 periods and 2.5 standard deviations). These represent the trading opportunity. The pairs trading can be explained in detail with the following **example**.

Let us take into account the trade which materialised in December 2013. The price of Ford fell significantly in comparison to GM, as is evident from Figures 3 and 4. The ratio fell below 2.5 standard deviations from 200-day norm on December 6 (presented in Figure 4 as lower red Bollinger Bands). The price of Ford was declining, while that of GM was rising, which implied that stock prices were deviating from the norm. The trade could be executed at the moment when the ratio crossed the 2.5 standard deviations Bollinger Bands. However, it would be wise to delay the trade till both the stock prices and ratio begin to move in sync

again, that is, back towards the standard norm. Thus, trades were executed when ratio went further 2.5 standard deviations and began to recover towards the normal ratio. It was exited at the time the ratio reached within 0.02 points of 200-day norm. Figure 5 represents the trade on the ratio chart.



Figure 4: Graph showing 200 Day Bollinger Bands (2.5 standard deviations) and F/GM share price with 200-day moving average

Source: <https://stockcharts.com/>



Figure 5: Graph showing entry and exit of pairs trade of F / GM ratio

Source: <https://stockcharts.com/>

Ford was bought near the close on January 2 at USD 15.44. A stop loss was placed below the recent low at USD 15.10. GM was short-sold near the close on January 2 at USD 40.95. A stop loss was placed above the recent high at USD 41.85. Figure 6 depicts the entry, exit and stop loss of the trade.



Figure 6: Graph showing entry, exit and stop-loss of a pairs trade

Source: <https://stockcharts.com/>

\$10,000 was allocated to each side of the trade. 647 shares of Ford (USD 10,000 / USD 15.44) were bought and 244 shares of General Motors (\$10,000 / \$40.95) were sold. Trade was squared off near the market close on January 24 because the ratio had moved to within 0.02 of the norm (200-day average). Therefore, it can be concluded the price relationship has been re-established and the motive for entering the trade has now diminished. GM was closed at \$36.83 and Ford at \$15.83. **Profit realised was:**

$$GM: USD (40.95 - 36.83) = USD 4.12 \times 244 \text{ shares} = USD 1,005.28$$

$$Ford: USD (15.83 - 15.44) = USD 0.39 \times 647 = USD 252.33$$

$$Net Profit: USD (1,005.28 + 252.33) = USD 1,257.61$$

There was minimal cash outlay because the short trade entered into created a cash inflow that offset the outflow of the long position. If we calculate the return based on the initial \$20,000 in positions though, the return would be greater than 6% in less than a month. Not all pairs trades work out this way; sometimes only one trade is profitable and the other a loser, other times both trades may be unprofitable. The stop losses also contain risk to a small amount of capital, and the profit potential is much greater than the risk with these stops in place.

1.4 Advantages and Risks in Pairs Trading

One of the advantages of this strategy is that it is market neutral. For applying this strategy, the dynamic which is going between stocks needs to be analysed in depth and only a limited study of broader market conditions is required. The strategy is also quite flexible; within a shorter time frame (say 30-minute chart) trade signals can be triggered by the short term traders.

One of the cons of this strategy includes the possibility that a divergence in the stock prices can prolong for a period longer than expected. Further, the prices of stocks may continue to diverge due to integral changes in structure or performance of the company. Therefore, it is imperative to set a risk limit to avoid adverse situations where the two stocks continue to diverge. Pairs trading strategy is also opposite to the traditional trend or momentum trading concepts wherein the strongest stocks are bought, and the weakest stocks are sold.

Other disadvantage is that this strategy is subjective also. The price must diverge, and then we wait to take the trades until the prices start to converge again. This might appear to be safer approach theoretically, but it requires a lot of expertise and practice to develop that timing.

Stock's beta also needs to be considered for applying this strategy. Two similar stocks might have varied betas which is an indication of discrepancy in volatility. If one stock is much more volatile than the other it could cause issues with the trade. Stocks which have high degree of correlation and similar betas are ideal for pairs trading.

Though statistical arbitrage strategies have resulted in huge profits for quantitative trading firms, still these strategies have their own set of risks. The strategy heavily relies on the mean reversion of prices to their historical or predicted normal. This may not necessarily happen in some cases and the prices can continue to drift away from the historical normal. Financial markets are in a continuous flux and evolve based on events occurring across the world. Hence, there is no guarantee of profit from statistical arbitrage all the times. In other words, losses may also be incurred in certain situations.

1.5 Use of Cointegration Theory in Statistical Arbitrage (with reference to pairs trading)

Use of cointegration between stock prices as a basis for a trading strategy is not a totally new concept. Yet, it is still a topic of contemporary interest in that it's up for debate as to what extent these models are profitable in today's markets. As compared to the early days when trading models based on these properties were relatively unknown, now it is far less certain that whatever statistical arbitrage opportunities are available, they have not already been exploited by other actors on the market.

In the recent literature, among others, the authors who have found trading based on models of this nature net excess returns are – Gatev *et al* (1999, 2006), Engelberg and Jagannathan (2009) and Miao (2014). At the same time there are authors who did not find similar success – Do and Faff (2010), Bowen *et al* (2010) and Hoel (2013).

To put it in other words, it's still very much an unresolved question as to whether these models are still profitable in a more contemporary setting or not.

Pairs trading has been in existence in multiple forms for a long time. The central concept of pairs trading is to identify a pair of stocks where the difference between the prices of the two stocks is, for some reason, believed to have mean-reverting properties. Essentially, the strategy generally revolves around identifying periods where the discrepancy between the price of the two stocks is larger than it ought to be and expected to shrink at a later point. One would therefore be able to earn profit from taking a long position in the "undervalued" stock and a short position in the "overvalued" stock simultaneously and closing the positions when the price discrepancy returns to some expected level.

As hinted at by the name, the **cointegration method** relies on identifying pairs of shares (or some other financial assets) that are likely to have a cointegrating relationship. When the time series of prices of two stocks have a cointegrating relationship, it means that while the prices would look to be driven by a stochastic (random) process individually (which would be seen examined with let us say a unit root test), these stochastic components are linked for the two time series in such a manner that there exists a linear combination among the two time series where the stochastic components cancel. In other words, the crux of the strategy essentially revolves around identifying pairs of stock prices which in some linear combination form a stationary time series. The utility of this is rather self-evident: if the series be stationary, a significant divergence would presumably be temporary and would be expected to revert in the future time periods. This is of course where a strategy of this nature would trigger a trade, taking one long and one short position and squaring them off later when the price discrepancy has returned to a level specified by the strategy.

Vidyamurthy (2004) in his book “Pairs Trading – Quantitative Methods and Analysis” has given a nice explanation on the concept of cointegration model as under:

“A subtle point to highlight at this juncture is that there are in effect two correlation measures. One correlation measure pertains to the innovation sequences of the common trend alone. This correlation value is either +1 or –1. Another correlation may be calculated on the innovation sequences of the whole series, taking into account both the common trend and the stationary components. This measure can take on a whole range of values depending on the variance of the stationary components. The two correlation measures are very different, and it is important not to confuse one for the other.

The next point pertains to the stationarity of the common trend and specific components of the two time series. As far as common trends go, there is no restriction on them. They can be stationary or nonstationary, and this is neither critical nor material for cointegration. The same cannot be said for the specific components. The definition of the common trends model relies on their being stationary time series. Therefore, for cointegration to exist, it is absolutely necessary for the specific components to be stationary.

By implication, the first difference of the specific component must not be white noise, because if the differenced series were white noise, then the specific series would be a random walk, a nonstationary series. This violates the stationarity condition for the specific component. Therefore, the first difference of the specific component cannot be white noise. In summary, there are two conditions that need to be satisfied for cointegration in a common trends model. First, the innovation sequences derived from the common trends of the two series must be identical up to a scalar. Next, the specific components of the two series must be stationary.”

1.6 The Bottom Line

In pairs trading, concurrent long position is taken in one security, while short position is taken in another where two securities are highly correlated with similar volatility. The security is bought when it underperforms the another by a certain threshold, while a short trade is taken in the security which outperforms with the intention that securities will eventually go back towards the standard norm resulting in gains. Since securities are highly correlated, it is likely that they will revert to the standard norm and profit can be realised. However, appropriate risk controls in the form of stops (stop-looses) should be applied where securities go on deviating. Restoration of security prices back to normal may take some time, thus, the probable wait and risk must be taken into account before the selection of the securities and executing the trade.

Pairs trading and market neutral strategies in one form or the other have been around since the establishment of organized and listed markets. These strategies have been employed by some of the renowned traders in the history of trading. The hedge fund industry revolutionised the way in which these strategies are being used. Earlier to the hedge fund boom, these strategies were applied only in the portfolios of high-net-worth individuals (HNIs) and institutional investors with huge resources at their disposal to make them work. These represented a collection of trades rather than being differentiated on their specific characteristics.

The fact that market-neutral strategies in particular have a very low correlation to traditional investment portfolios make them particularly attractive as a diversification tool.

Through diversification, investors are able to improve their overall risk-adjusted return profile. In addition to the diversification benefit, there have been huge opportunities and investors have been able to take advantage of the continuing expansion and ongoing developments within the capital market to profit from pricing inefficiencies. Moreover, with the reduced expenses and increased access to information technology, individual investors are not constrained by infrastructure issues and are able to employ these strategies to make profits which were earlier the domain of hedge funds and institutional investors.

1.7 Preliminary Literature Review and Research Gap

A large body of literature is available on the various statistical arbitrage opportunities in securities market all over the world. One of the largest centres of statistical arbitrage in early 1980s, Morgan Stanley, defines statistical arbitrage as, “a model-based investment process, which aims to build long and short portfolios whose relative value is currently different from a theoretically or quantitatively predicted value.” Pairs trading was first carried out by Gerry Bamberger, though the concept of pairs trading is accredited to Nunzio Tartaglia’s quant team at Morgan Stanley in the mid-1980s (Vidyamurthy 2004).

After a very optimistic start, the trading strategy however, started to show negative results and the group was disintegrated. But pairs trading persisted to allure practitioners (traders and investors) and academics equally. A huge and still developing body of study has concentrated on the execution of pairs trading in different securities markets (Nath 2003, Hong and Susmel 2003, Andrade *et al* 2005, Gatev *et al* 2006, Perlin 2009, Do and Faff 2010).

Gatev *et al* (1999) in their breakthrough study, found statistically significant returns from a simple pairs trading strategy applied in U.S. equity stock market in 1962-1997. The robustness of the results were confirmed with stringent estimates of transaction costs and it was concluded that pairs trading payoffs were not particularly related to a classical mean reversion effect. Gatev *et al* (2006) then expanded their study till 2002 and found average annualized superior returns of up to 11%. The researchers opined that such excess returns from the pairs trading strategies were basically a reward to arbitrageurs for implementing the law of one price.

In Brazilian financial market, Perlin (2009) found that the pairs trading strategy had performed well while focusing on the fact that the positive superior returns were not the result of chance. Do and Faff (2010) used same methodology as Gatev’s *et al* (1999) during the period of 2000-2009 and reported that the pair trading strategy was still profitable but with a downward trend. They attributed this trend to a worsening of arbitrage risks and increasing market efficiency. After incorporating the impact of trading costs they concluded that after 2002 pairs trading was largely a loss making proposition. Using high frequency pairs trading,

Bowen *et al* (2010) concluded that returns from pairs trading were highly susceptible to transaction costs and speed of execution. They also presented that the maximum of returns happen in the first and last hour of trading.

Mori and Ziobrowski (2011), in order to expand the scope of pairs trading, contrasted the implementation of pairs trading strategies in the U.S. REIT (real estate investment trust) market and the equity market during 1987-2008. It was found that the REIT market gave excess returns during 1993-2000, which vanished later on. Alsayed and McGroarty (2012) found pairs trading to be a significant price correcting mechanism in ADR (American depository receipt) market. U.K. stocks and ADRs were used to form pairs and it was found that pairs trading strategy generated 1.45% excess return vis-à-vis risk free return. In Finnish stock market, Broussard and Vaihekoski (2012) used various weighting structures and trade initiation conditions to test the profitability of pairs trading strategy. They established that the returns from a pairs trading strategy were not associated to market risk and the returns could be increased by reducing the threshold for opening a pair.

In Indian context, Aggarwal and Gupta (2015) carried out pairs trading using futures contracts traded on financial stock futures. They found that superior returns of 3.71% were generated by pairs trading portfolio using methodology used by Gatev *et al* (2006) with holding period of maximum two weeks.

The recent available literature on statistical arbitrage stressed on the optimization of different phases of the pairs trading strategy and on the control of the variables that influence its profitability. Interesting models were proposed by Huck (2010), Xie and Wu (2013) and Goncu and Akyildirim (2015) in this direction. Many researchers studied changes to the pairs trading methodology employed by Gatev *et al* (2006). For example, Elliott *et al* (2005) used a 'Gaussian Markov chain model' for measuring and exploiting the spread while Do *et al* (2006) captured the spread using theoretical asset pricing methods and mean reversion.

While Vidyamurthy (2004), Burgess (2005) and Haque and Haque (2014) applied cointegration for pairs selection, Papadakis and Wysocki (2007) expanded the scope of methodology used by Gatev *et al* (2006) by testing the influence of accounting information events (that is, analyst forecasts and earnings announcements) on the amount of returns of the pairs trading strategy.

Various academic researches and studies proposed frameworks to apply pairs trading rather than giving empirical evidence of the effectiveness of pairs trading. Vidyamurthy (2004), for example, explained the link between pairs trading and pricing theory by proposing an execution strategy based on cointegration.

Elliott *et al* (2005) proposed an analytical framework for pairs trading by applying a mean reverting Gaussian Markov chain model. Huck (2010) applied multi-criteria decision tools for the selection of pairs for pairs trading. Huck and Afawubo (2015) using the components of the S&P 500 index examined the profitability of a pairs trading strategy using various pairs selection methods. It was found that after controlling for risk and transaction costs, the distance method generated insignificant superior returns. It was concluded that cointegration approach provided a stable, high and robust return.

The **gap** is clearly evident on the following counts – although many studies have been done about statistical arbitrage, the literature lacks a comprehensive study of different securities using different methodologies of statistical arbitrage techniques in Indian context. The study will extend the aforementioned literature by studying statistical arbitrage opportunities in Indian securities market and studying its profitability from retail investor's point of view.

1.8 Research Aim, Approach and Methodology

1.8.1 Aim – The main aim of the research is to study the statistical arbitrage opportunities in Indian securities market.

1.8.2 Approach – This research relies on secondary data. Based on literature and past research, it tries to gain deeper insights in the various issues related to the concept. Its application is studied in the context of Indian securities markets based on data collected from secondary sources.

1.8.3 Methodology – Following steps have been planned for the research:

- a) Review of literature
- b) Gain a deeper understanding of the concept by examining different perspectives
- c) Identifying the data set requirements
- d) Collect, compile and process data
- e) Analyse data on the basis of key study variables
- f) Statistically test significance of the results
- g) Accept / Reject Null hypothesis
- h) Draw key findings and conclusions
- i) Offer suggestions

1.9 Research Objectives

Following are the objectives set for the research –

- 1) To study statistical arbitrage opportunities present in Indian securities market.

- 2) To study the profitability of statistical arbitrage opportunities in Indian securities market.
- 3) To attribute the returns generated from statistical arbitrage to different risk factors.

The rationale for selection of the above objectives along with plan for their achievement is given below:

Table 1: Study Objectives and Rationale for Selection

S.No.	Objective	Rationale for selection
1	To study statistical arbitrage opportunities present in Indian securities market	This is to understand whether such opportunities exist so as to gather a more practical view of the markets as against theories that specify market efficiency.
2	To study the profitability of statistical arbitrage opportunities in Indian securities market	To what extent are the opportunities profitable will give an idea of the risk-return pay-off.
3	To attribute the returns generated from statistical arbitrage to different risk factors	A model like CAPM can assess the risk attribution to something like 70% only. But on the other hand a model like Fama and French (1993) three factor model is more comprehensive in assessment of the risk to the factors beyond market risk as identified by CAPM.

1.10 Need and Significance of Study

- a) The study will give new insights about different statistical arbitrage opportunities existing in Indian securities market.
- b) It will also provide profitability of arbitrage opportunities from retail investor's view point.
- c) From the general non-investor community's perceptive including farmers, this will help them identify the right timing of buying and selling of commodities.
- d) While market efficiency may hold good in the long-run, practically markets do present a number of short-term opportunities and hence it is important to know how such opportunities can be encashed.
- e) A model like the Fama and French model used in this study presents a finer analysis of the underlying risk in financial assets. It not only takes into account the market risk (as per CAPM), it also considers the size and value risk. Using thousands of random stock portfolios, Fama and French conducted studies to test their model and found that when size and value factors are combined with the beta factor, they could then explain as much as 95% of the return in a diversified stock portfolio.

- f) Studies like this in the context of Indian markets have been very few (as stated in the research gap). This study will add value to the existing research knowledge on Indian securities markets and will also provide valuable suggestions to practitioners. Thus, the study has both academic and real-life significance.
- g) Indian financial markets are maturing and are attracting sizable retail and institutional investments. Advanced applications like the one presented in this study are of significance for the investors and investment consultants so that they can benefit from the different trading strategies like the one researched in this study.

1.11 Scope of Study

The scope of the study can be summarized by way of the following Table 2.

Table 2: Scope of the Study

Asset Type	Stocks	Commodities	Currencies
Observations to be recorded	i. Daily spot prices ii. Daily future prices iii. Transaction costs	i. Daily spot prices ii. Daily future prices iii. Transaction costs	i. Daily spot prices ii. Daily future prices iii. Transaction costs
Time period	Jan 01, 2011 – Dec 31, 2017		
Sample	Stocks listed in F&O section	Commodities listed at MCX	i. USD-INR ii. EUR-INR iii. GBP-INR iv. JPY-INR
Formation Period and Trading Period	Formation period (training period) of one year followed by trading period of 6 months on a rolling basis.		
Scenarios	Spot-Spot Future-Future Spot-Future	Future-Future	Spot-Spot Future-Future Spot-Future

1.12 Outline of the Thesis

CHAPTER I. INTRODUCTION

This chapter carries an introduction to the study including an introduction to the topic. It provides the detailed background and historical context of the topic chosen for the research. It also explains the aim and approach of the study apart from stating its objectives and rationale for selection of these objectives.

CHAPTER II. REVIEW OF LITERATURE

This chapter will begin with an introduction to the literature review. It will also state clear objectives for carrying out the Literature Review based on some guidelines so that the review is focused. The chapter will end by identifying the gap in the existing literature.

CHAPTER III. RESEARCH METHODOLOGY

This chapter would state the research approach and strategy. It will clarify the hypotheses formulation process and also lay down the scheme for testing the hypotheses. The chapter will also present the methodology for data analysis.

CHAPTER IV. RESULTS AND DISCUSSION

This chapter will present the results of the three-phase analysis, namely, identifying statistical arbitrage opportunities in Indian securities market, calculating its profitability and attributing the profitability to various risk factors using Fama and French three factor model. The results will be discussed in details.

CHAPTER V. SUMMARY

This being the last chapter will present summary of the entire research including a snapshot view. It will then present key findings from the study. Conclusions drawn would be presented next. This would be followed by suggestions including the scope for further research. Limitations of the study would also be mentioned.

CHAPTER II

REVIEW OF LITERATURE

This chapter reviews the literature on statistical arbitrage opportunities in various securities markets. It begins with an introduction to the literature review. Along with this, it also states the objectives for carrying out the literature review and the need for the study. It ends by identifying the gap in the existing literature.

The basic purpose of review of literature is to gather knowledge about contributions made by various researchers and academicians to a specific topic to identify the gaps in existing literature and frame the objectives for the study. This chapter is organized as follows: Section 2.1 deals with the introduction, section 2.2 presents review of literature, section 2.3 provides literature review in terms of quantified results and finally section 2.4 discusses the observations and research gap.

2.1 Introduction

Financial markets have been a subject matter of wide research across the globe. Majority of studies have been done in advanced countries like U.S., Italy, Japan and others. However, of late, attempts to study the “emerging markets” like India have been on the rise. Concepts like statistical arbitrage have been of immense interest for researchers in the financial domain. Various strategies to make money from such short-term opportunities have been stated. Given the vast amount of literature available, it is a difficult task to effectively carry out the literature review. Hence the following objectives for literature review have been formulated and used:

- a) to review literature on concept of statistical arbitrage,
- b) to review literature on concept of pairs trading,
- c) to review literature on concept of attributing the arbitrage profitability to various risk factors using the Fama and French three factor model,
- d) to review literature on usage of statistical arbitrage in Indian securities market, and
- e) to review studies in order to understand their end results

2.2 Review of Literature

This section deals with review of existing literature and is divided into four sub-sections: review of literature on statistical arbitrage, pairs trading, Fama and French three factor model and statistical arbitrage opportunities in Indian securities market respectively.

2.2.1 Statistical Arbitrage

Lazzarino *et al* (2018) has stated that while statistical arbitrage has been broadly investigated in literature, scholars either focus on definitions or on developing and testing

investment strategies, but attempt to reconcile these two areas of research are not seen much. The authors (Lazzarino *et al* 2018) have given a three-way classification of the take on statistical arbitrage which is shown below in Table 3.

Table 3: Definitions of Statistical Arbitrage (SA)

Author Name and Definition

Panel A: Lexical definitions

- Burgess (2000) - SA is a framework for identifying, modeling and exploiting small but consistent regularities in asset price dynamics
- Zapart (2003) - SA is an investment opportunity arising from the choice of models for hedging
- Do *et al* (2006) - SA is an equity trading strategy that employs time series methods to identify relative mispricing between stocks
- Thomaidis and Kondakis (2006) - SA is an attempt to profit from pricing discrepancies that appear in a group of assets
- Pole (2007) - SA uses mathematical models to generate returns from systematic movements in securities prices
- Avellaneda and Lee (2010) - SA encompasses a variety of strategies characterized by: i) systematic trading signals, ii) market neutral trades and iii) statistical methods
- Montana *et al* (2008) - SA is an investment strategy that exploits patterns detected in financial data streams

Panel B: Conceptual definitions

- Connor and Lasarte (2003) - SA is a zero-cost portfolio where the probability of a negative payoff is very small but not exactly zero
- Stefanini (2006) - SA seeks to capture imbalances in expected value of financial instruments, while trying to be market neutral
- Saks and Maringer (2008) - SA accepts negative pay-outs with a small probability as long as the expected positive payouts are high enough and the probability of losses is small enough
- Focardi *et al* (2016) - SA strategies aim at producing positive, low-volatility returns that are uncorrelated with market returns

Panel C: Operational definitions

- Ledoit (1995) - δ -Arbitrage (δA) is a strategy with a Sharpe ratio above a constant and positive δ

Contd...

- Chochrane and Saa-Requejo (1998) - Good Deal consists in buying (selling) securities whose market price lies outside a range of plausible prices
- Bernardo and Ledoit (2000) - Approximate Arbitrage is a strategy whose gain-loss ratio is above a predefined constant value greater than 1
- Carr *et al* (2001) - Acceptable Opportunity is a strategy with a non-negative expected value under each valuation measure and losses capped under the set of stress measures
- Bertsimas *et al* (2001) - ϵ -Arbitrage (ϵ A) consists in buying (selling) those derivatives strategies whose price significantly differs from the least costly optimal replication strategy
- Bondarenko (2003) – SA is a strategy with expected positive payoff and expected non-negative payoff conditional on the augmented information set
- Hogan *et al* (2004) - With time SA strategy has positive expected payoff, probability of a loss which tends to zero and time averaged variance which converges to zero

Note: Adapted from “What Is Statistical Arbitrage?” by Lazzarino *et al* (2018), *Theoretical Economics Letters*, 8, 888-908.

Analysis of some of the definitions of statistical arbitrage shows that while on one hand there are several studies that introduce definitions extending the concept of arbitrage through statistics but with little emphasis on strategies (for instance, Ledoit 1995, Chochrane and Saa-Requejo 1998, Bernardo and Ledoit 2000, Bertsimas *et al* 2001, Carr *et al* 2001, Bondarenko 2003, Hogan *et al* 2004); there are on other hand, researches on statistically determined arbitrage strategies that focus on models and investment opportunities (for instance, Stefanini 2006, Pole 2007) with little or no discussion on definitions and theoretical framework.

Technological developments in computational modeling have also paved the way for the use of statistical arbitrage in high frequency trading and with the so-called machine learning methods, such as neural networks and genetic algorithms (see Brogaard *et al* 2014, Chaboud *et al* 2014, Ortega *et al* 2015). In more recent years, statistical arbitrage has seen renewed interest in emerging areas such as bitcoin (Brandvold *et al* 2015, Lintilhac and Tourin 2016), big data (McAfee *et al* 2012, Lazer *et al* 2014, Nardo *et al* 2016) and factor investing (Maeso and Martellini 2017).

2.2.2 Pairs Trading

Pairs trading is a statistical arbitrage strategy that is quite popular in equity (Vidyamurthy 2004). In its simplest formulation, pairs trading aims to identify pairs of stocks whose prices have historically moved together in either direction. When the spread between

the two components of the pair significantly widens, the strategy is to sell the best performing security and to simultaneously buy the laggard. If the spread reverts to the mean (which is an expectation) the trade will be profitable regardless of market trends. This strategy relies on the assumption of a (long-term) equilibrium in the investigated spreads (Do and Faff 2010) which can be identified through a variety of statistical methods (Gatev *et al* 2006, Avellaneda *et al* 2010, Do *et al* 2006, Nath 2003, Vidyamurthy 2004, Elliott *et al* 2005, Do and Faff 2010). Long and short positions can be combined in a ratio which makes the trade market-neutral (with a neutral beta position versus the market) or dollar (currency)-neutral. The use of pairs trading is not restricted to stocks. There are applications to other areas such as spreads between different commodities (Monroe and Cohn 1986, Johnson *et al* 1991, Wahab *et al* 1994, Barrett and Kolb 1995, Girma and Paulson 1999, Cummins and Bucca 2012), commodity future contracts (Cui *et al* 2015) and freight markets (Roehner 1996, Alizadeh and Nomikos 2002). The concept can also be used to model the spread between different portfolios (Alexander *et al* 2005, Cheng *et al* 2011, Acosta-Gonzalez *et al* 2015).

The elusive area of pairs trading as a "short-term speculation strategy" (Gatev *et al* 2006) has attracted widespread interest in the academic discipline. Nevertheless, this dynamic investment strategy is still considered a comparably new concept in academic research as well as public debate. Some form of consensus has been reached with respect to the potential for exploitation of financial market inefficiencies in the recent literature, which is a reflection of the fundamental idea of statistical arbitrage (Perlin 2009). The pairs trading strategy hence bets on the fundamental premise that "these deviations are temporary and will be corrected over time" (Bogomolov 2013).

Predominantly, the implementation of a pairs trading strategy can be divided into three principal approaches, namely, a) the distance approach, b) the cointegration method, and c) the stochastic spread technique. All of the above mentioned approaches share much the same internal framework: the formation of pairs is largely dependent upon ex-post analysis of historical prices. This is complemented by the different stipulations determining the threshold limits triggering the initiation of signal, performance and subsequent closure, which are successively dependent on the development of the spread process (Bogomolov 2010).

An important differentiating factor associated with the distance method relates to the composition of pairs based on the "**minimum-distance principle**". The aforementioned criterion is based on a two-step process that begins with the employment of a cumulative total returns' index for each security individually and then finding a matching partner for each individual security. The unique pair's combination can hence be formed by "finding the security that minimizes the sum of squared deviations between the two normalized price series" (Gatev *et al* 2006).

The other category of the literature area emphasizes on the “**cointegration approach**” (see Alexander 1999, Vidyamurthy 2004, Caldeira and Moura 2013). The authors posit to take advantage of a cointegrating relationship between the two securities so as to explore and analyse the performance of a pairs trading strategy. To achieve this, varied methods are identified. On the one hand, there are studies that largely emphasize on the Engle-Granger 2-Step approach to model and test for a cointegrating relationship (see Dunis *et al* 2010, Caldeira and Moura 2013); on the other hand, there are studies that instead provide the Johansen's test combined with a vector error correction model (VECM) as a viable option (see Dunis and Ho 2005, Huck and Afawubo 2015). Notwithstanding, both the methods empirically evaluate if a long-term steady relationship between two time-series can be identified. Do *et al* (2006) and Lim and Martin (1995) assert that in spite of its qualifications, the Engle-Granger 2-Step procedure suffers from two basic limitations. First, the regression analysis residuals may be vulnerable to changing set of statistical properties because of the result's sensitivity to correct sequence of the variables. Second, along with it, the generation of spurious regressions may be a repercussion of the lack of cointegration between the two time-series. Puspaningrum *et al* (2011) explain that in order to overpower the limitations associated with the Engle-Granger approach, the Johansen's method applies vector error correction model that facilitate the usage of all the variables used in the regression specification to be endogenous. Haque and Haque (2014) emphasize on this fact as the residuals produced from the estimated equation perform a vital part in pursuing a pairs trading strategy. Regardless, because of its practical relevance and application, the Engle-Granger 2-Step method remains the favourite approach in the literature. Alexander (1999) substantiates the aforementioned proposition on the basis of its straight-forward execution and superiority of the minimum variance criterion over that of the maximum stationarity measure used by Johansen in risk management considerations.

With the focus shifting towards the “**stochastic spread method**”, Elliot *et al* (2005) suggest modeling the spread between two securities as a mean-reverting process (Gaussian Markov chain) that is premised on the market observations. The long and short positions are either entered into or unwound respectively by analysing and comparing the actual market values with the forecasts of the spread. However, the stochastic spread method is impacted by the increase in transaction and trading costs because of the frequent trading signals produced by the model, which may adversely affect the accumulated excess returns. Regardless of the obvious limitation in regard to the other two methods (distance method and cointegration method), it can be marked that the stochastic spread method is the only technique that has a delineated exit-strategy established by the certain thresholds levels. This is an important component of this approach as the other two approaches do not take into account the likelihood

of increased price divergence. This divergence from the equilibrium level of the relative stock price relationship may result in ensuing losses (Bogomolov 2010). However, it is pertinent to acknowledge that although the stochastic spread approach has received certain attention in the academic field, it is still a quite undeveloped area with not many back tests and few number of performance evaluation results (Tianyong *et al* 2013).

The calculation of portfolio excess returns for the pairs trading investment tactics is conceptualized with the usage of committed and fully invested capital metrics. While the former scales the returns using the portfolio pairs formed in the training period, the latter divides returns to all the pairs engaged in a position during the formation period (Bowen *et al* 2014). Further, it is quite apparent that most of the authors have selected daily security closing prices as the most suitable data for the testing and evaluation of a pairs trading strategy considering their relative higher frequent intervals and thus greater coverage based on observation.

In general, the academic domain concedes with the fact that so as to comprehensively test and evaluate a trading strategy and hence build a robust system, the models should be back-tested comprising of time periods of varied market regimes on different markets. Muslumov *et al* (2010) further extend this proposition by applying a rolling window technique which changes the pair's formation and trading periods by a period of one month until the entire sample period is considered. By rightly executing the process, a comprehensive vector of overlapping abnormal returns can be obtained. On the other hand, the results might have some bias because of the focus on special sub-periods, but contrarily may act as a stress-test revealing how a certain trading strategy is performing during crisis times.

2.2.3 Fama and French Three Factor Model

Fama and French (1998) confirm their results on large number of stock markets across the globe. They find that the price ratios that produce problems for the Capital Asset Pricing Model (CAPM) in U.S. data show up in similar manner in the stock returns of twelve non-U.S. major markets as well, and they are present in emerging market returns also. This evidence suggests that the contradictions of the CAPM associated with price ratios are not sample specific but quite broad based. Davis (1994) confirms the effect of book-to-market in the U.S. market.

The empirical evidence on the three factor model (Fama and French 1993), in Italy, is well documented by Fama and French (1998), Cavaliere and Costa (1999) and Aleati *et al* (2000). Cavaliere and Costa (1999), for instance, investigate all Italian listed companies during the period 1986-1995 and identify a relationship between beta and size. They also note the beta's tendency to increase with the size of the company.

Aleati *et al* (2000) study the Italian stock market during the period 1981-1993 through the modified three factor Model to cover other macroeconomic variables such as the change in interest rates and the default premium, and discover that the relationship between beta and stock return is quite robust. The relationship between size and stock return depend instead on the estimation methodology. Bruni *et al* (2006) find that the CAPM do not have a strong explanatory power and require additional factors beyond the beta to better explain the risk-return relationship.

Achola and Muriu (2016) state that “for over half a century, financial economists have grappled with the factors that determine stock returns. This has yielded several models for pricing assets. However, these models were developed for advanced markets such as the U.S. stock market. It is probable that these models may not hold in markets classified as emerging such as Kenya. An emerging market has unique characteristics like lower market liquidity, inexperienced market participants, shorter history, domination by institutional investors especially commercial banks and concentration of trade in a few stocks”.

The inconsistencies with the CAPM have been termed market “anomalies” since they violate CAPM’s predictions (Fama and French 1996). Furthermore there are various other unexplained patterns that have been observed in empirical studies of CAPM. For instance, Basu (1977, 1983) observe a positive association between expected returns and earnings to price ratio; Banz (1981) finds that small firms have higher returns as compared to big firms; Bhandari (1988) finds that the correlation between debt levels and stock returns to be positive while Chan *et al* (1991) observe that the ratio of book equity to market equity can explain stock returns in Japanese market, an observation that has been later confirmed by Fama and French (1992) in American markets.

Fama and French (2004) contend that market proxies applied in usage of CAPM are the same ones used in empirical tests. Therefore, if contradictions are found in empirical test, it is for sure they will be reflected in poor estimates of average returns in applications. They conclude that if a market proxy is unacceptable in empirical tests of CAPM, then it implies that the application of the model is invalid.

Evidence of research going beyond the CAPM is seen in some other studies as well. This supports the claims that CAPM model may not be tested positive always. For instance scholars such as Bundoo (2011) and Hearn (2009) justify their approach by considering in their studies time varying beta and liquidity factor respectively. Further previous studies such as Riro and Wambugu (2015), attempt to factor the unique market characteristics such as liquidity and concentration.

The augmented three factor model’s performance as applied by Achola and Muriu (2016) conforms with Claessens *et al* (1995) who note that size of a firm and the volumes of

trade could explain returns in emerging markets. They attribute the significance of trading volume to participation in the market by foreign investors.

2.2.4 Statistical Arbitrage in Indian Securities Market

Zargar and Kumar (2019) in their work “Opening Noise in the Indian Stock Market: Analysis at Individual Stock Level”, suggest that the traders in the Indian stock market should shorten the stock at the beginning of the day and lengthen the same stock at the end of the day when the overnight return (ONR) is positive, and when the same (ONR) is negative do the reverse, that is, buy at the beginning and sell at the end. Pritamani and Singal (2001) in their work “Return Predictability Following Large Price Changes” prove that trading on information is profitable.

Thomaidis and Kondakis (2006) study stocks of Infosys and WIPRO from the Indian stock markets and propose an intelligent combination of neural network theory and financial statistics for the identification of statistical arbitrage opportunities in specific pairs of stocks. Reasoning the choice of the two stocks, the authors state that they are from the same sector, both have ADRs listed on the U.S. markets and further they are from emerging markets. The authors conclude that the performance of the proposed intelligent trading system is properly measurable with the aid of profit & loss diagrams, for a number of different experimental settings (i.e. sampling frequencies). However they also express that while first the results seemed to be encouraging further experimentation on the optimal sampling frequency, the forecasting horizon and the points of entry and exit are necessary so as to achieve highest economic value when transaction costs are considered.

Aggarwal and Gupta (2015) carry out pairs trading using contracts traded on financial stock futures. They find that superior returns of 3.71% are generated by pairs trading portfolio using methodology used by Gatev *et al* (2006) with holding period of maximum two weeks.

Gupta and Singh (2007, 2009) list studies carried world-wide on application of cointegration, causal and lead-lag relationship between cash and futures markets. They also list empirical evidences on pricing efficiency of futures markets. Table 4 is presented in order to understand the extent to which Indian markets have been studied in comparison to markets of the other countries.

2.3 Summary of Studies and their Empirical Findings

Despite of the fact that pairs trading strategies have already been applied in financial markets for several decades, the corresponding academic literature is not as rich as for other finance topics when it comes to Indian securities market. Table 5 is a summary table showing study outcomes in terms of quantified results.

Table 4: Empirical Evidences on Pricing Efficiency of Futures Markets

Author (Year of Study)	Country Understudy	Market Understudy	Period Understudy	Mispricing
Cornell and Reinganum (1981)	U.S.A	IMM	1974-1979	No
Cornell and French (1983)	U.S.A	NYSE and S&P 500	June 1982-September 1982	Yes
Figlewski (1984)	U.S.A	S&P 500	1982-1983	No
Klemkosky and Lasser (1985)	U.S.A	T-Bond Futures	1978-1981	Yes
Merrick Jr. (1988)	U.S.A	NYSE and S&P 500	1982-1986	Yes
Mackinlay and Ramaswamy (1988)	U.S.A	S&P 500	1982-1987	Yes
Diagler (1990)	U.S.A	S&P 500 and MMI	1987-1988	No
Yadav and Pope (1990)	U.K.	FTSE 100	1984-1988	Yes
Klemkosky and Lee (1991)	U.S.A	S&P 500	1983-1987	Yes
Puttonen and Martikainen (1991)	Finnish	FOX	1988-1990	Yes
Twite (1992)	Australia	SPI	1983-1988	Yes
Yadav and Pope (1994)	U.K.	FTSE 100	1986-1990	Yes
Neal (1996)	America	S&P 500	1989	Yes
Brailsford and Hodgson (1997)	Australia	AOI and SPI	1989-1993	Yes
Brailsford and Cusack (1997)	Australia	SPI	1994-1995	Yes
Akin (2003)	America	11 commodity contracts traded on CME	1982-2000	Yes
Lee (2005)	Korea	KOSPI	1996-2001	Yes
Vipul (2005)	India	NIFTY, ACC, INFOSYS, RIL, SATYAM, TELCO, TISCO	2002-2004	Yes
Gupta and Singh (2007)	India	Nifty	July 2000 to December 2005	Yes
Roll <i>et al</i> (2007)	America	S&P 500	1988-2002	Yes
Gupta (2008)	India	Nifty and 84 Individual Stocks	January 2003 to December 2006	Yes

Note: U.S.A: United States of America, IMM: International Monetary Market, NYSE: The New York Stock Exchange, T-Bond: Treasury Bond, MMI: The Major Market Index, U.K.: United Kingdom, FOX: Finnish Stock Exchange, AOI: Australian Stock Exchange, CME: Chicago Mercantile Exchange, KOSPI: The Korea Composite Stock Price Index

Source: Adapted from “Price Discovery and Arbitrage Efficiency of Indian Equity Futures and Cash Markets” by Gupta and Singh 2009

Table 5: Summary of Literature Review in terms of quantified results

S.No.	Author (Year)	Topic	Sample and Time Period	Major Findings
1	Andrade <i>et al</i> (2005)	Understanding the Profitability of Pairs Trading	647 listed companies on Taiwan Stock Exchange from January 5, 1994 to August 29, 2002	<p>The pairs trading portfolio earns 3.876 basis points (bps) per day or 10.18% annualized returns.</p> <p>The risk-adjusted returns range between 2.612 basis points (6.75% per annum) and 3.886 basis points (10.20% annually). The paper concludes that pairs trading profits are compensation for providing liquidity in the markets with limited risk bearing capacity.</p>
2	Badhani and Suyal (2006)	Stock Price-Volume Causality at Index level	Stock prices and volume data obtained from NSE over the period April 1995 - March 2005.	<p>The results indicate one-way causality running from stock prices to volume.</p> <p>The absence of the causality of volume on prices shows the market efficiency.</p> <p>The study also finds the evidence suggesting that the market efficiency has improved during recent time period, particularly after July 2001.</p>
3	Gatev <i>et al</i> (2006)	Pairs Trading: Performance of a Relative Value Arbitrage Rule	U.S. stocks over the period 1962-2002	<p>Pairs trading implementation in two stages: formation of pairs over a twelve-month period (formation period) and trade them in the next six-month period (trading period).</p> <p>A simple trading rule yields average annualized excess returns of up to 11% for self-financing portfolios of pairs. The profits typically exceed conservative transaction costs estimates.</p>

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S.No.	Author (Year)	Topic	Sample and Time Period	Major Findings
4	Bianchi <i>et al</i> (2009)	Pairs Trading Profits in Commodity Futures Market	Daily closing prices of 27 commodity futures from U.S. and U.K. for the period January 1990 - August 2008	The portfolio of top 5 pairs produces an average monthly excess return of 1.44% while the portfolio of top 15 pairs reports an average monthly excess return of 1.26%. The excess returns from pairs trading strategy in commodity futures are not related to conventional market risk factors.
5	Bolgün <i>et al</i> (2009)	Dynamic Pairs Trading Strategy for the Companies Listed in the Istanbul Stock Exchange	ISE-20 index shares over the period 2002-2008	The results show that pairs generated average returns of 3.36% daily in contrast to the naïve buy and hold strategy. However ISE 30 daily average return is 0.038% between 2002-2008 period.
6	Mahalik <i>et al</i> (2009)	Price Discovery and Volatility Spillovers in Futures and Spot Commodity Markets: Some Empirical Evidence from India	Spot and future prices data of four indices of MCX, India, viz., MCXCOMDEX, MCXAGRI, MCXENERGY and MCXMETAL from June 2005 to December 2008	The cointegration results indicate that agriculture future price index (LAGRIFP), energy future price index (LENERGYFP) and aggregate commodity index (LCOMDEXFP) effectively facilitate the price discovery mechanism in the spot market which imply that there is a flow of information from future to spot commodity markets but the non-existence of reverse causality.
7	Müslümov <i>et al</i> (2009)	The Profitability of Pairs Trading in an Emerging Market Setting: Evidence from the Istanbul Stock Exchange	Daily adjusted closing prices of the stocks listed on Istanbul Stock Exchange between January 1, 1990 and April 20, 2007	Distance-based pairs trading methodology gives an average excess return of 5.4% for the top 20 best pairs portfolios.

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S.No.	Author (Year)	Topic	Sample and Time Period	Major Findings
8	Muslumov <i>et al</i> (2010)	Pairs Trading with Turkish Stocks	Stocks traded on the ISE between January 1, 1990 and March 31, 2007	Relatively large positive excess returns, which range from 1.26% to 3.50% per month, are available around short trading periods of between one and two months.
9	Rudy <i>et al</i> (2010)	Profitable Pair Trading: A Comparison Using the S&P 100 Constituent Stocks and the 100 Most Liquid ETFs	Daily closing prices of stocks that formed the S&P 500 index and the hundred most liquid ETFs as of June 11, 2010, with time period that spanned from January 3, 2000 to June 25, 2010	The average out-of-sample information ratios obtained for fifty such pairs selected from ETFs and shares are 2.93 and 0.46, respectively.
10	Do and Faff (2012)	Are Pairs Trading Profits Robust to Trading Costs?	U.S. equity market between the period July 1962 and June 2009	The pairs trading strategies generate an average alpha of 24 bps per month when applied and executed on the top 30 percent of the largest stocks. Pairs trading strategy exhibit a lower return and lower risk profile than a short-term reversal strategy which positions stocks relative to their industry peers.
11	Mori and Ziobrowski (2011)	Performance of Pairs Trading Strategy in the U.S. REIT Market	U.S. REIT market and U.S. stock market over the period 1987 to 2008	In comparison to the U.S. stock market, pairs trading in the U.S. REIT market started producing superior pairs trading profits after 1993. This is likely because of the structural changes that happened in the REIT industry, resulting in significantly larger excess returns from this pairs trading strategy with REITs (0.60% per month) when compared to common stocks (0.01% per month), supplemented by a significantly smaller standard deviation (0.62% with REITs compared to 3.46% with common stocks) for the period 1994–2000 after accounting for the effect of bid-ask bounce.

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S.No.	Author (Year)	Topic	Sample and Time Period	Major Findings
12	Kim (2011)	Performance Analysis of Pairs Trading Strategy Utilizing High Frequency Data with an Application to KOSPI 100 Equities	Most liquid 100 stocks in KOSPI from October 1, 2008 to July 31, 2010	<p>The trading strategy is formed which selected 5 high-ranking pairs as the trading portfolio for the trading time period, based on a set of in-sample statistics.</p> <p>The study generates average rate of return per trade as 2.55%, 0.80%, 0.39% and 0.68% for bearish, bullish, flat and entire period respectively.</p> <p>It is verified that the enhanced strategy has better profitability and stability compared to its basic strategy.</p>
13	Almeida (2011)	Improving Pairs Trading	Daily price and volume data for all U.S. listed stocks (from the major indices) over the period January 1, 1990 – January 1, 2011	<p>Results imply that pairs opened after a single sided shock are less profitable.</p> <p>A limitation on the numbers of days a pair is open can significantly improve the profitability by as much as 30 basis points per month.</p> <p>The paper draws the conclusion that it is best to avoid pairs which trigger around abnormal volume changes in one of the assets.</p>
14	Modi <i>et al</i> (2012)	Finding the Identical Twin	2000 trading days daily data ending on November 30, 2011 of DJIA, FTSE 100, CAC 40, DAX, Shanghai Composite, Hang Sang, BSE 30, Nikkei 225, Straits Times, Bovespa and MerVel	<p>DJIA is tested for correlation and ADF statistics with FTSE 100, CAC 40, DAX, Shanghai Composite, Hang Sang, BSE 30, Nikkei 225, Straits Times, Bovespa and MerVel.</p> <p>The most negative ADF test statistics -3.262 is found with DJIA-DAX time series.</p> <p>The highest degree of correlation 0.90 is found between DJIA-FTSE 100 time series followed by DJIA-Straits Times.</p>

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S.No.	Author (Year)	Topic	Sample and Time Period	Major Findings
15	Caldeira and Moura (2013)	Selection of a Portfolio of Pairs Based on Cointegration: A Statistical Arbitrage Strategy	Daily closing prices of most liquid 50 stocks with largest weights in the Ibovespa index from Sao Paulo Stock Exchange from January 2005 to October 2012	Empirical analysis shows that the proposed strategy exhibits the cumulative net profit of 189.29% from the four year period of rolling window out-of-sample tests with an annual mean of 16.38%. The study implies the annual excess returns of 16.38%, Sharpe ratio of 1.34 and low correlation with the market.
16	Desai <i>et al</i> (2013)	The Case of Gold and Silver: A New Algorithm for Pairs Trading	Closing prices of gold and silver on MCX, India from January 1, 2004 to June 30, 2012	The proposed algorithm generates 100% accurate trades with return of 44.45% for the testing period (January 1, 2008 - June 20, 2012).
17	Huck (2013)	The High Sensitivity of Pairs Trading Returns	U.S. S&P 500 stocks from June 2004 to May 2009	The monthly excess returns of pairs trading are highly sensitive to the length of the formation period. With a 1.5-year and 2-year formation period, the raw monthly returns are all greater than 0.60% per month and economically significant.
18	Pizzutilo (2013)	A Note on the Effectiveness of Pairs Trading For Individual Investors	All the shares listed on Milan Stock Exchange and traded over the period 2002-2011	The study witnesses the net yearly return of 6.69% for top 5 pairs. Evidence is found that restrictions to the number of shares that are allowed to be shorted had a relevant impact on the risk profile of the pairs portfolios. Results support the hypothesis that pairs trading is an equity market neutral investment strategy.

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S.No.	Author (Year)	Topic	Sample and Time Period	Major Findings
19	Bowen and Hutchinson (2016)	Pairs Trading in the U.K. Equity Market: Risk And Return	6729 securities included in FTSE All-Share Index from January 1979 to December 2012	The top 5 and top 20 pairs have mean annualized monthly returns of 7.4% and 11.5% respectively before transaction costs, which is equivalent to the FTSE All-Share Index return. The results show that pairs trading portfolios typically have little or no exposure to known equity risk factors such as market, size, value, momentum and reversal.
20	Clegg (2014)	On the persistence of Cointegration in Pairs Trading	Daily adjusted closing prices of stocks in S&P 500 for the period January 1, 2001 through December 31, 2012	The paper examined whether cointegration is a persistent property in the case of pairs of U.S. equities. The results do not support the hypothesis and indicate that if two securities are cointegrated in one year, no useful information is gained as to whether they would be cointegrated in the following year.
21	Haque and Haque (2014)	Pairs Trading Strategy in Dhaka Stock Exchange: Implementation and Profitability Analysis	Daily stock prices of 20 stocks listed in Dhaka Stock Exchange from September 24, 2012 to September 30, 2013	The study shows that the three stock pairs generate positive returns for both in-sample and out-of-sample data. The returns are as high as 15.38% using out-sample data.
22	Zhnag <i>et al</i> (2014)	A Multi-factor Adaptive Statistical Arbitrage Model	All U.S. stocks in the S&P 500 from 2004 to 2011	The paper attempts to examine the implementation and execution of a statistical arbitrage trading strategy based on co-integration relationships when portfolios are identified using multiple factors instead of only price data. The portfolio selection methodologies comprise of K-means clustering, graphical lasso and a combination of the two. The results reveal that clustering appears to yield better candidate portfolios on average than naively using graphical lasso over the entire equity pool.

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S.No.	Author (Year)	Topic	Sample and Time Period	Major Findings
23	Aggarwal and Gupta (2015)	Pairs Trading in Financial Stock Futures: An Empirical Investigation in Indian Stock Market	Daily future closing prices of 28 financial stocks listed in NSE from January 1, 2011 to December 31, 2013	Pairs portfolio generates large positive returns ranging from -0.21% to 7.14% per month for maximum holding period of two weeks.
24	Huck and Afawubo (2015)	Pairs Trading and Selection Methods: Is Cointegration Superior?	U.S. S&P 500 stocks from August 2000 to September 2011	After controlling for risks factors, transaction costs and data snooping biases, pairs trading based on cointegration method exhibit high and robust positive alpha, with returns rising up to 5% per month.
25	Ungever (2015)	Pairs Trading to the Commodities Futures Market using Cointegration Method	Daily future closing prices of 10 commodities traded on CBOT, CME and ICE from December 1, 2004 to May 1, 2015	The study found that pairs trading in commodity futures markets earn statistically significant returns with 202% average return per trade and average annualized return of 358.5%.
26	Yang <i>et al</i> (2017)	Pairs Trading with Commodity Futures: Evidence from the Chinese Market	Daily closing prices of commodity futures traded in DCE, SHFE and CZCE from January 1, 2005 to June 1, 2016	Annual average return ranges from 24.03% with 1 pair in the portfolio to 16.34% with 6 pairs in the portfolio without transaction costs. Average returns drop by 3.28% after factoring transaction costs. The paper implies that the profitability of pairs trading strategies was mainly dependent on the identification of suitable pairs.

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S.No.	Author (Year)	Topic	Sample and Time Period	Major Findings
27	Caldas <i>et al</i> (2016)	Is Pairs Trading Performance Sensitive to the Methodologies?: A Comparison	Three financial markets - Brazil - stocks listed in Bovespa between 1995 and 2012 United States - 4471 most liquid stocks from 1962 to 2012 Europe - 1000 most liquid stocks from 1973 to 2012	Brazil - Cointegration method has a cumulative return of up to 2499%, while distance method has a cumulative return of up to 148%. United States - Distance method has delivered up to 13.331% cumulative return, more than the 1.047% return of the cointegration method. Europe - Cointegration method has delivered up to 14.602% cumulative return against 1.860% for the distance method; indicating cointegration being a superior method.
28	Chen <i>et al</i> (2017)	Empirical Investigation of an Equity Pairs Trading Strategy	Monthly stock prices of all the CRSP firms from January 1931 to December 2007	The empirical evidence indicates that a trading strategy that bets on the convergence generates six-factor (market, size, book-to-market, momentum, short-term reversal, and liquidity) alphas of up to 9% annually for a value-weighted self-financing portfolio, and 36% for an equal-weighted portfolio. The pairs trading profits are largely explained by the short-term reversal and a version of the industry momentum, and cannot be explained by investment-based factors, funding liquidity risk or financial intermediary leverage factor.

Note: NSE: National Stock Exchange of India, ISE: Istanbul Stock Exchange, MCX: The Multi Commodity Exchange of India Limited, REIT: Real Estate Investment Trust, KOSPI: The Korea Composite Stock Price Index, DJIA: Dow Jones Industrial Average, FTSE 100: Financial Times Stock Exchange Index, CAC 40: Cotation Assistée en Continu (a benchmark French stock market index), DAX: Deutscher Aktien Index (a stock index that represents 30 of the largest and most liquid German companies that trade on the Frankfurt Exchange), BSE 30: S&P Bombay Stock Exchange Sensitive Index, Nikkei 225: A price-weighted index composed of Japan's top 225 blue-chip companies traded on the Tokyo Stock Exchange, Straits Times: The benchmark index that tracks the performance of the top 30 companies listed on the Singapore Exchange, Bovespa/Ibovespa: The benchmark index of about 60 stocks that are traded on the B3 (Brasil Bolsa Balcão), Merval: Index of the Buenos Aires Stock Exchange, Argentina, CBOT: Chicago Board of Trade, CME: World's largest financial derivatives exchange, ICE: Intercontinental Exchange, DCE: Dalian Commodity Exchange, SHFE: Shanghai Futures Exchange, CZCE: Zhengzhou Commodity Exchange, CRSP: Center for Research in Security Prices

Source: Compiled from review of literature

2.4 Observations and Research Gap

Investors have begun to understand that for active managers to outperform passive benchmarks has become difficult and this debate is going on from decades. As William Sharpe explained in his article “Arithmetic of Active Management”, for the average manager to outperform a passive benchmark that, in fact, represented the performance of the average manager is hard (Sharpe 1991). And this difficulty occurs **before costs**. Jack Bogle, in his “cost matters” hypothesis, argued for a similar “arithmetic” to explain that the gross return in the financial markets minus the costs of financial intermediation equals the net return actually delivered to investors (Bogle 2005). Gross return, in his view, is unpredictable and fleeting, whereas the costs of financial intermediation are large and highly predictable. Based on collective consideration of the research material, the following could be deduced:

- a) Research on concepts of statistical arbitrage, pairs trading and the Fama and French model is quite extensively done.
- b) However, studies carried in Indian context are relatively very less in numbers.
- c) Moreover, studies in the Indian context are mostly confined to stocks and related derivatives.
- d) Classical models like CAPM have been challenged and improvised versions like the Fama and French three factor model have found favor with the researchers.

In terms of concept, a single study combining statistical arbitrage, profitability measurement and its attribution to different risk factors is not seen on record in Indian context. Further studies using advanced concepts are very limited. Also studies researching statistical arbitrage opportunities in commodities and currencies along with stocks is nearly non-existent in Indian securities context. This study is attempted to provide insights about different statistical arbitrage opportunities existing in Indian securities market.

CHAPTER III

RESEARCH METHODOLOGY

This chapter describes the research methodology that has been used to study the profitability of statistical arbitrage opportunities present in Indian securities market across different asset classes and its attribution to different risk factors.

To perform the research in a most effective and systematic way, it is essential to determine the research methodology well in advance, which details the procedures necessary for solving the research problem along with the logic behind them. This chapter defines the research methodology which is adopted to achieve the objectives of the study in an effective manner. It outlines the research purpose, the hypotheses, detail of population, sample, methods and procedures to test the hypotheses. It will spell out the methodology applied for this research. It will explain the nature of the research and the rationale behind the selection of specific techniques to test the hypotheses.

This chapter is organized as follows: Section 3.1 presents the conceptual framework of the study, section 3.2 provides objectives, scope and hypotheses, section 3.3 deals with the population and sampling of the study, section 3.4 and section 3.5 discuss the time period and sources of data respectively. Next, section 3.6 presents the framework of analysis and finally section 3.7 lists the risks and limitations of the study.

3.1 Conceptual Framework of the Study

The present study is undertaken to study the existence and profitability of statistical arbitrage opportunities in Indian securities market. Statistical arbitrage represents statistically significant deviations from historically identified average price relationships. It involves taking counteracting positions in securities that are historically or mathematically associated, but taking these positions at times when their inter-relationship has been temporarily askewed. Statistical arbitrage in Indian securities market is studied in the form of pairs trading. Pairs trading was pioneered by Gerry Bamberger and later led by Nunzio Tartaglia's quantitative group at Morgan Stanley in the 1980s. Pairs trading is a market-neutral trading strategy that tries to match a long position with a short position in a pair of significantly correlated instruments such as two stocks, currencies, commodities, exchange-traded funds (ETFs) or options. It has three main components, namely:

- a) **Market Neutrality:** It implies that it is neutral to the market return. Irrespective of whether the market goes up or down, in good times and bad times, the market neutral strategy performs in a steady manner, and results are typically achieved with a lower volatility. It derives its returns from the relationship between the performance of its long

and short positions, irrespective of whether this relationship is done on the security or portfolio level.

- b) **Relative Value or Statistical Arbitrage:** It is based on implied or perceived pricing flaws rather than on real ones and is a result of the perception that the relationship between two securities has deviated from its historical average in a statistically significant way. In terms of pairs trading, the most important feature of arbitrage is the convergence of these fluctuations (temporary distortion of relationship between two historically or mathematically related securities) back to their expected value, popularly known as the concept of mean reversion.
- c) **Technical Analysis:** From a pairs trading perspective, and particularly a short-term statistical arbitrage standpoint, technical analysis plays an important role, and often, is the driving force behind trades.

The working of pairs trading involves three key features, which are:

- a) the combination of long and short investing,
- b) the ability to use leverage, and
- c) an arbitrage situation (Ehrman 2006).

Although the pairs trading technique of statistical arbitrage is commonly used by hedge funds and investment banks, empirical studies testing the performance of this strategy are scarce in Indian context. Moreover, its profitability from a retail investor's point of view after duly incorporating all transaction costs and trade restrictions have not been studied in Indian context. The present study attempts to fulfil that gap. The study is a comprehensive one, covering three asset classes, viz., stocks/equities, commodities and currencies. The study involves a systematic process, starting with the identification of pairs for the pairs trading; then forming the trading rules and trading it in real case scenario; and measuring performance with the help of various risk-adjusted measures.

3.2 Objectives, Scope and Hypotheses

3.2.1 Objectives of the Study

The following objectives have been set to understand whether statistical arbitrage opportunities exist in India, so as to gather a more practical view of the markets as against theories that specify market efficiency. Further, the objectives are framed to get to know to what extent these opportunities are profitable and their risk-return pay-off.

- 1) To study statistical arbitrage opportunities present in Indian securities market.
- 2) To study the profitability of statistical arbitrage opportunities in Indian securities market.

- 3) To attribute the returns generated from statistical arbitrage to different risk factors.

It is a comprehensive study spanning across equities, commodities and currencies. Studies like this in the context of Indian markets have been very few (as stated in the research gap). This study is expected to add value to the existing research knowledge on Indian securities markets and provide valuable suggestions to practitioners. Ergo, the study has both academic and real-life significance.

3.2.2 Saunders Research Onion

A very popular guide “the research onion” was developed by Saunders *et al* (2007). It illustrates the stages that must be covered when developing a research strategy. When seen from the outside, each layer of the “onion” elaborates a more detailed stage of the research process (Saunders *et al* 2007). Table 6 presents the gist of this study in terms of the Saunders Research Onion framework.

Table 6: Saunders Research Onion Framework for the Study

S.No.	Element of the paradigm	Applications in the current study
1	Research Philosophy	Positivist approach is adopted for this study as it involves usage of empirical data and existing concepts. At the same time inquiries are made into application of statistical arbitrage opportunities in Indian markets, its profitability and allocation of the same to different risks. To an extent the study can also be called as one with interpretivism philosophy.
2	Research Approaches	Since the key variables of this study were investigated by way of mathematical and statistical calculations, the nature of the study is quantitative . Even the basic data used for the study is of quantitative nature. From established theories the study aims at applying those in the context of Indian markets. Hence the approach is one of deductive reasoning .
3	Research Strategy	The study has shades of action research as it involves application of established concepts in the context of Indian markets. It tries and ascertains if statistical arbitrage opportunities exist in the Indian markets and if yes, are they profitable. Further, it also investigates the allocation of the returns to different risk parameters using the Fama and French (1993) three factor model.
4	Choices	Given the objectives, hypotheses to be tested, the choice of quantitative analysis is justified.

Contd...

S.No.	Element of the paradigm	Applications in the current study
5	Time Horizons	The data to be collected involved different time frames and hence the time horizon is longitudinal. Prices of financial assets are studied over a period of seven years from 2011 to 2017 (January 2011 to December 2017). Moreover the time period is divided over two parts – formation period and trading period, on a rolling basis.
6	Data collection and Analysis	Only secondary data is used for this study. The data is collected from stock markets and other websites like ProwessIQ from Centre for Monitoring Indian Economy (CMIE). The analysis of data is planned as under: <ul style="list-style-type: none"> i) Identifying statistical arbitrage opportunities in Indian securities market. ii) Calculating its profitability. iii) Attributing the profitability to various risk factors using Fama and French (1993) three factor model.
7	Research Design	The method specifically designed to test the hypotheses has been outlined in Section 3.6 of this chapter. Sequential steps are used to draw key inferences from the data analysis.
8	Samples	Section 3.3 of this chapter explains the population and sample details including the sample size, the methodology used etc. Judgmental sampling method is adopted in selection of the stocks, commodities and currencies selected for the study.

3.2.3 Nature and Scope of the Study

The study is a quantitative research. Main objective of the research is to explore the opportunities for use of statistical arbitrage in Indian securities market. The study is based on the prices of stocks, commodities and currencies and hence the underlying data is quantitative. Moreover the techniques used for analyzing the data are also quantitative in nature. The study attempts to cover all major asset classes of securities market. The scope of the study can be summarized by way of Table 7.

Table 7: Scope of the Study

Asset Type	Stocks	Commodities	Currencies
Observations to be recorded	i. Daily spot prices ii. Daily future prices iii. Transaction costs	i. Daily spot prices ii. Daily future prices iii. Transaction costs	i. Daily spot prices ii. Daily future prices iii. Transaction costs
Time period	Jan 01, 2011 – Dec 31, 2017		
Sample	Stocks listed in F&O section	Commodities listed at MCX	i. USD-INR ii. EUR-INR iii. GBP-INR iv. JPY-INR
Formation Period and Trading Period	Formation period (training period) of one year followed by trading period of 6 months on a rolling basis.		
Scenarios	Spot-Spot Future-Future Spot-Future	Future-Future	Spot-Spot Future-Future Spot-Future

3.2.4 Statement of Hypotheses

The main purpose of the research is to identify opportunities for use of statistical arbitrage in Indian securities market. It aims at unfolding these opportunities and investigating if they are profitable and further how the returns could be attributed to different risk factors. Based on the research objectives and the scheme of variables, following scheme of hypotheses formulation has emerged, as shown in Table 8.

Table 8: Proposed Hypotheses

Hypotheses Statements

Panel A: Stocks***Futures Market***

- H1:** There are no statistical arbitrage opportunities present in Indian stock futures market.
- H2:** The statistical arbitrage opportunities in Indian stock futures market are not profitable.
- H3:** The returns generated from statistical arbitrage opportunities in Indian stock futures market cannot be attributed to market risk as per Fama-French three factor model.
- H4:** The returns generated from statistical arbitrage opportunities in Indian stock futures market cannot be attributed to size risk as per Fama-French three factor model.
- H5:** The returns generated from statistical arbitrage opportunities in Indian stock futures market cannot be attributed to value risk as per Fama-French three factor model.

Contd...

Spot/Cash Market

- H6:** There are no statistical arbitrage opportunities present in Indian stock spot market.
- H7:** The statistical arbitrage opportunities in Indian stock spot market are not profitable.
- H8:** The returns generated from statistical arbitrage opportunities in Indian stock spot market cannot be attributed to market risk as per Fama-French three factor model.
- H9:** The returns generated from statistical arbitrage opportunities in Indian stock spot market cannot be attributed to size risk as per Fama-French three factor model.
- H10:** The returns generated from statistical arbitrage opportunities in Indian stock spot market cannot be attributed to value risk as per Fama-French three factor model.

Spot-Future

- H11:** There is no spot-future statistical arbitrage present in Indian stock market.
- H12:** The spot-future statistical arbitrage in Indian stock market is not profitable.
- H13:** The returns generated from spot-future statistical arbitrage in Indian stock market cannot be attributed to market risk as per Fama-French three factor model.
- H14:** The returns generated from spot-future statistical arbitrage in Indian stock market cannot be attributed to size risk as per Fama-French three factor model.
- H15:** The returns generated from spot-future statistical arbitrage in Indian stock market cannot be attributed to value risk as per Fama-French three factor model.

Panel B: Commodities

Futures Market

- H16:** There are no statistical arbitrage opportunities present in Indian commodity futures market.
- H17:** The statistical arbitrage opportunities in Indian commodity futures market are not profitable.
- H18:** The returns generated from statistical arbitrage opportunities in Indian commodity futures market cannot be attributed to market risk as per Single Index model.

Panel C: Currencies

Futures Market

- H19:** There are no statistical arbitrage opportunities present in Indian currency futures market.
- H20:** The statistical arbitrage opportunities in Indian currency futures market are not profitable.

Contd...

Spot/Cash Market

H21: There are no statistical arbitrage opportunities present in Indian currency spot market.

H22: The statistical arbitrage opportunities in Indian currency spot market are not profitable.

Spot-Future

H23: There is no spot-future statistical arbitrage present in Indian currency market.

H24: The spot-future statistical arbitrage in Indian currency market is not profitable.

3.3 Population and Sampling

This work studies statistical arbitrage opportunities using pairs trading across three major asset classes in Indian financial markets – equities, commodities and currencies. Table 9 shows the population and sample along with rationale for selection.

Table 9: Population and Sample selection

S. No.	Category	Population	Sample selected	Basis for sample selection
1	Stocks	Stocks on leading stock exchanges like the BSE & NSE in cash and futures segment	Stocks traded on futures segment of the NSE.	The Indian market does not permit inter-day short selling in the cash segment. Therefore, only futures segment is considered.
2	Commodities	Wide range of commodities listed on the MCX.	Commodities traded on the MCX futures segment with adequate trading volume.	Commodities that are prominent and fairly represent the entire market in terms of value as well as volume.
3	Currencies	Currency pairs allowed for trading in Indian currency market.	Select currency pairs - USD-INR, EUR-INR, GBP-INR and JPY-INR.	Currency pairs that are prominent like (INR/USD) and fairly represent the entire market.

3.3.1 Stock Markets

The basis of sample selection is that the Indian market does not permit short selling in the inter-day cash/spot market. The pairs trading require taking long and short positions simultaneously in two stocks of a pair. Hence, the population of the study includes stocks listed on the futures segment of the National Stock Exchange (NSE). For the purpose of the study, stocks have been selected for the analysis on the basis of trading volume and taking top quintile of all the stocks traded in F&O segment. The sample of stocks selected for the study are given in following Table 10.

The pairs trading is studied in Indian stock market using three different segments:

- a) **Futures Market:** Pairs are formed and traded using stock futures. NSE offers stock futures contracts with maturities of one, two and three months. However, only one-month future contracts have been used as volumes tend to be lower in longer maturities. The most liquid stocks have been taken so that transaction costs would be low.
- b) **Cash/Spot Market:** Under this, pairs are identified and traded using stock spot prices. This study is more from theoretical point of view as inter-day naked short selling is not allowed in Indian equities cash segment.
- c) **Spot-Future Statistical Arbitrage:** Under spot-future statistical arbitrage, a pair is identified as a stock in its respective spot market and future market. It is done for every stock in the sample.

Table 10: List of stocks taken in the sample

Sector	Stocks
Automobiles	Ashok Leyland Ltd.
	Bajaj Auto Ltd.
	Hero Motocorp Ltd.
	Mahindra & Mahindra Ltd.
	Maruti Suzuki India Ltd.
Financial Services	Axis Bank Ltd.
	HDFC Bank Ltd.
	IDBI Bank Ltd.
	State Bank of India
	Yes Bank Ltd.
Energy	NTPC Ltd.
	Petronet LNG Ltd.
	Power Grid Corporation of India Ltd.
	Reliance Industries Ltd.
	Reliance Infrastructure Ltd.
Metals	Hindalco Industries Ltd.
	Jindal Steel & Power Ltd.
	Steel Authority of India Ltd.
	Tata Steel Ltd.
	Vedanta Ltd.

3.3.2 Commodities

The commodities listed on MCX (The Multi Commodity Exchange of India) in spot and future segment constitute the population of the study. The market share is a main source of motivation for considering MCX rather than any other exchange in the analysis. The commodities in the futures market are used to form and trade pairs for the study instead of commodities in the spot market because there is a basic difference between a commodity spot market and a commodity future market. Delivery of a commodity is compulsory in the spot market. So it is not feasible to trade using arbitrage opportunities in commodity spot market. Also, spot markets tend to be more limited to geographies, while commodity futures are largely region agnostic. MCX offers commodities future contracts with maturities of one, two and three months. However, only one-month future contracts have been used as volumes tend to be lower in longer maturities. The most liquid commodities are taken so that transaction costs would be lower. The sample of commodities chosen for analysis is given in Table 11 below.

Table 11: List of commodities taken in the sample

Sector	Commodities
Agricultural (Agro) Commodities	Cardamom
	Crude Palm Oil (CPO)
	Mentha Oil
Base Metals	Aluminium
	Copper
	Lead
	Nickel
	Zinc
Bullion	Gold
	Silver
Energy	Crude Oil
	Natural Gas

3.2.3 Currencies

In the realm of currency trading in India, only the currencies that are benchmarked against INR trades can be traded. Also, foreign currency cannot be traded from India. RBI allows trading in the following INR currency pairs:

Table 12: List of currencies pairs available for trading in India

S.No.	INR Currency Pairs
1	USDINR
2	EURINR
3	GBPINR
4	JPYINR

Using these currency pairs, pairs trading is carried out in the following segments:

a) Currency Future Market

Currency futures are traded on platforms offered by exchanges like the NSE, BSE, MSE (Metropolitan Stock Exchange), USE (United Stock Exchange of India). Till August 2019, there was no cash segment in Indian stock exchange for trading in Indian currency market. Therefore, all pairs are traded using currency future prices only.

b) Currency Spot Market

In August 2019, the Clearing Corporation of India Ltd (CCIL) launched a centralised electronic forex trading platform (FX-Retail) for individual as well as small and medium enterprise customers. The facility is currently available only for U.S. dollar, but more currencies are expected to be added gradually. The study is done in currency spot market to provide the currency trader an idea about pairs trading when eventually all the currency pairs would be allowed to trade in the spot market.

c) Currency Spot-Future Statistical Arbitrage

Under spot-future statistical arbitrage, a pair is identified as a currency pair in its respective spot market and future market. It is done for every currency pair in the sample.

3.4 Time Period

The study is conducted over a time-period of January 1, 2011 to December 31, 2017, a time period that covers several market upturns and downturns, as well as relatively calm and volatile periods. There is a formation period (training period) of twelve months in which pairs are identified and traded over next six-month period (trading period) on a rolling basis. The formation period and trading period of twelve and six months respectively has been chosen based on the prior studies (Andrade *et al* 2005, Gatev *et al* 2006, Do *et al* 2006, Do and Faff 2010). The formation and trading periods have been illustrated in Table 13 and Figure 7.

Table 13: Formation Period and respective Trading Period on rolling basis

S.No.	Formation Period (Training Period)	Trading Period
1	Jan 1, 2011 – Dec 31, 2011	Jan 1, 2012 – Jun 30, 2012
2	Jul 1, 2011 – Jun 30, 2012	Jul 1, 2012 – Dec 31, 2012
3	Jan 1, 2012 – Dec 31, 2012	Jan 1, 2013 – Jun 30, 2013
4	Jul 1, 2012 – Jun 30, 2013	Jul 1, 2013 – Dec 31, 2013
5	Jan 1, 2013 – Dec 31, 2013	Jan 1, 2014 – Jun 30, 2014
6	Jul 1, 2013 – Jun 30, 2014	Jul 1, 2014 – Dec 31, 2014
7	Jan 1, 2014 – Dec 31, 2014	Jan 1, 2015 – Jun 30, 2015
8	Jul 1, 2014 – Jun 30, 2015	Jul 1, 2015 – Dec 31, 2015
9	Jan 1, 2015 – Dec 31, 2015	Jan 1, 2016 – Jun 30, 2016
10	Jul 1, 2015 – Jun 30, 2016	Jul 1, 2016 – Dec 31, 2016
11	Jan 1, 2016 – Dec 31, 2016	Jan 1, 2017 – Jun 30, 2017
12	Jul 1, 2016 – Jun 30, 2017	Jul 1, 2017 – Dec 31, 2017

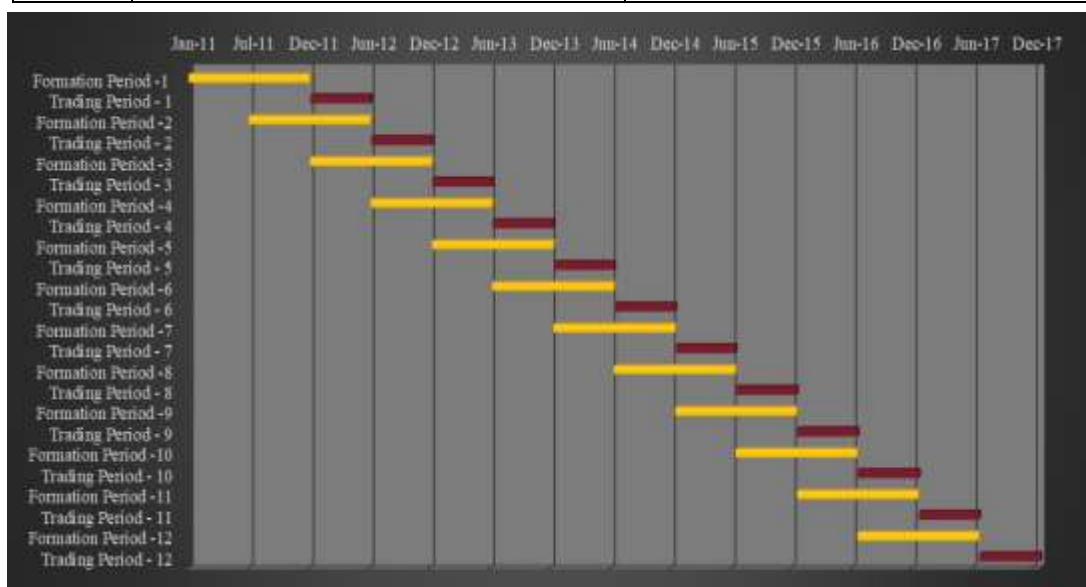


Figure 7: Depiction of formation period and trading period on rolling basis

3.5 Sources of Data

The present study is based solely on secondary data which is collected from following sources:

- a) Daily spot prices of all currency pairs are taken from Reserve Bank of India's website (<https://www.rbi.org.in/>)
- b) Daily future prices of stocks, commodities and currencies are collected from websites of stock and commodities exchanges:
 - <https://www.mcxindia.com/>
 - <https://www.nseindia.com/>

- c) Daily spot prices of stocks are taken from ProwessIQ database maintained by Centre for Monitoring Indian Economy (CMIE)
- d) Transaction costs of trading are tracked through various stock brokers in India (Zerodha, Angel Broking, Motilal Oswal, ICICI Direct, HDFC Securities)

3.6 Framework of Analysis

The statistical arbitrage opportunities in Indian securities market are studied in context of – stocks, commodities and currencies. The methodology used to study these statistical arbitrage opportunities focuses on the following steps:

- i) identifying two securities for pairs trading;
- ii) how to trigger a long/short market neutral position;
- iii) performance measurement; and
- iv) attributing the performance to various risk factors (Desai *et al* 2012).

3.6.1 Identification of Pairs

To carry out the study, stocks listed on NSE and traded in future segment of NSE are considered. Only the stocks traded in F&O section are considered as naked short selling is not allowed in inter-day spot market in India. The commodities for the study include commodities listed on MCX and traded under futures segment. The currency pairs included are USD-INR, EUR-INR, GBP-INR and JPY-INR.

In case of stocks, pair formation and performance testing is done under different scenarios namely, pairing securities in spot market only, pairing securities in futures market only and pairing by using spot and futures market for the same security. In the context of commodities, pairs are identified and traded only in futures segment. Meanwhile in case of currencies, pairs are identified and traded in three scenarios, spot market, futures market and pairing and trading in spot and futures market of the same currency benchmarked against Indian rupee.

There are total twenty stocks across four sectors under study. Therefore, total possible number of pairs in stocks comes out to be 190. Likewise, possible number of pairs in commodities is 66 and in currencies it is 6. The list of all possible pairs across three asset classes is presented in Annexure I.

The following approaches are used for identifying statistical arbitrage opportunities in the form of pairs:

- 1) Distance Approach (popularly known as Gatev methodology, Gatev *et al* 2006)
- 2) Cointegration Approach (Engle and Granger 1987)

Gatev methodology, popularly known as distance approach, involves choosing a pair of securities that minimizes the sum of squared deviations between the two normalized price series. The pairs are then ordered on the basis of distance. After all the securities have been paired according to least distance criterion, top 5, top 10 and top 20 pairs with the smallest historical distance measure are studied.

Cointegration approach is used to find the cointegrating pair of securities. Cointegration tests identify scenarios where two or more non-stationary time series are integrated together in a way that they cannot deviate from equilibrium in the long term. The cointegration model is fitted to the logarithm of stock prices. Figure 8 depicts the approaches to formation of pairs for the purpose of pairs trading.

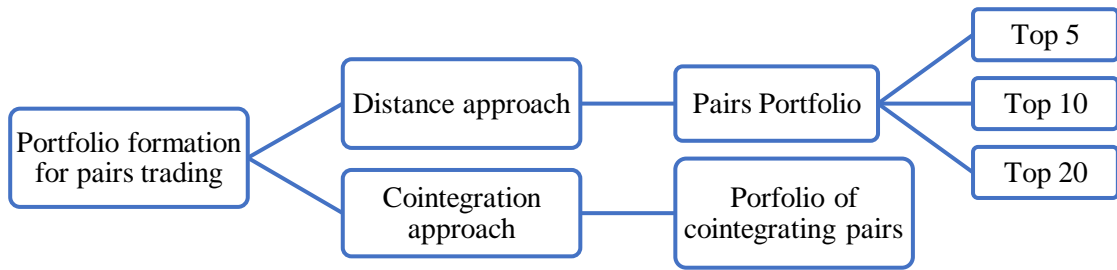


Figure 8: Portfolio Formation Approaches for Pairs Trading

3.6.1.1 Distance Method

The distance approach as used in Gatev *et al* (2006), involves minimising distance between two securities' price series. The selection process involves using squared distance between two normalized price series as follows:

$$D = \sum_{i=1}^n (P_{ai} - P_{bi})^2 \quad (1)$$

where P_{ai} and P_{bi} are normalized security prices

D is the sum of squared deviations between the two normalized price series

The transformation employed is the normalization of the price series based on its mean and standard deviation as follows:

$$P_{it} = \frac{P_{it} - E(P_{it})}{\sigma_i} \quad (2)$$

where P_{it} is normalized price of asset i at time t

$E(P_{it})$ is the expected value of P_{it} (the average)

σ_i is the standard deviation of P_{it}

The pairs are then ordered in ascending order on the basis of distance (D). After all the securities have been paired according to the least distance criterion, top 5, top 10 and top 20 pairs with the smallest historical distance measure are used to create portfolios, that are then traded using different trading rules.

3.6.1.2 Cointegration Method

Cointegration is an econometric property of time series variables which says that if two or more series are non-stationary, but a linear combination of them is stationary, then the series are said to be cointegrated (Engle and Granger 1987). A stationary time series is one whose statistical properties such as mean, variance, autocorrelation, etc. remain constant over time. Stationary means that probability distribution does not change when shifted in time. Stationary time series are mean reverting – an important property exploited for pairs trading.

Engle and Granger (1987) approach has been used to identify cointegrating pairs of securities. A regression is performed on the two non-stationary series of prices of securities. Consider $P_{1,t}$ and $P_{2,t}$ are the prices of stocks 1 and 2 at time t ; then the regression of $P_{1,t}$ against $P_{2,t}$ can be expressed as:

$$P_{1,t} - P_{2,t} = \mu + \epsilon_t \quad (3)$$

where μ denotes an intercept. Potential cointegration between the two securities is examined using the order of integration of the residuals, ϵ_t and securities are cointegrated if the residuals of the regression are stationary. Hence, cointegration is a statistical feature, where two time series that are integrated of order 1, $I(1)$, can be linearly combined to produce one time series which is stationary, or $I(0)$.

The pairs trading technique used to study statistical arbitrage, is based on the assumption that a linear combination of prices reverts to a long-run equilibrium and a trading rule can be constructed to exploit any temporary deviations. In general, linear combination of non-stationary time series are also non-stationary, thus not all possible pairs of securities cointegrate. A $n \times 1$ time series vector y_t is cointegrated if

- each of its elements individually are non-stationary and
- there exists a non-zero vector γ such that γy_t is stationary.

Cointegration has been performed pair-wise in R using ‘egcm-package’. It has done using command ‘allpairs.egcm’ which performs cointegration tests for all pairs of securities in a list. It returns a ‘data.frame’ containing the results of the tests.

3.6.1.3 Formation of Pairs with and without Sector Restriction

The formation of pairs and further analysis has been divided into two parts namely, with and without sector restriction. Each category has been further analyzed including and excluding transaction costs. The Figure 9 below presents the scheme followed.

The pairs of stocks are formed **with and without sector restriction**. A sector means a group of securities that share a common line of business – or set of risk factors – and are therefore expected to perform similarly to one another (Hoffstein 2017). Without sector restriction, a stock can be paired with any other stock from the entire sample of stocks, but with sector restriction, both stocks of a pair will belong to the same sector, say, banking or IT. Similarly, in context of commodities, without sector restriction, a commodity can be paired with any other commodity from the entire sample, but with sector restriction, both commodities of a pair will belong to the same sector, say, agro commodities or energy.

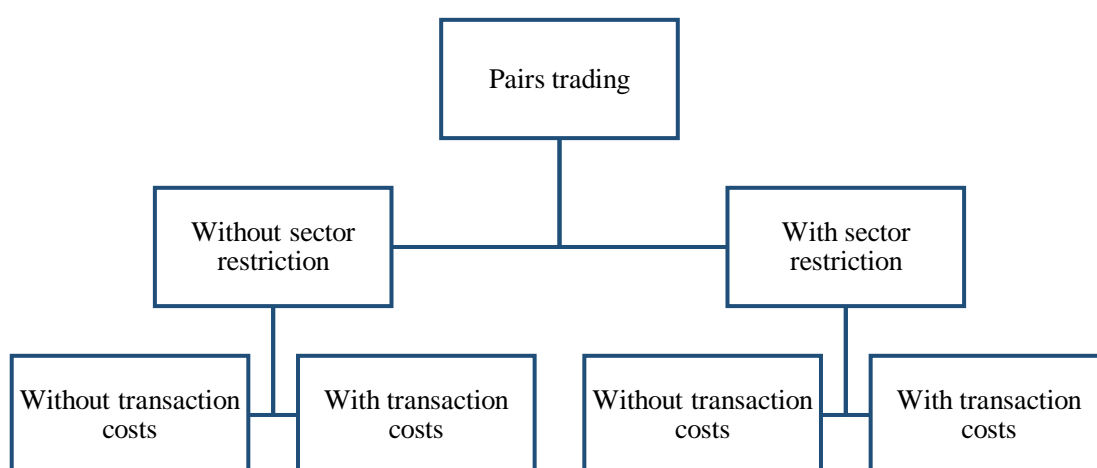


Figure 9: Scheme for Pairs Trading Analysis

In case of stocks, the sample consists of 20 stocks across four sectors, that are, automobiles, financial services, energy and metals. If we do not apply sector restrictions, the total number of possible stock pairs turns out to be 190. However, with sector restrictions this number falls to 40 only. The portfolios are carved out of these possible pairs only. Similarly for commodities, without sector restrictions, the total number of possible pairs comes out to be 66 and with sector restrictions, this number is reduced to 15. The list of all possible pairs with sector restriction for stocks and commodities is presented in Annexure I. Table 14 presents the portfolio of top 5, top 10 and top 20 pairs for stock futures, both with sector restriction and without sector restriction, that are formed in 1st formation period (Jan 1, 2011 – Dec 31, 2011), and subsequently traded in the next six months (trading period from Jan 1, 2012 to Jun 30, 2012).

Table 14: Portfolio of stock future pairs formed with and without sector restriction for 1st formation period

		S.No.	Without sector restriction	With sector restriction
Portfolio of top 20 pairs	Portfolio of top 10 pairs	Portfolios formed using Distance Approach		
		1	ID B I Bank Ltd. and Tata Steel Ltd.	Tata Steel Ltd. and Vedanta Ltd.
		2	Tata Steel Ltd. and Vedanta Ltd.	Steel Authority Of India Ltd. and Tata Steel Ltd.
		3	Steel Authority Of India Ltd. and Tata Steel Ltd.	Hindalco Industries Ltd. and Steel Authority Of India Ltd.
		4	ID B I Bank Ltd. and Vedanta Ltd.	Hindalco Industries Ltd. and Tata Steel Ltd.
		5	ID B I Bank Ltd. and Steel Authority Of India Ltd.	Hindalco Industries Ltd. and Vedanta Ltd.
		6	Hindalco Industries Ltd. and Steel Authority Of India Ltd.	ID B I Bank Ltd. and State Bank Of India
		7	Reliance Infrastructure Ltd. and Hindalco Industries Ltd.	Steel Authority Of India Ltd. and Vedanta Ltd.
		8	Hindalco Industries Ltd. and Tata Steel Ltd.	Jindal Steel & Power Ltd. and Tata Steel Ltd.
		9	State Bank Of India and Tata Steel Ltd.	Jindal Steel & Power Ltd. and Steel Authority Of India Ltd.
	10	Hindalco Industries Ltd. and Vedanta Ltd.	Axis Bank Ltd. and ID B I Bank Ltd.	
	11	Reliance Infrastructure Ltd. and Steel Authority Of India Ltd.	Hindalco Industries Ltd. and Jindal Steel & Power Ltd.	
	12	ID B I Bank Ltd. and Jindal Steel & Power Ltd.	Axis Bank Ltd. and State Bank Of India	
	13	ID B I Bank Ltd. and State Bank Of India	Jindal Steel & Power Ltd. and Vedanta Ltd.	
	14	State Bank Of India and Steel Authority Of India Ltd.	Reliance Industries Ltd. and Reliance Infrastructure Ltd.	
	15	ID B I Bank Ltd. and Reliance Infrastructure Ltd.	N T P C Ltd. and Reliance Infrastructure Ltd.	
	16	Steel Authority Of India Ltd. and Vedanta Ltd.	H D F C Bank Ltd. and Yes Bank Ltd.	
	17	Jindal Steel & Power Ltd. and Tata Steel Ltd.	Bajaj Auto Ltd. and Hero Motocorp Ltd.	
	18	Jindal Steel & Power Ltd. and Steel Authority Of India Ltd.	N T P C Ltd. and Reliance Industries Ltd.	
	19	Reliance Infrastructure Ltd. and Tata Steel Ltd.	Hero Motocorp Ltd. and Mahindra & Mahindra Ltd.	
20	State Bank Of India and Hindalco Industries Ltd.	Bajaj Auto Ltd. and Mahindra & Mahindra Ltd.		
		Portfolio formed using cointegration		
		1	H D F C Bank Ltd. and Yes Bank Ltd.	H D F C Bank Ltd. and Yes Bank Ltd.
		2	H D F C Bank Ltd. and Power Grid Corpn. Of India Ltd.	Tata Steel Ltd. and Vedanta Ltd.
		3	Yes Bank Ltd. and Power Grid Corpn. Of India Ltd.	
		4	Petronet L N G Ltd. and Jindal Steel & Power Ltd.	
		5	ID B I Bank Ltd. and Tata Steel Ltd.	
		6	ID B I Bank Ltd. and Vedanta Ltd.	
		7	Tata Steel Ltd. and Vedanta Ltd.	

Note: As can be seen, using cointegration, only 7 pairs could be formed without sector restriction and 2 with sector restriction during first formation period (Jan 1, 2011 – Dec 31, 2011).

3.6.2 Implementation of Pairs Trading Strategy

The pairs identified using the two approaches in formation periods are traded in their respective trading periods using various guidelines and assumptions. The trading positions are entered and exit on the basis of standard deviation metric wherein the mutual mispricing between two securities in a pair is captured by the notion of spread. The greater the spread, the higher the magnitude of mispricing and greater the profit potential. The trading signals are generated using z-score. A z-score or standardised score is the measure of the value's relation to the mean of a group of values. Z-scores indicate the number of standard deviations an element is away from the mean. The z-score of a raw score X is:

$$z = \frac{X - \mu}{\sigma} \quad (4)$$

where μ and σ are mean and standard deviation respectively.

For implementing pairs trading strategy, the z-score is calculated for the logarithm of the price ratio of two price series of securities in a pair, using mean value and standard deviation of the logarithm of the ratio of prices during the formation period. Logarithm of the ratio is preferred for two major reasons: the first is to respond to the skewness of data – the ratio can vary a lot if one value increases and the other decreases; the second reason is to show percentage change or multiplicative factors.

Threshold limits are set on the z-score to trigger trade orders. Once the conditions are attained, the overperforming stock is sold short and the underperforming one is bought long. Stop-loss (SL) and take-profit (TP) parameters are defined to close positions. These parameters are defined to exit a trade once the loss or profit made on trade has reached the predefined SL or TP parameters. Table 15 describes the various trading strategies employed to enter and exit the trade.

Table 15: Pairs Trading Strategies

No.	Trading Strategy	Trade Initiation	Squaring off
1	Profit and loss (stop loss and take profit) approach	When log of price ratio is 2 or more the standard deviations above or below the mean of log of price ratio during formation period.	When returns reach any of the stop loss (SL) or take profit (TP) trigger.
2	Standard deviation approach		When log of price ratio comes above or below the mean of log of price ratio during formation period down to one standard deviation.
3	Combined approach		Whichever of 1 or 2 happens first

In profit and loss approach, positions are triggered when log of price ratio series deviate more than two standard deviation from the mean of log of price ratio during formation period in either direction and squared off when returns reach either the stop loss or take profit parameters. Under standard deviation approach positions are triggered when log of price series deviates more than two standard deviation from the mean of log of price ratio during formation period in either direction and squared off when log of price series comes down to one standard deviation of log of price ratio during formation period. In case of combined approach, positions are triggered when log of price series deviate more than two standard deviation from the mean of log of price ratio during formation period in either direction and squared off when either log of price series comes down to one standard deviation log of price ratio during formation period, or returns reach any of the SL or TP parameters.

The pairs trading strategy is designed using various guidelines and assumptions. The following are the assumptions made to trade the securities in a pair:

- i) Pairs trading is a market neutral strategy and therefore should involve INR¹ neutrality. It refers to buying equal amounts of long and short investments so that the INR risk is equal on each side of the portfolio. By employing INR neutrality in a market-neutral strategy, an investor ensures that her net INR exposure to market swings is zero.
- ii) Bid/Ask Spread is ignored.
- iii) Only closing prices at the end of each trading day are considered.
- iv) Transaction costs are averaged on the basis of the trading expenses tracked through various stock brokers in India (Zerodha, Angel Broking, Motilal Oswal, ICICI Direct, HDFC Securities). Transaction costs include:
 - a) Brokerage charges
 - b) Securities Transaction Tax (STT) / Commodities Transaction Tax (CTT)
 - c) Exchange Transaction Charges
 - d) SEBI Charges
 - e) GST / Service Tax (before GST regime)
 - f) Stamp Duty
- v) Margin is considered for each trade across stocks, commodities and currencies as shown in Table 16.

¹ INR: Indian Rupee

Table 16: Margin percentage across asset classes for pairs trading

Asset	Margin ²	Asset	Margin	Asset	Margin
Stocks		Commodities		Currencies	
Future	15%	Future	10%	Future	2.50%
Spot	50%			Spot	100%
Spot-Future	32.50%			Spot-Future	56%

- vi) The stop-loss and take-profit are set at approximately 2% and 4% of the total trading value respectively.
- vii) The data is discrete, i.e., squaring off only at the end of the day.
- viii) Percentage of margin is same for both buy and sell sides.
- ix) Only one lot is traded at a time and new signals are ignored while the trade is on.
- x) If prices do not cross before the end of the trading interval, positions are squared off at the end of the last trading day of the respective trading interval and gains or losses are calculated.
- xi) The duration of the strategy is six months on a rolling basis.

As shown in Figure 9, each scenario is considered both with and without transaction costs. Hence, profitability is calculated both including and excluding transaction costs. Six-monthly profitability for each pair is calculated as gross profit or net profit divided by average investment per trade. Net profit is gross profit excluding transaction costs. The following section 3.6.3 illustrates the strategy using a commodity future pair.

3.6.3 Illustrating Pairs Trading Strategy

The working and implementation of pairs trading strategy is explained through a commodity future pair. The step by step implementation is carried out as follows:

- Commodity Pair: Copper and Lead
- Trading Strategy: Combined approach, which is combination of profit and loss (stop loss and take profit) and standard deviation approach
- Formation Period: January 1, 2011 – December 31, 2011
- Trading Period: January 1, 2012 – June 30, 2012

Mean and standard deviation during formation period are calculated for log of price ratio of the commodity pair using daily closing prices as shown in Table 17:

² Margins are taken as a percentage of the value. Margins are on the conservative side to get more realistic view of the results.

Table 17: Daily future closing prices of copper and lead (Jan 1, 2011 – Dec 31, 2011)

Date	Copper	Lead	Log of Price Ratio
	Close Price	Close Price	
1-Jan-11	439.55	115.45	1.337
3-Jan-11	441.90	116.50	1.333
4-Jan-11	439.20	117.55	1.318
5-Jan-11	443.60	121.35	1.296
6-Jan-11	435.90	121.30	1.279
7-Jan-11	432.40	120.60	1.277
8-Jan-11	432.15	120.85	1.274
10-Jan-11	430.70	118.40	1.291
11-Jan-11	435.60	118.65	1.301
12-Jan-11	441.35	120.50	1.298
13-Jan-11	438.95	120.25	1.295
.	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
24-Dec-11	407.00	105.85	1.347
26-Dec-11	407.15	105.95	1.346
27-Dec-11	403.20	105.45	1.341
28-Dec-11	399.55	103.55	1.350
29-Dec-11	400.05	105.60	1.332
30-Dec-11	406.20	105.45	1.349
31-Dec-11	406.00	107.65	1.327
Mean			1.311
Standard deviation			0.036

This formation period mean and standard deviation is used to calculate z-score of each individual log of price ratio in trading period:

$$z = \frac{x - \mu}{\sigma} \quad (5)$$

where μ and σ is the average and standard deviation respectively of the log of price ratio of the pair in the formation period and X is the log of price ratio of the pair in the trading period. Z-score indicates the direction and distance of how far away from the mean is the standard deviation of the log of price ratio of the pair of commodities. Threshold parameters are then used to impose conditions on z-score to generate trading signals. The input parameters for the trading are as follows in Table 18:

Table 18: Input Parameters for Copper-Lead Pairs Trading Model

Input Parameters	
Entering the trade (Limit on z-score)	
Buy Threshold	-2
Sell Threshold	2
Squaring off (exiting the trade)	
Stop Loss (in INR)	-20000
Take Profit (in INR)	40000
Limit on z-score	
If buy order	-1
If sell order	1
Other inputs	
Copper Order Value (in INR)	500000
Lead Order Value (in INR)	500000
Margin for trades	10%
Transaction Charges (per INR)	0.04%
Sample Duration (in years)	0.50 (6 months)

Note: Buy order = buy copper and sell lead

Sell order = sell copper and buy lead

Conditions are set on the z-score to trigger trade orders. The limits to take positions are + 2 or – 2. Once the conditions are attained, the overperforming commodity is sold short and the underperforming one is bought long. Stop-loss (SL) and take-profit (TP) parameters are defined to close positions once a trade has been entered. Under combined approach, position is squared off when either log of price ratio series comes down to one standard deviation of log of price ratio during formation period, or returns reach any of the predefined SL or TP parameters. The order value for both copper and lead is INR 500,000. This amount is approximately equal to the value of one lot of commodity future contract. The margin is

assumed to be 10% of the trade value, and the transaction charges are assumed as INR 4000 per crore (0.04% per INR) of the trade value. The duration of the trading strategy is 6 months or 0.5 year. The commodity pair Copper-Lead is traded using combined approach as shown in Table 19.

The trade orders are executed when the log of price ratio of the pair is either 2 times the standard deviation above or below the mean of the log of price ratio during formation period. Buy implies copper is bought and lead is sold. Sell implies copper is sold and lead is bought. Once a buy or sell order has been triggered, the MTM (mark-to-market) value is calculated for each day. MTM is the fair value of a portfolio based on the realized market price of its constituents. This value is used to execute the stop-loss (SL) or take-profit (TP) orders. SL or TP orders are triggered when either log of price series came down to one standard deviation of log of price ratio during formation period, or returns reach any of the predefined SL or TP parameters. In this model, the TP is INR 40,000 and the SL is INR -20000. The profit or loss generated by closing positions are stored in the Profit/Loss column and the next column stores the cumulative sum of the Profit/Loss column. The transaction charge is the value of the trade multiplied by the transaction charges per INR. It is calculated at two instances, first when trade is initiated and second while closing the position. Margins are used while executing the trade and it is calculated by multiplying the market value of the trades by the margin percentage (which is 10% in this model).

Table 19: Trading of Copper-Lead Pair using Combined Approach

Date	Copper	Lead	Log of price ratio	z-Score	Signal	Buy price	Sell Price	MTM	Status	Profit/Loss	Cumulative	Transaction Charge	Margin
2-Jan-12	407.80	108.10	1.328	0.457						0.00	0.00	0.00	0.00
3-Jan-12	413.90	109.80	1.327	0.436						0.00	0.00	0.00	0.00
4-Jan-12	403.55	108.90	1.310	-0.038						0.00	0.00	0.00	0.00
5-Jan-12	402.40	106.05	1.334	0.619						0.00	0.00	0.00	0.00
6-Jan-12	402.30	103.70	1.356	1.234						0.00	0.00	0.00	0.00
7-Jan-12	401.90	103.85	1.353	1.166						0.00	0.00	0.00	0.00
9-Jan-12	399.05	103.35	1.351	1.103						0.00	0.00	0.00	0.00
10-Jan-12	403.95	103.35	1.363	1.442						0.00	0.00	0.00	0.00
11-Jan-12	407.45	103.50	1.370	1.641						0.00	0.00	0.00	0.00
12-Jan-12	416.80	104.65	1.382	1.964						0.00	0.00	0.00	0.00
13-Jan-12	415.85	104.00	1.386	2.074	Sell	104.000	415.850		Sell	0.00	0.00	400.00	100000.00
14-Jan-12	415.95	104.05	1.386	2.067		104.000	415.850	120.15	Sell	0.00	0.00	0.00	0.00
16-Jan-12	418.60	104.05	1.392	2.243		104.000	415.850	-3066.10	Sell	0.00	0.00	0.00	0.00
17-Jan-12	419.70	106.05	1.376	1.788		104.000	415.850	5226.70	Sell	0.00	0.00	0.00	0.00
18-Jan-12	419.00	107.00	1.365	1.494		104.000	415.850	10635.65	Sell	0.00	0.00	0.00	0.00
19-Jan-12	424.00	108.45	1.363	1.449		104.000	415.850	11595.02	Sell	0.00	0.00	0.00	0.00
20-Jan-12	417.25	108.30	1.349	1.042		104.000	415.850	18989.78	Sell	0.00	0.00	0.00	0.00
21-Jan-12	418.10	108.45	1.349	1.060		104.000	415.850	18688.93	Sell	0.00	0.00	0.00	0.00
23-Jan-12	421.15	110.70	1.336	0.692				25839.05	TP	25839.05	25839.05	415.43	0.00
24-Jan-12	422.45	111.55	1.332	0.565						0.00	25839.05	0.00	0.00

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Date	Copper	Lead	Log of price ratio	z-Score	Signal	Buy price	Sell Price	MTM	Status	Profit/Loss	Cumulative	Transaction Charge	Margin
25-Jan-12	423.15	112.45	1.325	0.388						0.00	25839.05	0.00	0.00
27-Jan-12	425.55	111.65	1.338	0.743						0.00	25839.05	0.00	0.00
28-Jan-12	425.65	111.45	1.340	0.799						0.00	25839.05	0.00	0.00
30-Jan-12	421.20	111.35	1.330	0.533						0.00	25839.05	0.00	0.00
31-Jan-12	417.15	111.85	1.316	0.140						0.00	25839.05	0.00	0.00
1-Feb-12	418.70	109.85	1.338	0.744						0.00	25839.05	0.00	0.00
2-Feb-12	411.70	105.85	1.358	1.306						0.00	25839.05	0.00	0.00
3-Feb-12	419.50	107.80	1.359	1.320						0.00	25839.05	0.00	0.00
4-Feb-12	419.35	108.05	1.356	1.246						0.00	25839.05	0.00	0.00
6-Feb-12	418.85	106.55	1.369	1.601						0.00	25839.05	0.00	0.00
8-Feb-12	424.90	107.25	1.377	1.817						0.00	25839.05	0.00	0.00
9-Feb-12	434.15	109.00	1.382	1.966						0.00	25839.05	0.00	0.00
10-Feb-12	424.15	105.85	1.388	2.133	Sell	105.850	424.150		Sell	0.00	25839.05	400.00	100000.00
11-Feb-12	424.45	106.30	1.385	2.035		105.850	424.150	1772.00	Sell	0.00	25839.05	0.00	0.00
13-Feb-12	418.90	104.10	1.392	2.250		105.850	424.150	-2077.57	Sell	0.00	25839.05	0.00	0.00
14-Feb-12	417.60	102.25	1.407	2.662		105.850	424.150	-9283.87	Sell	0.00	25839.05	0.00	0.00
15-Feb-12	415.50	101.30	1.411	2.781		105.850	424.150	-11295.81	Sell	0.00	25839.05	0.00	0.00
16-Feb-12	414.85	99.85	1.424	3.138		105.850	424.150	-17378.89	Sell	0.00	25839.05	0.00	0.00
17-Feb-12	405.00	99.85	1.400	2.470		105.850	424.150	-5767.43	Sell	0.00	25839.05	0.00	0.00
20-Feb-12	407.60	100.60	1.399	2.440		105.850	424.150	-5289.64	Sell	0.00	25839.05	0.00	0.00
21-Feb-12	415.70	102.65	1.399	2.427		105.850	424.150	-5154.63	Sell	0.00	25839.05	0.00	0.00
22-Feb-12	417.20	104.55	1.384	2.017		105.850	424.150	2052.09	Sell	0.00	25839.05	0.00	0.00

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Date	Copper	Lead	Log of price ratio	z-Score	Signal	Buy price	Sell Price	MTM	Status	Profit/Loss	Cumulative	Transaction Charge	Margin
23-Feb-12	412.95	104.95	1.370	1.627		105.850	424.150	8951.58	Sell	0.00	25839.05	0.00	0.00
24-Feb-12	418.00	106.85	1.364	1.466		105.850	424.150	11973.46	Sell	0.00	25839.05	0.00	0.00
25-Feb-12	417.20	106.65	1.364	1.465		105.850	424.150	11971.79	Sell	0.00	25839.05	0.00	0.00
27-Feb-12	420.70	108.90	1.351	1.117		105.850	424.150	18474.14	Sell	0.00	25839.05	0.00	0.00
28-Feb-12	422.30	108.95	1.355	1.210		105.850	424.150	16824.20	Sell	0.00	25839.05	0.00	0.00
29-Feb-12	417.60	109.25	1.341	0.823				23781.79	TP	23781.79	49620.84	403.34	0.00
1-Mar-12	430.80	106.85	1.394	2.304	Sell	106.850	430.800		Sell	0.00	49620.84	400.00	100000.00
2-Mar-12	431.50	108.45	1.381	1.936		106.850	430.800	6674.69	Sell	0.00	49620.84	0.00	0.00
3-Mar-12	431.65	108.55	1.380	1.920		106.850	430.800	6968.54	Sell	0.00	49620.84	0.00	0.00
5-Mar-12	428.65	107.35	1.385	2.035		106.850	430.800	4835.09	Sell	0.00	49620.84	0.00	0.00
6-Mar-12	422.10	104.45	1.397	2.368		106.850	430.800	-1133.20	Sell	0.00	49620.84	0.00	0.00
7-Mar-12	421.90	104.90	1.392	2.236		106.850	430.800	1204.68	Sell	0.00	49620.84	0.00	0.00
8-Mar-12	422.55	106.25	1.381	1.923		106.850	430.800	6767.53	Sell	0.00	49620.84	0.00	0.00
9-Mar-12	427.10	106.05	1.393	2.273		106.850	430.800	550.77	Sell	0.00	49620.84	0.00	0.00
10-Mar-12	426.50	106.10	1.391	2.221		106.850	430.800	1481.12	Sell	0.00	49620.84	0.00	0.00
12-Mar-12	427.40	106.85	1.386	2.084		106.850	430.800	3946.15	Sell	0.00	49620.84	0.00	0.00
13-Mar-12	432.20	107.55	1.391	2.213		106.850	430.800	1650.74	Sell	0.00	49620.84	0.00	0.00
14-Mar-12	429.00	105.55	1.402	2.527		106.850	430.800	-3994.16	Sell	0.00	49620.84	0.00	0.00
15-Mar-12	434.60	106.65	1.405	2.600		106.850	430.800	-5346.29	Sell	0.00	49620.84	0.00	0.00
16-Mar-12	432.15	105.55	1.410	2.731		106.850	430.800	-7650.15	Sell	0.00	49620.84	0.00	0.00
17-Mar-12	432.20	105.60	1.409	2.721		106.850	430.800	-7474.21	Sell	0.00	49620.84	0.00	0.00
19-Mar-12	434.85	105.35	1.418	2.956		106.850	430.800	-11719.74	Sell	0.00	49620.84	0.00	0.00

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Date	Copper	Lead	Log of price ratio	z-Score	Signal	Buy price	Sell Price	MTM	Status	Profit/Loss	Cumulative	Transaction Charge	Margin
21-Mar-12	431.00	102.85	1.433	3.376		106.850	430.800	-18949.96	Sell	0.00	49620.84	0.00	0.00
22-Mar-12	429.90	102.20	1.437	3.481				-20714.91	SL	-20714.91	28905.93	390.88	0.00
23-Mar-12	432.10	102.70	1.437	3.488	Sell	102.700	432.100		Sell	0.00	28905.93	400.00	100000.00
24-Mar-12	432.15	102.65	1.437	3.504		102.700	432.100	-301.28	Sell	0.00	28905.93	0.00	0.00
26-Mar-12	440.10	102.70	1.455	3.997		102.700	432.100	-9257.12	Sell	0.00	28905.93	0.00	0.00
27-Mar-12	437.30	101.70	1.459	4.091		102.700	432.100	-10885.67	Sell	0.00	28905.93	0.00	0.00
28-Mar-12	430.70	101.00	1.450	3.861		102.700	432.100	-6656.54	Sell	0.00	28905.93	0.00	0.00
29-Mar-12	431.75	102.35	1.439	3.560		102.700	432.100	-1298.99	Sell	0.00	28905.93	0.00	0.00
30-Mar-12	431.25	103.35	1.429	3.258		102.700	432.100	4148.13	Sell	0.00	28905.93	0.00	0.00
2-Apr-12	439.05	105.25	1.428	3.250		102.700	432.100	4372.68	Sell	0.00	28905.93	0.00	0.00
3-Apr-12	438.35	105.50	1.424	3.139		102.700	432.100	6399.82	Sell	0.00	28905.93	0.00	0.00
4-Apr-12	430.80	103.50	1.426	3.188		102.700	432.100	5399.12	Sell	0.00	28905.93	0.00	0.00
5-Apr-12	430.00	105.95	1.401	2.487		102.700	432.100	18252.78	Sell	0.00	28905.93	0.00	0.00
7-Apr-12	430.90	105.90	1.403	2.558		102.700	432.100	16967.92	Sell	0.00	28905.93	0.00	0.00
9-Apr-12	422.65	105.65	1.386	2.087		102.700	432.100	25297.19	Sell	0.00	28905.93	0.00	0.00
10-Apr-12	418.35	104.60	1.386	2.081		102.700	432.100	25160.91	Sell	0.00	28905.93	0.00	0.00
11-Apr-12	415.60	106.05	1.366	1.515		102.700	432.100	35402.44	Sell	0.00	28905.93	0.00	0.00
12-Apr-12	421.50	107.50	1.366	1.529		102.700	432.100	35634.72	Sell	0.00	28905.93	0.00	0.00
13-Apr-12	413.70	106.65	1.356	1.231				40522.14	TP	40522.14	69428.07	399.18	0.00
16-Apr-12	414.75	107.40	1.351	1.107						0.00	69428.07	0.00	0.00
17-Apr-12	415.05	106.50	1.360	1.361						0.00	69428.07	0.00	0.00
18-Apr-12	416.20	106.00	1.368	1.568						0.00	69428.07	0.00	0.00

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Date	Copper	Lead	Log of price ratio	z-Score	Signal	Buy price	Sell Price	MTM	Status	Profit/Loss	Cumulative	Transaction Charge	Margin
19-Apr-12	418.25	107.90	1.355	1.211						0.00	69428.07	0.00	0.00
20-Apr-12	424.75	110.00	1.351	1.104						0.00	69428.07	0.00	0.00
21-Apr-12	425.35	110.00	1.352	1.144						0.00	69428.07	0.00	0.00
23-Apr-12	422.70	109.05	1.355	1.211						0.00	69428.07	0.00	0.00
24-Apr-12	426.65	109.05	1.364	1.469						0.00	69428.07	0.00	0.00
25-Apr-12	429.15	109.30	1.368	1.568						0.00	69428.07	0.00	0.00
26-Apr-12	436.20	110.70	1.371	1.667						0.00	69428.07	0.00	0.00
27-Apr-12	441.40	111.55	1.375	1.783						0.00	69428.07	0.00	0.00
28-Apr-12	444.00	111.85	1.379	1.872						0.00	69428.07	0.00	0.00
30-Apr-12	443.85	113.20	1.366	1.529						0.00	69428.07	0.00	0.00
2-May-12	444.85	113.15	1.369	1.604						0.00	69428.07	0.00	0.00
3-May-12	444.35	112.50	1.374	1.733						0.00	69428.07	0.00	0.00
4-May-12	440.45	112.45	1.365	1.501						0.00	69428.07	0.00	0.00
5-May-12	440.30	112.35	1.366	1.516						0.00	69428.07	0.00	0.00
7-May-12	442.00	112.45	1.369	1.598						0.00	69428.07	0.00	0.00
8-May-12	436.55	111.50	1.365	1.489						0.00	69428.07	0.00	0.00
9-May-12	438.70	111.70	1.368	1.576						0.00	69428.07	0.00	0.00
10-May-12	435.80	111.05	1.367	1.554						0.00	69428.07	0.00	0.00
11-May-12	431.60	110.60	1.362	1.398						0.00	69428.07	0.00	0.00
12-May-12	432.00	110.45	1.364	1.461						0.00	69428.07	0.00	0.00
14-May-12	425.05	109.55	1.356	1.238						0.00	69428.07	0.00	0.00
15-May-12	421.55	108.70	1.355	1.224						0.00	69428.07	0.00	0.00

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Date	Copper	Lead	Log of price ratio	z-Score	Signal	Buy price	Sell Price	MTM	Status	Profit/Loss	Cumulative	Transaction Charge	Margin
16-May-12	418.90	106.95	1.365	1.500						0.00	69428.07	0.00	0.00
17-May-12	419.80	105.55	1.381	1.926						0.00	69428.07	0.00	0.00
18-May-12	420.80	107.05	1.369	1.600						0.00	69428.07	0.00	0.00
19-May-12	420.20	107.00	1.368	1.573						0.00	69428.07	0.00	0.00
21-May-12	426.60	107.05	1.383	1.980						0.00	69428.07	0.00	0.00
22-May-12	429.60	108.10	1.380	1.903						0.00	69428.07	0.00	0.00
23-May-12	426.30	108.35	1.370	1.625						0.00	69428.07	0.00	0.00
24-May-12	423.95	108.25	1.365	1.497						0.00	69428.07	0.00	0.00
25-May-12	423.35	107.70	1.369	1.599						0.00	69428.07	0.00	0.00
26-May-12	423.90	107.75	1.370	1.623						0.00	69428.07	0.00	0.00
28-May-12	426.10	107.30	1.379	1.883						0.00	69428.07	0.00	0.00
29-May-12	428.85	108.35	1.376	1.791						0.00	69428.07	0.00	0.00
30-May-12	423.00	107.90	1.366	1.525						0.00	69428.07	0.00	0.00
31-May-12	420.25	108.45	1.355	1.203						0.00	69428.07	0.00	0.00
1-Jun-12	407.65	105.85	1.348	1.031						0.00	69428.07	0.00	0.00
4-Jun-12	408.10	105.45	1.353	1.167						0.00	69428.07	0.00	0.00
5-Jun-12	405.90	105.80	1.345	0.925						0.00	69428.07	0.00	0.00
6-Jun-12	411.90	106.05	1.357	1.267						0.00	69428.07	0.00	0.00
7-Jun-12	411.05	105.85	1.357	1.262						0.00	69428.07	0.00	0.00
8-Jun-12	404.15	105.05	1.347	1.002						0.00	69428.07	0.00	0.00
9-Jun-12	405.00	105.15	1.348	1.034						0.00	69428.07	0.00	0.00

Contd....

Date	Copper	Lead	Log of price ratio	z-Score	Signal	Buy price	Sell Price	MTM	Status	Profit/Loss	Cumulative	Transaction Charge	Margin
11-Jun-12	411.45	106.20	1.354	1.197						0.00	69428.07	0.00	0.00
12-Jun-12	410.80	105.60	1.358	1.311						0.00	69428.07	0.00	0.00
13-Jun-12	409.95	105.50	1.357	1.279						0.00	69428.07	0.00	0.00
14-Jun-12	412.75	106.55	1.354	1.193						0.00	69428.07	0.00	0.00
15-Jun-12	417.25	106.45	1.366	1.521						0.00	69428.07	0.00	0.00
16-Jun-12	418.20	106.35	1.369	1.610						0.00	69428.07	0.00	0.00
18-Jun-12	418.55	105.90	1.374	1.751						0.00	69428.07	0.00	0.00
19-Jun-12	423.90	106.70	1.379	1.895						0.00	69428.07	0.00	0.00
20-Jun-12	421.50	105.65	1.384	2.011	Sell	105.650	421.500		Sell	0.00	69428.07	400.00	100000.00
21-Jun-12	414.60	103.80	1.385	2.044		105.650	421.500	-570.27	Sell	0.00	69428.07	0.00	0.00
22-Jun-12	417.25	103.65	1.393	2.261		105.650	421.500	-4423.70	Sell	0.00	69428.07	0.00	0.00
23-Jun-12	417.70	103.95	1.391	2.210		105.650	421.500	-3537.72	Sell	0.00	69428.07	0.00	0.00
25-Jun-12	417.15	102.20	1.407	2.645		105.650	421.500	-11167.35	Sell	0.00	69428.07	0.00	0.00
26-Jun-12	416.80	100.80	1.419	3.005		105.650	421.500	-17377.82	Sell	0.00	69428.07	0.00	0.00
27-Jun-12	420.05	100.10	1.434	3.414				-24545.93	SL	-24545.93	44882.14	388.81	0.00
28-Jun-12	417.65	100.20	1.427	3.227	Sell	100.200	417.650		Sell	0.00	44882.14	400.00	100000.00
29-Jun-12	433.25	101.10	1.455	3.997		100.200	417.650	-14184.91	Sell	0.00	44882.14	0.00	0.00
30-Jun-12	429.40	104.10	1.417	2.937				5394.28	TP	5394.28	50276.42	413.41	0.00
Total										50276.42		4811.04	600000.00

The total profit from this trading strategy is the sum of loss from SL and profit from TP. Six-monthly return is calculated as total profit divided by average investment per trade, and average investment per trade is total investment divided by total number of trades. Net return (after transaction costs) for six months is calculated using net profit, i.e. total profit minus transaction costs divided by average investment per trade. Annualized return is calculated by compounding the net six-monthly return. The overall performance is presented in Table 20.

Table 20: Output obtained from trading commodity pair Copper-Lead

Parameter	Value
Loss from SL (INR)	-45260.83
Profit from TP (INR)	95537.25
Total Profit (INR)	50276.42
Total Transaction Costs (INR)	4811.04
Net Profit (INR)	45465.38
Number of Loss Trades	2
Number of Profitable Trades	4
Average Profit per trade (INR)	8379.40
Net Average Profit per trade (INR)	7577.56
Total Investment (INR)	600000.00
Average Investment per trade (INR)	100000.00
Gross Return for 6 months (before transaction costs)	50.28% ³
Net Return for 6 months (after transaction costs)	45.47%
Annualized Return	111.60%

Similarly, pairs are traded across other asset classes – stocks and currencies, using various trading strategies.

3.6.4 Risk-Adjusted Returns and Attribution of Returns

3.6.4.1 Sharpe Ratio

Sharpe (1994) conceived a composite measure to evaluate the performance of portfolios. The Sharpe measure of portfolio performance (designated S_i) is stated as follows:

$$S_i = \frac{\bar{R}_i - \bar{R}_f}{\sigma_i} \quad (6)$$

³ This percentage might seem unusually high because calculations are done for average investment per trade; but at a particular time, only INR 1,00,000 is committed to a trade, so it is justified.

where,

\bar{R}_i = the average rate of return for pairs portfolio i during a specific time period,

\bar{R}_f = the average rate of return on a risk-free investment during the same time period, and

σ_i = the standard deviation of the rate of return of Portfolio i during the same time period.

It seeks to measure the total risk of the portfolio by using standard deviation of returns. This measure indicates the risk premium return earned per unit of total risk. The Sharpe measure produces relative (not absolute) performance rankings. It can be used to evaluate the portfolios by considering the risk along with the returns.

3.6.4.2 Single Index Model

Further, a single index model developed by Sharpe is applied to know the value added by the strategy (alpha), using systematic factor as measured by the return on the market index of respective asset class (MCX COMDEX Composite Index for commodities). Sharpe's model or the single index model is symbolically presented as:

$$R_{eit} = \alpha_i + \beta_i(R_{mt} - R_{ft}) + \varepsilon_i \quad (7)$$

where,

R_{eit} = Excess return on pairs portfolio i during time t ,

R_{mt} = Returns from market portfolio during time t ,

R_{ft} = Risk free rate of return during time t ,

β_i = Measure of the sensitivity of portfolio's return to that of the market index,

α_i = Intercept showing value added by the pairs portfolio i , and

ε_i = Error term.

Since the single index model is linear, α_i (intercept) and β_i (slope) can be estimated on the index using a single-variable linear regression.

3.6.4.3 Fama-French Three-Factor Model

In case of stocks, the returns are further attributed to Fama-French three factor asset pricing model (1993). Fama-French have used empirical research output to identify relevant sources of systematic risk related to characteristics of a firm. The Fama-French model has come to dominate research and industry application. It uses firm characteristics that empirically seem to proxy for exposure to systematic risk. The factors chosen are the ones which on the basis of the past evidence seem to predict some part of the portfolio return. The model is mathematically presented as follows:

$$R_{eit} = \alpha_i + b_i(R_{mt} - R_{ft}) + S_i(SMB_t) + h_i(HML_t) + e_{it} \quad (8)$$

where,

R_{eit} = Excess return on pairs portfolio i in time t ,

R_{mt} = Returns from market portfolio in time t ,

- R_{ft} = Risk free rate of return in time t ,
- SMB_t = Size risk: Small minus big, that is, excess of return of portfolio of small stocks over portfolio of large stocks,
- HML_t = Value risk: High minus low, that is, excess of return of portfolio of high book-to-market ratio over profitability of stocks of low book-to-market ratio,
- α_i = Intercept showing value added by the pairs strategy,
- b_i = Measure of exposure of pairs portfolio to systematic market risk,
- S_i = Measure of exposure of pairs portfolio to size risk (SMB), and
- h_i = Measure of exposure of pairs portfolio to value risk (HML).

The Fama-French model expands single index model by adding size and value factors to the market risk factor for explaining portfolio returns. This model takes into consideration the fact that value and small cap stocks tend to outperform market on regular basis. The model adjusts for the outperformance tendency of the value and small cap stocks. This model is used by a number of finance professionals to explain the risk and return of equity portfolios.

The data has been taken from ‘Fama French and Momentum Factors: Data Library for Indian Market’ maintained by Indian Institute of Management, Ahmedabad. The standard methodology has been used for calculation of different risk factors provided by Agarwalla *et al* (2013) in their working paper ‘Four factor model in Indian equities market’. It is accredited to Centre for Monitoring Indian Economy (CMIE) for implementing their methodology and providing the data files in this data library. The ordinary least squares regression is applied to calculate the intercept value and sensitivity of pairs portfolio to each factor. The methodology for the three types of data analysis is summarised in Table 21.

Table 21: Summary of Methodology for Data Analysis

S.No.	Type of data analysis	Methodology
1	Statistical arbitrage	Through distance approach and through cointegration approach
2	Calculating Profitability	Net Profit for each pair of stocks, commodities and currency Net profit = Gross profit for each pair less transaction costs Profitability = Net profit / Average Investment
3	Attributing profitability to different risk factors	Analyzing the return using market risk premium, size factor and value factor

3.7 Risks and Limitations

No trading strategy is devoid of all types of risks. Also, every research has its own set of limitations. The limitations of the study include:

- i) Study is confined to select stocks, currencies and commodities.
- ii) Moreover in terms of time the study is limited to a time period between Jan 1, 2011 and Dec 31, 2017.
- iii) The secondary data used is from Indian financial markets alone.

Further, statistical arbitrage strategies have resulted in huge profits for quantitative trading firms, but still these strategies have their own set of risks which are following:

- i) The strategy heavily relies on the mean reversion of prices to their historical or predicted normal. This may not necessarily happen in some cases and the prices can continue to drift away from the historical normal.
- ii) Financial markets are in a continuous flux and evolve based on events occurring across the world. Hence, there is no guarantee of profit from statistical arbitrage all the times. In other words, losses may also be incurred in certain situations.

CHAPTER IV

RESULTS AND DISCUSSION

In this chapter, an attempt has been made to empirically analyse the statistical arbitrage opportunities and its profitability in Indian securities market. Further, returns generated from statistical arbitrage are attributed to different risk factors. Fama-French three factor asset pricing model (1993) has been applied to study the alpha generated by various trading strategies under different methods of pairs formation.

This chapter contains the analysis and discussion of the secondary data to meet the objectives of the study. This chapter presents the results in order to test the hypotheses. This is followed by a discussion of the results. The present study is undertaken with the following objectives: to study statistical arbitrage opportunities present in Indian securities market; to study the profitability of statistical arbitrage opportunities in Indian securities market; and to attribute the returns generated from statistical arbitrage to different risk factors. It is a comprehensive study spanning across equities, commodities and currencies. This chapter presents findings of the study asset-wise. In order to examine the statistical arbitrage opportunities in Indian securities market, the following hypotheses (stated in null form) have been tested:

A. Stocks - Futures Market

H25: There are no statistical arbitrage opportunities present in Indian stock futures market.

H26: The statistical arbitrage opportunities in Indian stock futures market are not profitable.

H27: The returns generated from statistical arbitrage opportunities in Indian stock futures market cannot be attributed to market risk as per Fama-French three factor model.

H28: The returns generated from statistical arbitrage opportunities in Indian stock futures market cannot be attributed to size risk as per Fama-French three factor model.

H29: The returns generated from statistical arbitrage opportunities in Indian stock futures market cannot be attributed to value risk as per Fama-French three factor model.

B. Stocks - Spot/Cash Market

H30: There are no statistical arbitrage opportunities present in Indian stock spot market.

H31: The statistical arbitrage opportunities in Indian stock spot market are not profitable.

H32: The returns generated from statistical arbitrage opportunities in Indian stock spot market cannot be attributed to market risk as per Fama-French three factor model.

H33: The returns generated from statistical arbitrage opportunities in Indian stock spot market cannot be attributed to size risk as per Fama-French three factor model.

H34: The returns generated from statistical arbitrage opportunities in Indian stock spot market cannot be attributed to value risk as per Fama-French three factor model.

C. Stocks - Spot-Future

H35: There is no spot-future statistical arbitrage present in Indian stock market.

H36: The spot-future statistical arbitrage in Indian stock market is not profitable.

H37: The returns generated from spot-future statistical arbitrage in Indian stock market cannot be attributed to market risk as per Fama-French three factor model.

H38: The returns generated from spot-future statistical arbitrage in Indian stock market cannot be attributed to size risk as per Fama-French three factor model.

H39: The returns generated from spot-future statistical arbitrage in Indian stock market cannot be attributed to value risk as per Fama-French three factor model.

A sample of 20 stocks traded on NSE futures segment has been selected for the analysis on the basis of highest trading volume. The study is conducted over a time-period of January 1, 2011 to December 31, 2017. The time period is divided over two parts – formation period and trading period, on a rolling basis.

D. Commodities - Futures Market

H40: There are no statistical arbitrage opportunities present in Indian commodity futures market.

H41: The statistical arbitrage opportunities in Indian commodity futures market are not profitable.

H42: The returns generated from statistical arbitrage opportunities in Indian commodity futures market cannot be attributed to market risk as per Single Index model.

The sample for the study consists of 12 commodities traded on MCX futures segment over the time-period from January 1, 2011 to December 31, 2017. Only one-month future contracts have been used as volumes tend to be lower in longer maturities. The most liquid commodities are taken so that transaction costs would be lower.

E. Currencies - Futures Market

H43: There are no statistical arbitrage opportunities present in Indian currency futures market.

H44: The statistical arbitrage opportunities in Indian currency futures market are not profitable.

F. Currencies - Spot/Cash Market

H45: There are no statistical arbitrage opportunities present in Indian currency spot market.

H46: The statistical arbitrage opportunities in Indian currency spot market are not profitable.

G. Currencies - Spot-Future

H47: There is no spot-future statistical arbitrage present in Indian currency market.

H48: The spot-future statistical arbitrage in Indian currency market is not profitable.

Only currency pairs that are benchmarked against INR trades can be traded from India. Therefore, following INR currency pairs – USD/INR, EUR/INR, GBP/INR and JPY/INR, that are allowed by RBI are used for the study over the time-period from January 1, 2011 to December 31, 2017.

This chapter is organised into different sections as follows: Section 4.1 analyses and discusses the existence of statistical arbitrage, its profitability and risk-return pay-off in stock futures. Section 4.2 analyses the statistical arbitrage opportunities and its risk-adjusted returns in stock spot/cash market. Section 4.3 includes findings related to spot-future statistical arbitrage present in Indian stock market. Next, section 4.4 identifies and analyses statistical arbitrage opportunities in commodity futures market. Section 4.5 discusses statistical arbitrage opportunities in currencies market (future market, spot market and spot-future arbitrage).

4.1 Statistical Arbitrage in Stock Futures

This section deals with statistical arbitrage opportunities in Indian stock futures market using pairs trading. The pairs of the stocks are formed with and without sector restriction. The pairs formation has already been explained in research methodology in Chapter 3. Their empirical results are presented in this section, which examines different dimensions:

- Does pair trading generate profits without transaction costs?
- Are pairs trading profits robust to transaction costs?
- Does one portfolio or one trading strategy dominate the others?
- Does pairs trading outperform the market?
- Is pairs trading still profitable after accounting for traditional risk factors?

4.1.1 Pairs Trading Without Sector Restriction

In this section, the summary statistics for the pairs trading strategy have been provided when pairs are formed without any sector restriction. They are unrestricted in the sense that the matching stocks do not necessarily belong to the same broad industry category. Various trading strategies have been deployed to trade different portfolios, that is, profit and loss (stop loss and take profit) approach, standard deviation approach and combined approach.

4.1.1.1 Profit and Loss Approach (Stop Loss and Take Profit)

Under profit and loss trading approach, positions are triggered when log of price ratio series deviates more than two standard deviation from the mean of log of price ratio during

formation period in either direction and squared off when returns reach either the stop loss or take profit parameters.

Table 22 shows the average six-monthly returns over the twelve trading periods for the pairs portfolios formed without sector restriction and traded using profit and loss approach. Portfolios are formed using distance method and cointegration method. In distance approach, portfolios of top 5, top 10 and top 20 pairs are formed according to least distance criterion. Cointegration approach involves the portfolio of cointegrating pairs. The pairs are traded according to rules and assumptions stated in Chapter 3. Further, returns are reported including and excluding transaction costs.

Table 22: Six-monthly returns of stock futures' pairs without sector restriction from profit and loss trading approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointe-grated pairs	Distance approach			Cointe-grated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
	Six-monthly returns (%)							
2012H1	68.30	32.11	13.27	67.00	61.95	24.15	2.80	60.14
2012H2	34.31	17.45	15.22	8.56	27.39	11.09	8.67	0.88
2013H1	29.95	31.55	10.38	32.16	23.85	24.16	3.55	27.45
2013H2	-1.87	-1.93	7.02	35.76	-18.47	-16.73	-7.57	24.59
2014H1	11.93	26.89	26.75	14.65	3.70	20.50	21.57	7.59
2014H2	1.94	-36.99	-10.34	-51.22	-7.30	-49.22	-20.67	-66.86
2015H1	14.96	-1.54	-0.53	33.41	6.28	-12.92	-12.07	24.65
2015H2	-22.34	-32.07	-34.22	-27.01	-35.58	-46.28	-46.84	-41.06
2016H1	21.98	9.93	14.05	0.00	6.82	-3.79	2.54	0.00
2016H2	2.00	7.33	-1.68	-7.15	-12.30	-2.95	-12.15	-16.09
2017H1	41.43	-13.40	1.11	17.76	34.82	-20.57	-5.37	1.79
2017H2	-0.97	-11.56	-2.20	54.62	-9.96	-19.19	-10.96	50.86
Average	16.80	2.32	3.24	14.88	6.77	-7.65	-6.38	6.16

Note: This table reports the six-monthly returns (in percent) when pairs are formed using stock future prices without sector restriction and traded using profit and loss strategy over the twelve trading periods.

It can be seen from Table 22 that portfolio of cointegrating pairs has more consistent returns than any other portfolio. Table 23 reports key descriptive statistics for return time series, both before and after trading costs, generated by four different portfolios, as described earlier. The study has used Shapiro-Wilk test for testing the normality of samples as power of

the Jarque-Bera test can be quite low in small samples (see Ghasemi and Zahediasl 2012, Thadewald and Buning 2004). The Shapiro-Wilk test is based on the correlation between the data and the corresponding normal scores.

Table 23: Descriptive statistics for six-monthly returns of stock futures' pairs without sector restriction with profit and loss trading approach

Statistics	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
Mean (%)	16.80**	2.32	3.24	14.88	6.77	-7.65	-6.38	6.16
SD (%)	24.17	23.08	15.49	33.38	26.68	24.93	17.06	35.92
Skewness	0.54	-0.29	-0.97	-0.39	0.49	-0.25	-0.80	-0.49
Kurtosis	2.96	2.04	4.06	2.62	2.75	2.07	3.99	2.78
Min (%)	-22.34	-36.99	-34.22	-51.22	-35.58	-49.22	-46.84	-66.86
Max (%)	68.30	32.11	26.75	67.00	61.95	24.16	21.57	60.14
SW Statistic	0.96 ^{NS}	0.95 ^{NS}	0.92 ^{NS}	0.98 ^{NS}	0.97 ^{NS}	0.93 ^{NS}	0.93 ^{NS}	0.96 ^{NS}

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using stock future prices without sector restriction and traded using profit and loss strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

Table 23 shows the summary statistics of profit and loss trading approach. The non-significant Shapiro-Wilk test statistic implies the normal distribution of data. The portfolio of the five best pairs using distance approach has six-monthly average return of 16.8% (statistically significant at 5% level) without considering the transaction costs. However, after considering the transaction costs, the average six-monthly return is reduced to 6.77%. As the number of pairs in a portfolio increases, the portfolio standard deviation falls. The returns from top 10, top 20 and cointegrating pairs portfolios are negatively skewed, suggesting pairs trading is profitable only in case of top 5 pairs portfolio when they are traded according to stop loss and take profit approach.

The following Figure 10 shows the graphical representation of six-monthly returns (with and without transaction costs) over all the trading periods for various portfolios formed without sector restriction and traded using profit and loss trading strategy.

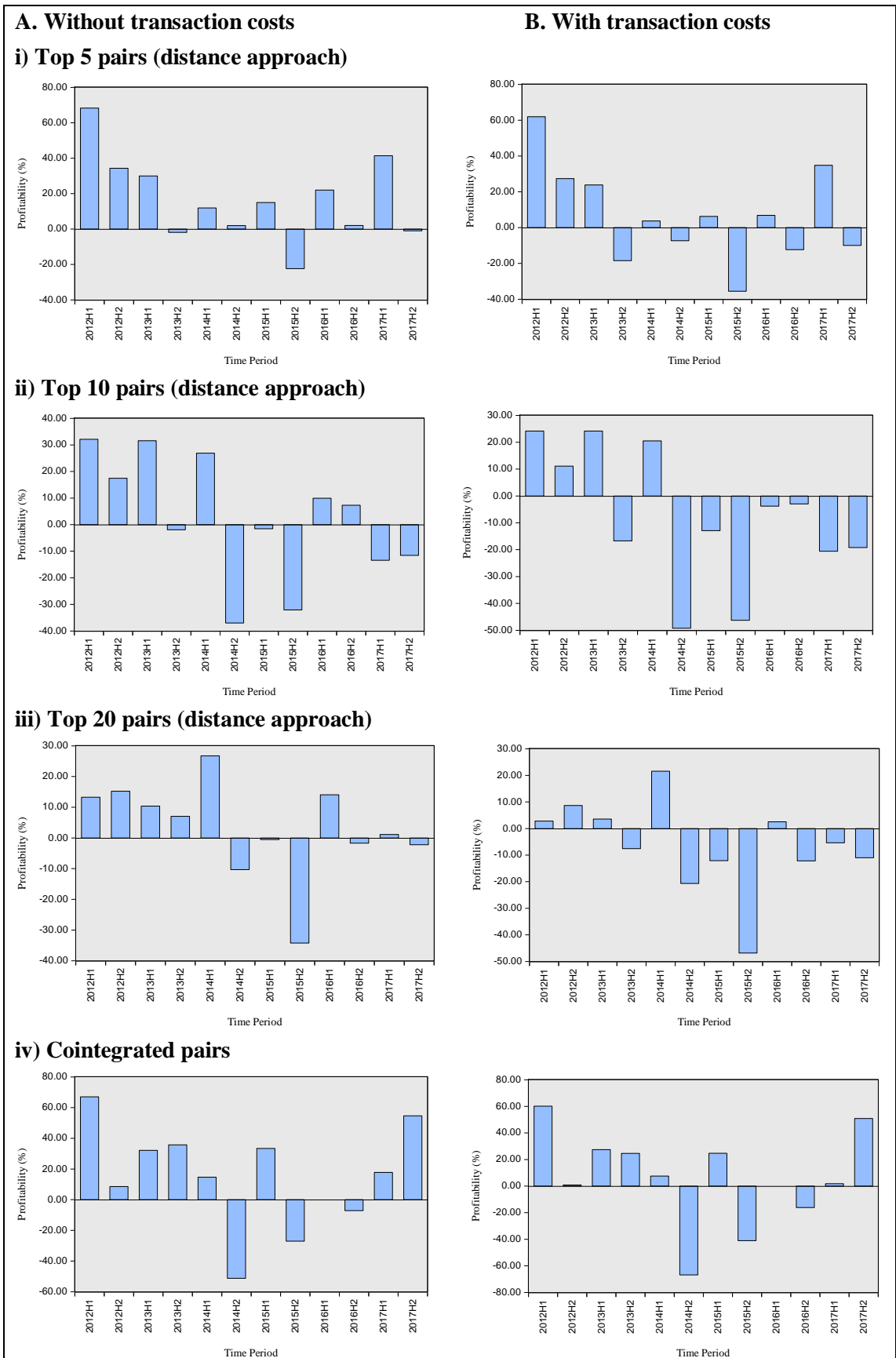


Figure 10: Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock future prices without sector restriction and traded using profit and loss strategy over twelve trading periods

4.1.1.2 Standard Deviation Approach

Under standard deviation approach, positions are triggered when log of price ratio deviates more than two standard deviation from the mean of log of price ratio during formation period in either direction and squared off when log of price series comes down to one standard deviation of log of price ratio during formation period.

Table 24 shows the average six-monthly returns over the twelve trading periods for various pairs portfolios formed without sector restriction and traded using standard deviation approach. Portfolios are formed using distance method and cointegration method.

Table 24: Six-monthly returns of stock futures' pairs without sector restriction from standard deviation trading approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
	Profitability (%)							
2012H1	72.35	52.98	22.76	80.14	69.50	50.61	20.98	76.92
2012H2	34.87	19.20	18.68	8.71	32.72	17.48	16.98	6.91
2013H1	19.88	16.52	3.15	25.83	18.79	15.26	2.00	24.54
2013H2	-9.41	7.49	12.16	21.44	-11.84	5.43	10.21	19.03
2014H1	6.91	21.37	28.80	5.82	5.48	19.56	27.30	4.28
2014H2	-9.33	-54.01	-18.53	-76.97	-10.89	-55.26	-19.76	-78.29
2015H1	-5.18	-19.32	-20.27	12.94	-6.13	-20.27	-21.26	11.99
2015H2	-53.80	-60.59	-44.55	-7.32	-55.06	-61.67	-45.55	-8.60
2016H1	12.54	2.20	6.46	0.00	11.46	1.15	5.36	0.00
2016H2	-47.61	-4.81	-8.61	-25.33	-48.72	-6.04	-9.73	-26.44
2017H1	43.22	-21.46	0.75	-45.15	42.23	-22.43	-0.22	-46.14
2017H2	-11.80	-17.08	-6.10	60.31	-13.36	-18.58	-7.50	58.41
Average	4.39	-4.79	-0.44	5.03	2.85	-6.23	-1.77	3.55

Note: This table reports the six-monthly returns (in percent) when pairs are formed using stock future prices without sector restriction and traded using standard deviation strategy over the twelve trading periods.

From Table 24, it can be observed that returns are not consistent through various trading periods. Six-monthly returns have turned negative from sixth trading period, with occasional positive returns in the portfolio of cointegrating periods. Hence portfolio of

cointegrating pairs has performed better than other portfolios, both including and excluding transaction costs, which can be further analysed from Table 25.

Table 25: Descriptive statistics for six-monthly returns of stock futures' pairs without sector restriction with standard deviation trading approach

Statistics	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointe- grated pairs	Distance approach			Cointe- grated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
Mean (%)	4.39	-4.79	-0.44	5.03	2.85	-6.23	-1.77	3.55
SD (%)	35.92	32.23	20.77	42.44	35.65	31.91	20.54	41.98
Skewness	0.12	-0.19	-0.57	-0.13	0.10	-0.21	-0.58	-0.16
Kurtosis	2.59	2.56	2.79	2.87	2.55	2.56	2.82	2.88
Min (%)	-53.80	-60.59	-44.55	-76.97	-55.06	-61.67	-45.55	-78.29
Max (%)	72.35	52.98	28.80	80.14	69.50	50.61	27.30	76.92
SW Statistic	0.97 ^{NS}	0.96 ^{NS}	0.97 ^{NS}	0.97 ^{NS}	0.97 ^{NS}	0.96 ^{NS}	0.97 ^{NS}	0.97 ^{NS}

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using stock future prices without sector restriction and traded using standard deviation strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

Table 25 shows the descriptive statistics for standard deviation approach where positions are triggered when log of price series deviate more than two standard deviation of the mean of log of price ratio during formation period in either direction and squared off when log of price series comes down to one standard deviation of log of price ratio during formation period. Except for portfolio of top 5 pairs, the returns of all pairs portfolios are negatively skewed. The average six-monthly return of portfolio of cointegrating pairs is 5.03%, although not statistically significant. The average six-monthly return diminishes with the inclusion of more pairs in distance approach, from 4.34% with 5 pairs to -0.44% when a portfolio consists of 20 pairs.

The following Figure 11 shows the graphical representation of six-monthly returns (with and without transaction costs) over all the trading periods for various portfolios formed without sector restriction and traded using standard deviation trading strategy.

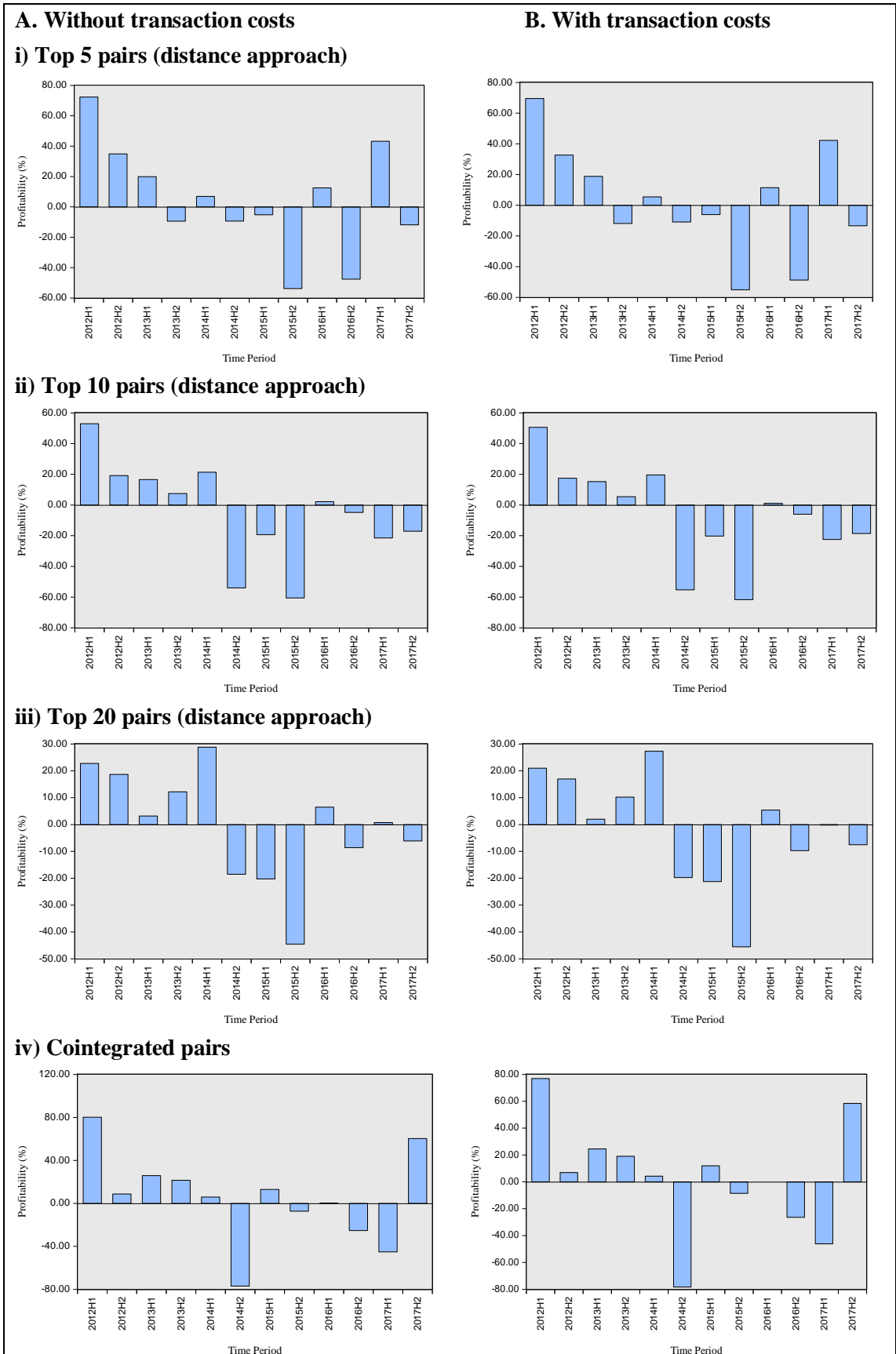


Figure 11: Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock future prices without sector restriction and traded using standard deviation strategy over twelve trading periods

4.1.1.3 Combined Approach

Under combined approach, positions are triggered when log of price series deviates more than two standard deviation from the mean of log of price ratio during formation period in either direction and squared off when either log of price series comes down to one standard deviation log of price ratio during formation period, or returns reach any of the stop loss or take profit parameters.

Table 26 shows the average six-monthly returns over the twelve trading periods for various pairs portfolios formed without sector restriction and traded using combined approach. Returns of various portfolios formed using distance method and cointegration approach are computed both including and excluding transaction costs.

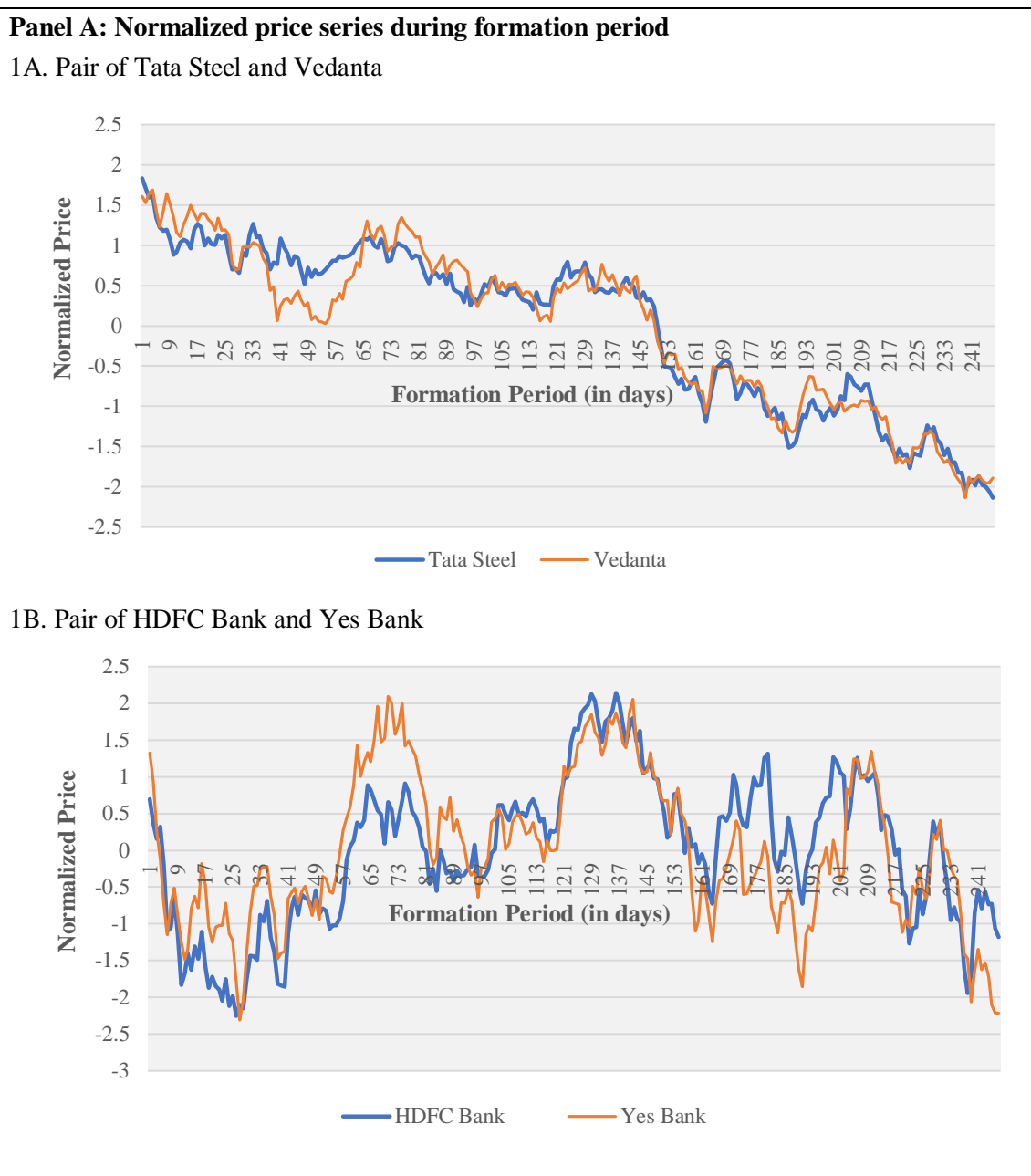
Table 26: Six-monthly returns of stock futures' pairs without sector restriction from combined trading approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
	Profitability (%)							
2012H1	68.30	32.11	13.27	67.00	61.95	24.15	2.80	60.14
2012H2	34.75	17.65	15.33	8.76	27.83	11.11	8.67	1.08
2013H1	29.95	31.55	10.38	32.16	23.85	24.16	3.55	27.45
2013H2	-4.05	-2.94	5.09	29.35	-20.85	-17.83	-9.54	18.04
2014H1	11.93	26.89	26.75	14.65	3.70	20.50	21.57	7.59
2014H2	1.94	-36.99	-10.34	-51.22	-7.30	-49.22	-20.67	-66.86
2015H1	14.96	-1.54	-0.53	33.41	6.28	-12.92	-12.07	24.65
2015H2	-22.34	-32.07	-34.22	-27.01	-35.58	-46.28	-46.84	-41.06
2016H1	21.98	9.93	14.68	0.00	6.82	-3.79	3.12	0.00
2016H2	2.00	7.33	-1.68	-7.15	-12.30	-2.95	-12.15	-16.09
2017H1	41.43	-13.40	1.11	17.76	34.82	-20.57	-5.37	1.79
2017H2	-0.97	-11.56	-2.20	54.62	-9.96	-19.19	-10.96	50.86
Average	16.66	2.25	3.14	14.36	6.61	-7.74	-6.49	5.63

Note: This table reports the six-monthly returns (in percent) when pairs are formed using stock future prices without sector restriction and traded using combined (profit and loss and standard deviation) trading strategy over the twelve trading periods.

As seen in Table 26, portfolio of top 5 pairs formed using distance approach and portfolio of cointegrating pairs have performed better than other portfolios. They are profitable both including and excluding transaction costs.

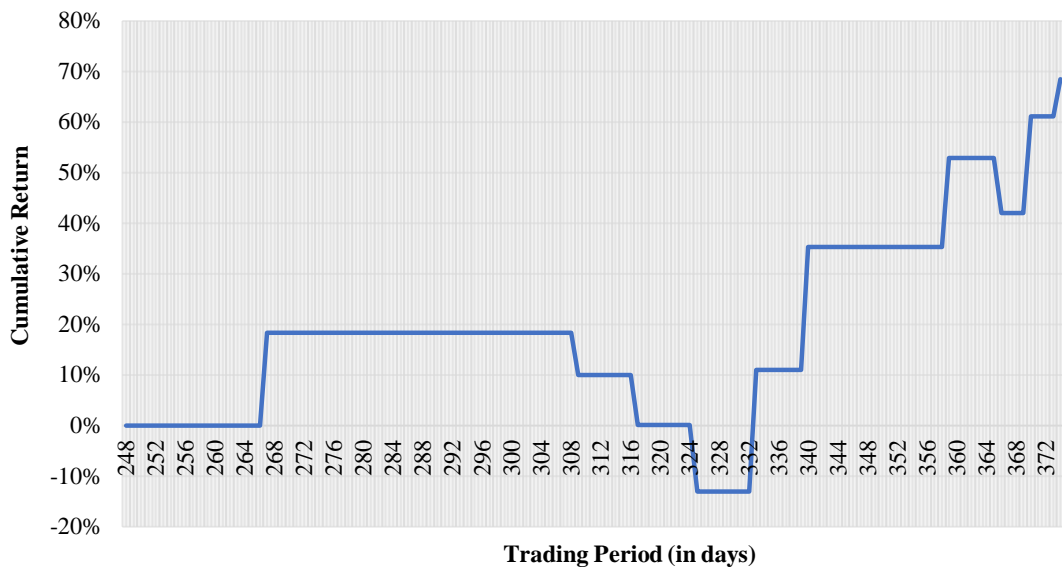
Further, for better comprehension, the relationship between two price series of a pair during the formation period and its returns over trading periods can be shown with the help of graphical presentation of two pairs taken from the portfolio of top 5 pairs formed through distance approach. Panel A of Figure 12 shows the normalized price series of two pairs during the formation period. Each pair includes two stocks. The graphs show the two matched pairs from the first formation period (January 1, 2011 to December 31, 2011) in our sample. Panel B of Figure 12 shows the cumulative returns to the pairs trading strategy when pairs are traded using combined approach. Both graphs are from first trading period in our sample (January 1, 2012 to June 30, 2012).



Contd...

Panel B: Cumulative Returns

2A. Pair of Tata Steel and Vedanta



2B. Pair of HDFC Bank and Yes Bank

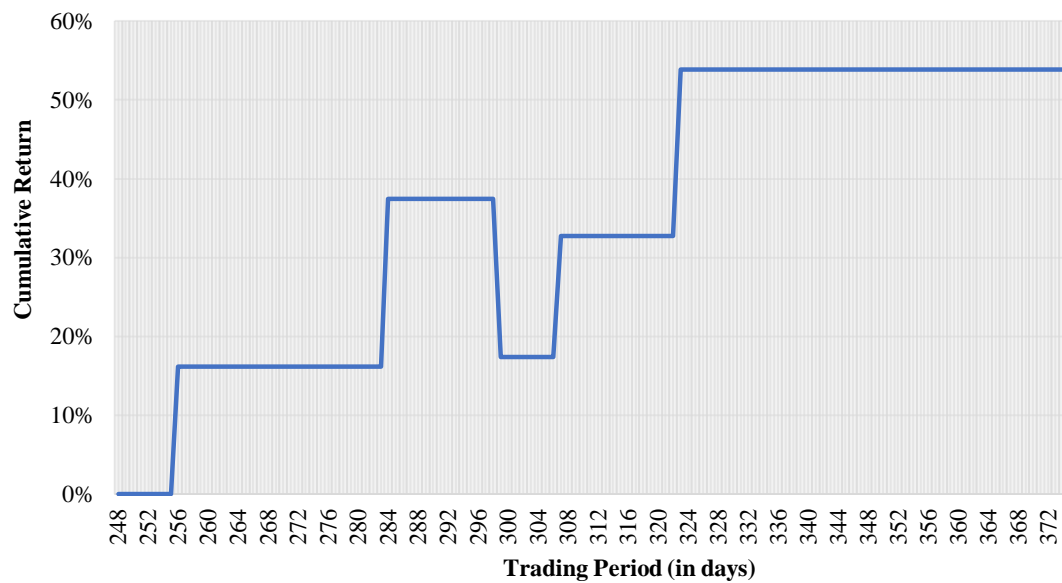


Figure 12: Formation period and trading period example

Table 27 shows the summary statistics of combined trading approach where positions are triggered when log of price series deviate more than two standard deviation of the mean of log of price ratio during formation period in either direction and squared off when either log of price series comes down to one standard deviation of log of price ratio during formation period, or returns reach any of the SL or TP parameters. Combined approach combines the characteristics of both profit and loss and standard deviation trading approach. The non-

significant Shapiro-Wilk test statistic implies the normal distribution of data. The portfolio of the five best pairs using distance approach has average six-monthly return of 16.66% (statistically significant at 5% level).

Table 27: Descriptive statistics for six-monthly returns of stock futures' pairs without sector restriction with combined trading approach

Statistics	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointe- grated pairs	Distance approach			Cointe- grated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
Mean (%)	16.66**	2.25	3.14	14.36	6.61	-7.74	-6.49	5.63
SD (%)	24.36	23.11	15.51	33.06	26.92	24.97	17.11	35.66
Skewness	0.53	-0.28	-0.94	-0.37	0.47	-0.24	-0.77	-0.46
Kurtosis	2.90	2.02	4.02	2.68	2.70	2.06	3.93	2.82
Min (%)	-22.34	-36.99	-34.22	-51.22	-35.58	-49.22	21.57	-66.86
Max (%)	68.30	32.11	26.75	67.00	61.95	24.16	-46.84	60.14
SW Statistic	0.97 ^{NS}	0.95 ^{NS}	0.92 ^{NS}	0.98 ^{NS}	0.97 ^{NS}	0.93 ^{NS}	0.93 ^{NS}	0.96 ^{NS}

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using stock future prices without sector restriction and traded using combined trading (profit and loss and standard deviation) strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

The Figure 13 shows the graphical presentation of six-monthly returns over all the trading periods for various portfolios formed without sector restriction and traded using combined trading (profit and loss and standard deviation) strategy.

When pairs are formed without sector restriction, portfolio of top 5 pairs formed using distance approach has given significant positive returns both with and without transaction costs. Out of all three approaches, profit and loss and combined trading strategies have performed better than the standard deviation approach. Though, profit and loss approach has given slightly better results than combined approach, yet investor can prefer combined trading strategy (profit and loss and standard deviation strategy) as investor is exiting the position based on standard deviation metric while protecting the gains or limiting the losses at the same time.

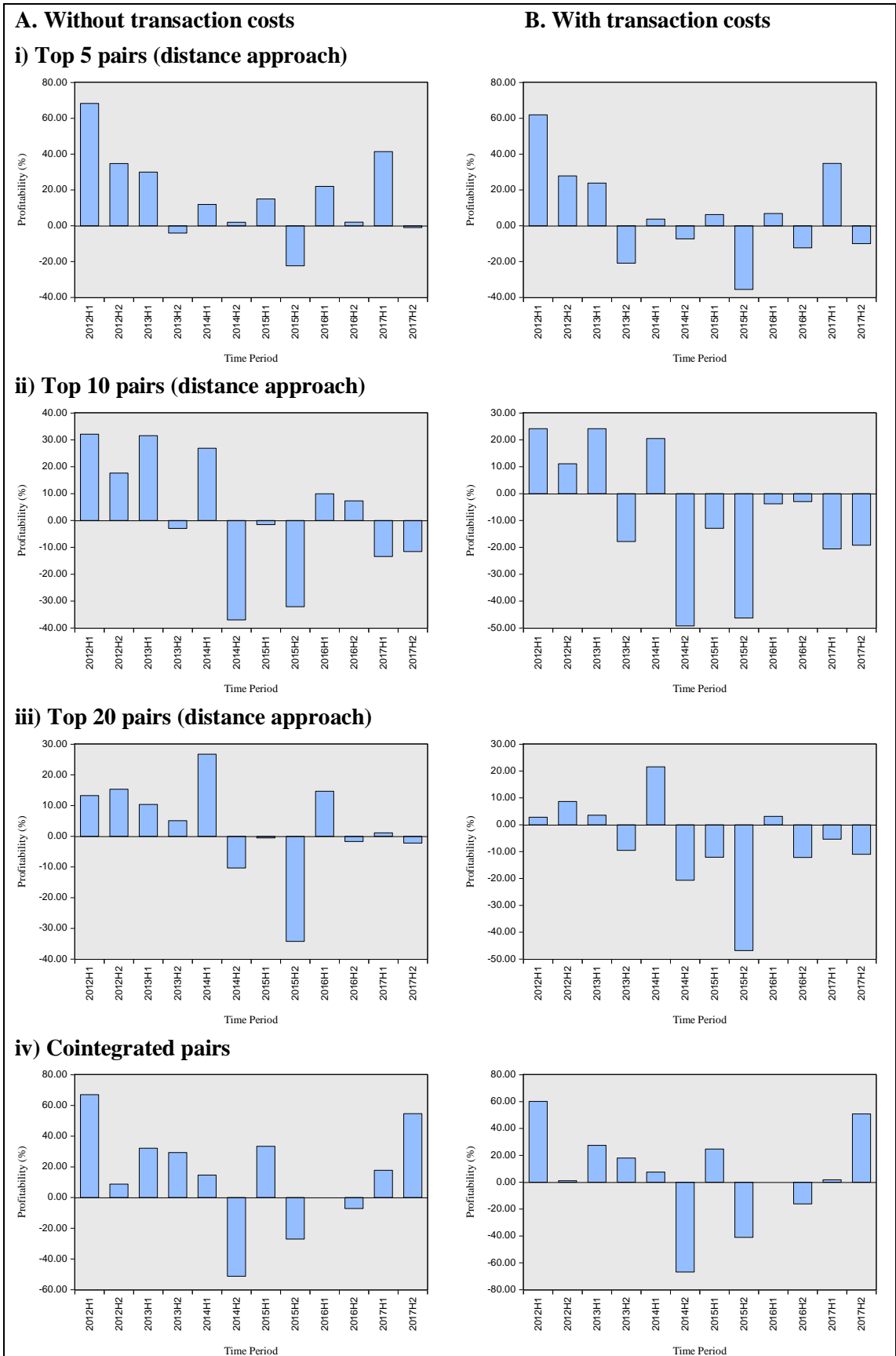


Figure 13: Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock future prices without sector restriction and traded using combined strategy over twelve trading periods

4.1.2 Pairs Trading With Sector Restriction

In the following section, returns on pairs trading are examined where stocks are matched only within the four sector groupings, viz., Automobiles, Financial Services, Energy and Metals. Tables 28 to 33 summarize the average six-monthly returns for the pairs portfolios with sector restriction. Different trading strategies have been employed to trade various portfolios., that is, profit and loss (stop loss and take profit) approach, standard deviation approach and combined approach. The pairs are traded according to rules and assumptions stated in Chapter 3. Further returns are reported including and excluding transaction costs.

4.1.2.1 Profit and Loss Approach (Stop Loss and Take Profit)

Table 28 shows the average six-monthly returns over the twelve trading periods for the pairs portfolios formed with sector restriction and traded using profit and loss approach. Portfolios are formed using distance method and cointegration method. In distance approach, portfolios of top 5, top 10 and top 20 pairs are formed according to least distance criterion. Cointegration approach involves the portfolio of cointegrating pairs.

Table 28: Six-monthly returns of stock futures' pairs with sector restriction from profit and loss trading approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
	Profitability (%)							
2012H1	45.42	39.17	48.51	60.25	40.89	35.35	44.05	53.51
2012H2	34.40	38.87	27.97	33.27	29.13	34.54	21.81	27.56
2013H1	22.39	6.85	-9.30	22.05	15.70	0.71	-16.41	18.23
2013H2	-16.94	4.33	22.94	75.61	-34.91	-11.39	8.82	61.87
2014H1	34.78	29.66	13.47	0.00	30.70	22.08	5.64	0.00
2014H2	-6.05	6.60	-24.79	-44.30	-16.71	-3.63	-37.58	-58.37
2015H1	14.96	-6.89	8.23	30.90	6.28	-18.80	-3.42	23.01
2015H2	1.88	3.97	16.83	25.14	-3.43	-2.64	8.96	19.33
2016H1	21.98	8.70	6.42	0.00	6.82	-4.13	-6.52	0.00
2016H2	2.23	13.84	-1.66	-23.51	-7.44	4.46	-11.91	-29.02
2017H1	18.36	11.26	1.84	0.00	13.72	6.60	-5.83	0.00
2017H2	20.57	14.58	5.41	0.00	14.64	6.82	-2.08	0.00
Average	16.17	14.25	9.66	14.95	7.95	5.83	0.46	9.68

Note: This table reports the six-monthly returns (in percent) when pairs are formed using stock future prices with sector restriction and traded using profit and loss strategy over the twelve trading periods.

Results show that portfolios formed with sector restriction are generating better retruns than portfolios formed without sector restriction, especially in later years. After factoring in transaction costs, portfolio of cointegrating pairs is giving highest six-monthly returns among all portfolios. Table 29 reports key descriptive statistics for return time series, both before and after trading costs, generated by four different portfolios, as described earlier.

Table 29: Descriptive statistics for six-monthly returns of stock futures’ pairs with sector restriction with profit and loss trading approach

Statistics	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointe- grated pairs	Distance approach			Cointe- grated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
Mean (%)	16.17**	14.25***	9.66*	14.95	7.95	5.83	0.46	9.68
SD (%)	18.14	14.36	18.72	33.52	21.33	16.93	20.27	32.77
Skewness	-0.23	0.69	0.26	0.13	-0.40	0.61	0.36	-0.38
Kurtosis	2.28	2.42	3.22	2.57	2.62	2.40	3.54	3.01
Min (%)	-16.94	-6.89	-24.79	-44.30	-34.91	-18.80	-37.58	-58.37
Max (%)	45.42	39.17	48.51	75.61	40.89	35.35	44.05	61.87
SW Statistic	0.97 ^{NS}	0.88 ^{NS}	0.98 ^{NS}	0.97 ^{NS}	0.98 ^{NS}	0.91 ^{NS}	0.96 ^{NS}	0.95 ^{NS}

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using stock future prices with sector restriction and traded using profit and loss strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

Table 29 summarizes the results when pairs are formed with the sector restriction and are traded using profit and loss trading approach (with stop loss and take profit parameters). The non-significant Shapiro-Wilk test statistic implies the normal distribution of data. The top 10 pairs portfolio formed using distance approach produces positive average six-monthly return of 14.25% (statistically significant at 1%). The returns are positively skewed. Even after factoring in transaction costs, all four portfolios are giving positive average returns over a six-month period.

The following Figure 14 presents the graphical representation of six-monthly returns (with and without transaction costs) over all the trading periods for various portfolios formed with sector restriction and traded using profit and loss trading strategy.

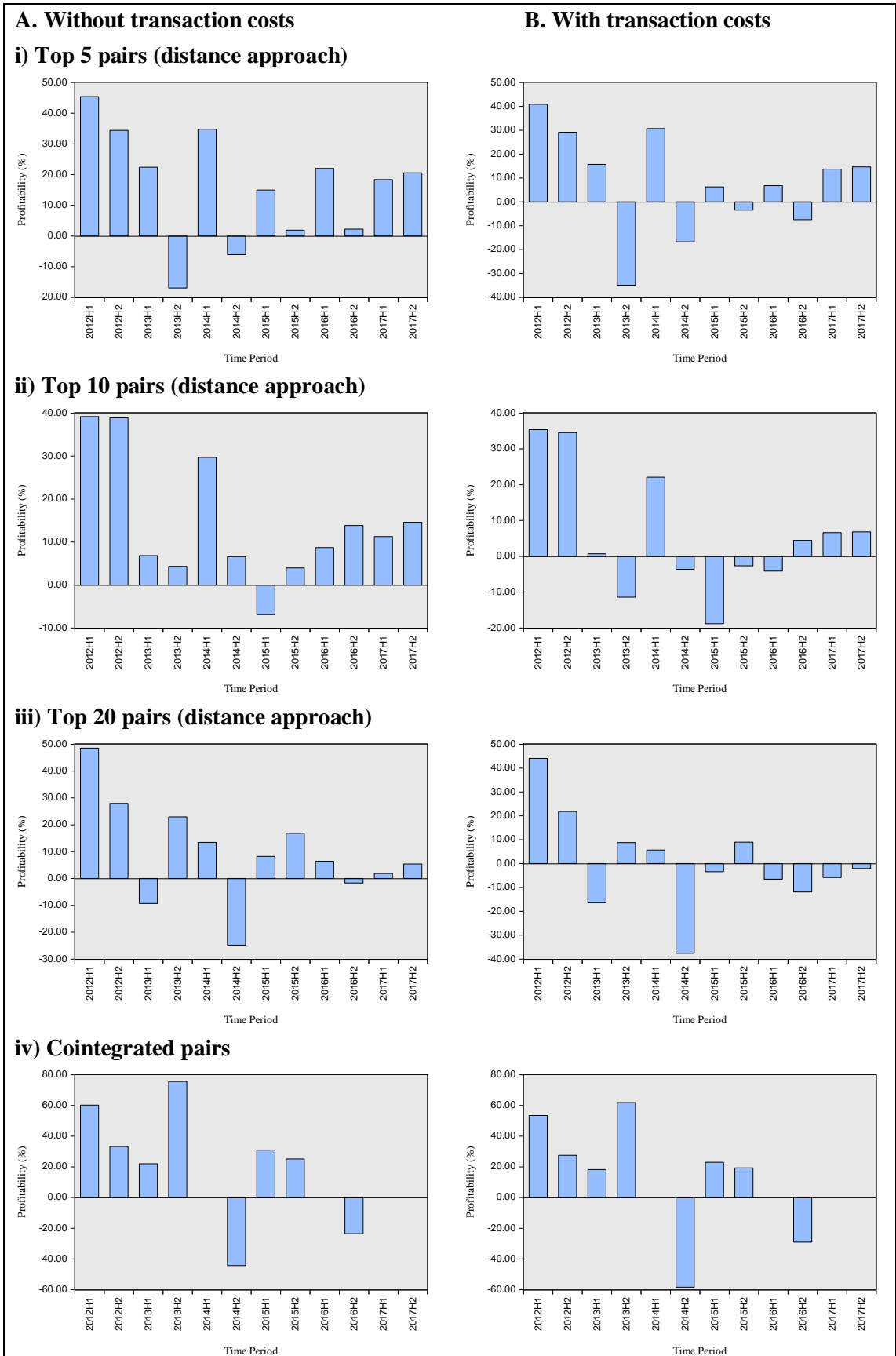


Figure 14: Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock future prices with sector restriction and traded using profit and loss strategy over twelve trading periods

4.1.2.2 Standard Deviation Approach

Table 30 shows the average six-monthly returns over the twelve trading periods for various pairs portfolios formed with sector restriction and traded using standard deviation approach. Portfolios are formed using distance method and cointegration method.

Table 30: Six-monthly returns of stock futures' pairs with sector restriction from standard deviation trading approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
	Profitability (%)							
2012H1	58.81	54.98	56.75	74.63	56.72	53.14	54.96	71.38
2012H2	31.34	41.84	28.48	27.40	29.67	40.04	26.55	25.49
2013H1	4.14	-3.76	-20.39	15.02	2.83	-4.87	-21.44	13.81
2013H2	-16.27	13.34	33.70	30.57	-18.29	11.12	31.74	27.57
2014H1	40.23	47.79	22.33	0.00	39.15	46.14	20.84	0.00
2014H2	-18.97	-2.23	-46.06	-64.07	-20.10	-3.55	-47.21	-65.78
2015H1	-5.18	-21.57	-7.60	17.38	-6.13	-22.51	-8.82	16.42
2015H2	6.09	16.63	24.06	10.63	4.88	15.48	22.98	8.95
2016H1	12.54	4.88	1.32	0.00	11.46	3.75	0.09	0.00
2016H2	-8.68	0.21	-3.32	-18.03	-9.80	-0.82	-4.43	-18.89
2017H1	15.06	6.68	-7.42	0.00	14.10	5.72	-8.55	0.00
2017H2	52.40	46.92	23.32	0.00	50.68	45.32	21.97	0.00
Average	14.29	17.14	8.77	7.79	12.93	15.75	7.39	6.58

Note: This table reports the six-monthly returns (in percent) when pairs are formed using stock future prices with sector restriction and traded using standard deviation strategy over the twelve trading periods.

It can be seen from Table 30 that portfolios formed with sector restriction and traded using standard deviation approach are giving the best returns so far, both including and excluding transaction costs. The returns from top 10 pairs formed under distance approach are highest as well as most consistent with least drawdown as compared to other portfolios.

Table 31 summarizes the results when pairs are formed with the sector restriction and are traded using standard deviation trading approach. The top 10 pairs portfolio formed using distance approach has positive six-monthly return of 14.25% (statistically significant at 5%). The returns are positively skewed as well. This trading strategy has given statistically significant positive results ($p < 0.05$) even after factoring in transaction costs.

Table 31: Descriptive statistics for six-monthly returns of stock futures' pairs with sector restriction with standard deviation trading approach

Statistics	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointe- grated pairs	Distance approach			Cointe- grated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
Mean (%)	14.29*	17.14**	8.77	7.79	12.93	15.75**	7.39	6.58
SD (%)	26.15	24.75	27.85	32.47	25.98	24.47	27.60	31.92
Skewness	0.42	0.26	-0.25	-0.20	0.40	0.27	-0.26	-0.31
Kurtosis	1.93	1.79	2.62	4.24	1.92	1.79	2.64	4.37
Min (%)	-18.97	-21.57	-46.06	-64.07	-20.10	-22.51	-47.21	-65.78
Max (%)	58.81	54.98	56.75	74.63	56.72	53.14	54.96	71.38
SW Statistic	0.94 ^{NS}	0.91 ^{NS}	0.97 ^{NS}	0.92 ^{NS}	0.94 ^{NS}	0.91 ^{NS}	0.97 ^{NS}	0.90 ^{NS}

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using stock future prices with sector restriction and traded using standard deviation strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

The following Figure 15 presents the graphical representation of six-monthly returns (with and without transaction costs) over all the trading periods for various portfolios formed with sector restriction and traded using standard deviation trading strategy.

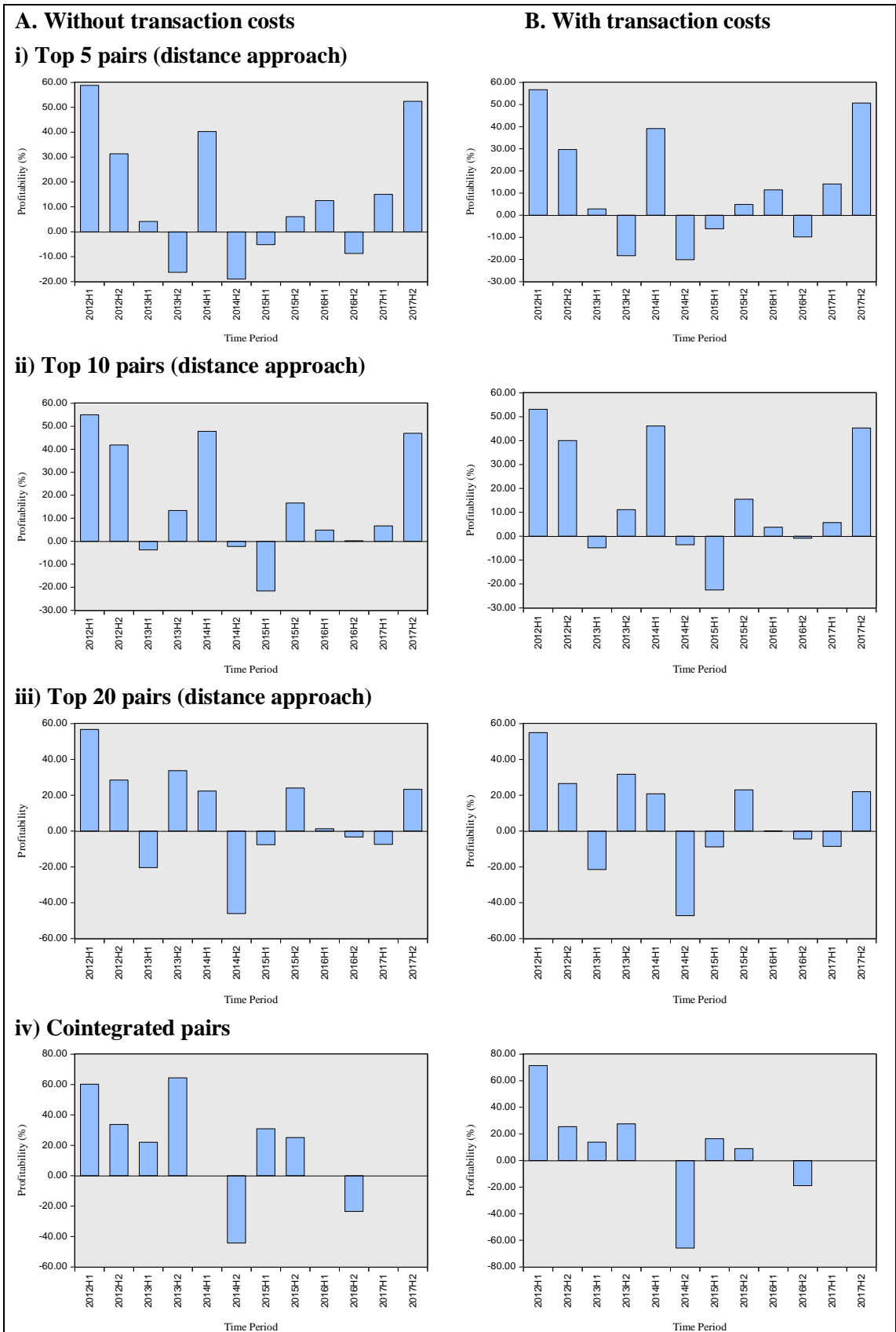


Figure 15: Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock future prices with sector restriction and traded using standard deviation strategy over twelve trading periods

4.1.2.3 Combined Approach

The average six-monthly returns over the twelve trading periods for various pairs portfolios formed with sector restriction and traded using combined approach are shown in Table 32. Returns of various portfolios formed using distance method and cointegration approach are computed both including and excluding transaction costs.

Table 32: Six-monthly returns of stock futures' pairs with sector restriction from combined trading approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
	Profitability (%)							
2012H1	45.42	39.17	48.18	60.25	40.89	35.35	43.73	53.51
2012H2	34.84	39.13	28.07	33.70	29.57	34.80	21.91	28.00
2013H1	22.39	6.85	-9.30	22.05	15.70	0.71	-16.41	18.23
2013H2	-17.85	1.31	21.40	64.43	-36.00	-14.50	7.25	50.38
2014H1	34.78	29.66	13.47	0.00	30.70	22.08	5.64	0.00
2014H2	-6.05	6.60	-24.79	-44.30	-16.71	-3.63	-37.58	-58.37
2015H1	14.96	-6.89	8.23	30.90	6.28	-18.80	-3.42	23.01
2015H2	1.88	3.97	16.50	25.14	-3.43	-2.64	8.63	19.33
2016H1	21.98	9.64	6.99	0.00	6.82	-3.28	-6.01	0.00
2016H2	2.23	13.84	-1.66	-23.51	-7.44	4.46	-11.91	-29.02
2017H1	18.36	11.26	1.84	0.00	13.72	6.60	-5.83	0.00
2017H2	20.57	14.58	5.41	0.00	14.64	6.82	-2.08	0.00
Average	16.13	14.09	9.53	14.06	7.89	5.67	0.33	8.76

Note: This table reports the six-monthly returns (in percent) when pairs are formed using stock future prices with sector restriction and traded using combined (profit and loss and standard deviation) trading strategy over the twelve trading periods.

As seen in Table 32, portfolio of top 5 pairs formed using distance approach has given maximum average returns excluding transaction costs. But after inclusion of transaction costs, portfolio of cointegrating pairs has the highest average returns among all portfolios, though in later trading periods, there has been no trading activity in this portfolio because of absence of cointegrating pairs.

Table 33 summarizes the results when pairs are formed with the sector restriction and are traded using combined approach (with stop loss and take profit parameters). All the portfolios formed under distance approach are generating statistically significant positive six-

monthly returns. Even after factoring in transaction costs, all four portfolios are giving positive average returns over a six-month period. The portfolio of cointegrating pairs has six-monthly return of 8.76% after transaction costs, though not statistically significant.

Table 33: Descriptive statistics for six-monthly returns of stock futures' pairs with sector restriction with combined trading approach

Statistics	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
Mean (%)	16.13***	14.09**	9.53*	14.06	7.89	5.67	0.33	8.76
SD (%)	18.34	14.59	18.55	31.82	21.57	17.24	20.13	31.26
Skewness	-0.26	0.67	0.26	-0.07	-0.43	0.56	0.36	-0.58
Kurtosis	2.31	2.37	3.27	2.42	2.67	2.37	3.59	3.07
Min (%)	-17.85	-6.89	-24.79	-44.30	-36.00	-18.80	-37.58	-58.37
Max (%)	45.42	39.17	48.18	64.43	40.89	35.35	43.73	53.51
SW Statistic	0.97 ^{NS}	0.90 ^{NS}	0.98 ^{NS}	0.96 ^{NS}	0.97 ^{NS}	0.91 ^{NS}	0.96 ^{NS}	0.93 ^{NS}

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using stock future prices with sector restriction and traded using combined trading (profit and loss and standard deviation) strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

The Figure 16 shows the graphical presentation of six-monthly returns over all the trading periods for various portfolios formed with sector restriction and traded using combined trading (profit and loss and standard deviation) strategy.

The pairs trading strategy is more profitable when pairs are formed with the sector restriction. The portfolios of cointegrating pairs and of top 5 and top 10 pairs under distance approach have sufficient returns that even after factoring in transaction costs, they remain fairly profitable. Portfolios formed using cointegration approach have given adequate positive average returns including transaction costs (though not statistically significant), both when pairs are formed without sector restriction and with sector restriction, and traded using various approaches.

Ergo, in view of the above evidence, the null hypotheses (*H1 and H2*) that there are no statistical arbitrage opportunities present in Indian stock futures market and the statistical arbitrage opportunities in Indian stock futures market are not profitable, respectively, are not accepted. We fail to accept hypotheses (*H1 and H2*) and therefore it can be established that statistical arbitrage opportunities exist in Indian stock futures market and that they are profitable.

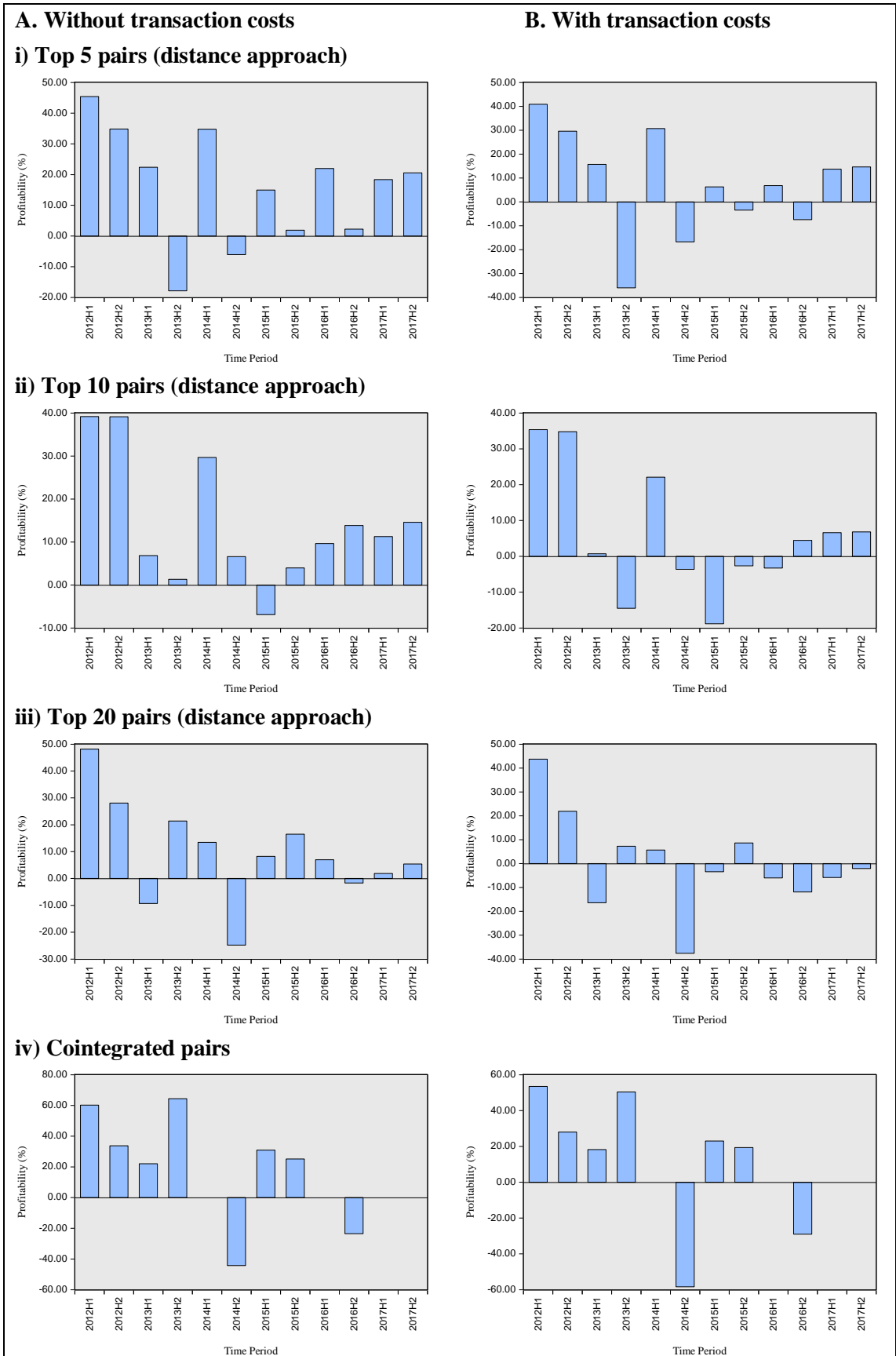


Figure 16: Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock future prices with sector restriction and traded using combined strategy over twelve trading periods

4.1.3 Returns' Attribution of Pairs Trading Strategies (Risk Characteristics of Pairs Trading)

In this section, an attempt has been made to choose the trading strategy that is most profitable for the retail trader with least risk involved. Sharpe ratio has been used to choose such portfolios. Further, to explore the contribution of different risk factors towards the returns from various strategies implementation, results from application of Fama-French (1993) asset pricing model have also been shown. The Tables 34 below seeks to share a glimmer of light into this area of discussion.

The Table 34 compares twenty four different portfolios formed using stock futures both with and without sector restriction, and traded using various trading strategies (profit and loss, standard deviation and combined). The purpose is to select the optimal portfolios considering both risk and return characteristics. For this purpose, only those portfolios have been considered that have generated statistically significant positive returns. However, Sharpe ratio can be misleading when return distributions have negative skewness (Gatev *et al* 2006). This is unlikely to be a concern, because in Tables 34, all the significant portfolios considered are positively skewed. An attempt has also been made to attribute the returns to various risk factors to determine the source of returns and to know whether any alpha is generated.

As seen from Table 34, the pairs portfolio of top 10 pairs formed with sector restriction under distance approach and traded using standard deviation approach has produced the highest returns (statistically significant at 5%), both excluding and including transaction costs (average six-monthly return of 17.14% and 15.75% respectively). However, after considering standard deviation and Sharpe ratio, the pairs portfolio of top 10 pairs formed with sector restriction and traded using stop loss and take profit approach is generating the highest risk-adjusted returns excluding transaction costs (average six-monthly return of 14.25%).

After including transaction costs, returns remain positive in all strategies. However the best portfolio after factoring in transaction costs is portfolio of top 10 pairs formed with sector restriction and traded using standard deviation approach, which is statistically significant at 5% (average six-monthly return of 15.75%). On more conservative side, from a retail trader perspective, the portfolio of top 10 pairs formed with sector restriction and traded through profit and loss trading strategy can also be considered (average six-monthly return of 5.83% including transaction costs), though not statistically significant.

Hence, it can be concluded that pairs trading is profitable with every trading strategy when pairs are formed with sector restriction, though only the portfolios of top 5 and top 10 pairs formed using distance approach have statistically significant profitability. The returns are large in an economical and statistical sense, and suggest that pairs trading is profitable. Also, the returns are superior to the six-monthly average market returns of 9.23%.

Table 34: Stock futures' portfolios with risk adjusted six-monthly returns and attribution of returns

Portfolio/Trading strategy		Without transaction costs		With transaction costs		Risk adjusted returns				
		AR (%)	SD (%)	AR (%)	SD (%)	Sharpe ratio	Fama-French (1993) Model			
							Intercept	Market	SMB	HML
Without sector restriction										
Profit and loss trading strategy										
Distance method	Top 5 pairs	16.80**	24.17	6.77	26.68	0.54	11.44	1.97**	-1.45**	-0.96
	Top 10 pairs	2.32	23.08	-7.65	24.93	-0.06	0.72	0.45	-1.31*	0.42
	Top 20 pairs	3.24	15.49	-6.38	17.06	-0.03	-2.21	1.09**	-0.97**	0.04
Cointegrated pairs		14.88	33.38	6.16	35.92	0.33	10.32	1.23	-1.59	0.41
Standard deviation trading strategy										
Distance method	Top 5 pairs	4.39	35.92	2.85	35.65	0.02	-4.56	3.24**	-2.03**	-1.22
	Top 10 pairs	-4.79	32.23	-6.23	31.91	-0.26	-8.32	1.28	-1.96**	0.53
	Top 20 pairs	-0.44	20.77	-1.77	20.54	-0.20	-7.48	1.47**	-1.25****	0.33
Cointegrated pairs		5.03	42.44	3.55	41.98	0.03	3.44	-0.16	-1.05	1.22
Combined trading strategy										
Distance method	Top 5 pairs	16.66**	24.36	6.61	26.92	0.53	11.23	1.99**	-1.45**	-0.99
	Top 10 pairs	2.25	23.11	-7.74	24.97	-0.06	0.63	0.46	-1.30*	0.40
	Top 20 pairs	3.14	15.51	-6.49	17.11	-0.04	-2.34	1.11**	-0.97**	0.01
Cointegrated pairs		14.36	33.06	5.63	35.66	0.32	9.64	1.30	-1.57	0.33

Contd....

Portfolio/Trading strategy		Without transaction costs		With transaction costs		Risk adjusted returns				
						Sharpe ratio	Fama-French (1993) Model			
		AR (%)	SD (%)	AR (%)	SD (%)		Intercept	Market	SMB	HML
With sector restriction										
Profit and loss trading strategy										
Distance method	Top 5 pairs	16.17**	18.14	7.95	21.33	0.69	9.26	1.16	-0.50	-0.30
	Top 10 pairs	14.25***	14.36	5.83	16.93	0.73	7.13	0.83	-0.34	0.17
	Top 20 pairs	9.66*	18.72	0.46	20.27	0.32	3.54	0.10	0.13	0.48
Cointegrated pairs		14.95	33.52	9.68	32.77	0.33	14.74	-1.05	-0.24	1.17
Standard deviation trading strategy										
Distance method	Top 5 pairs	14.29*	26.15	12.93	25.98	0.40	3.17	1.56	-0.35	0.22
	Top 10 pairs	17.14**	24.75	15.75**	24.47	0.54	5.81	1.04	-0.05	0.86
	Top 20 pairs	8.77	27.85	7.39	27.60	0.18	0.91	-0.13	0.29	1.34
Cointegrated pairs		7.79	32.47	6.58	31.92	0.13	5.60	-0.23	-0.55	0.77
Combined trading strategy										
Distance method	Top 5 pairs	16.13***	18.34	7.89	21.57	0.68	9.20	1.17	-0.50	-0.32
	Top 10 pairs	14.09**	14.59	5.67	17.24	0.71	6.92	0.86	-0.34	0.13
	Top 20 pairs	9.53*	18.55	0.33	20.13	0.31	3.39	0.12	0.12	0.46
Cointegrated pairs		14.06	31.82	8.76	31.26	0.32	13.56	-0.95	-0.21	1.01

Note: This table reports the risk-adjusted six-monthly returns and coefficients of Fama-French three factor model of portfolios of stock futures formed both with and without sector restriction. AR, SD, Market, SMB and HML denote six-monthly average return, six-monthly standard deviation, market factor, size factor and value factor respectively. Superscripts ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively.

Risk-adjusted returns of the strategy are estimated by employing the Fama and French (1993) three factor asset pricing model and the results of the same are shown in Table 34. The foremost component is the intercept value, α (alpha) which signifies the value added by the strategy over and above the compensation for the risk factors considered in the model. Risk-adjusted alpha is positive for all strategies excluding transaction costs (though not statistically significant) over and above the market risk, size risk and value risk factors considered in the model.

In line with the literature, the pairs trading strategy is market neutral: the exposure to the market factor is insignificant in majority of the cases. Hence, we fail to reject the hypothesis (**H3**) that the returns generated from statistical arbitrage opportunities in Indian stock futures market cannot be attributed to market risk as per Fama-French three factor model.

The size factor, SMB, is a strategy of going long small-capitalization stocks and short large-cap stocks. Hence, a positive loading on SMB reflects a tendency to buy small-cap stocks, so pairs trading strategy's negative loading reflects a tendency to buy large-cap stocks. The exposure to the size has predictable sign and is statistically significant when portfolios are formed without sector restriction but is statistically insignificant when portfolios are formed with sector restriction. Thus it is prudent to say that hypothesis (**H4**) that the returns generated from statistical arbitrage opportunities in Indian stock futures market cannot be attributed to size risk as per Fama-French three factor model is not accepted. Majority of the stocks listed in future segment in Indian stock market are large cap stocks; this is the major reason for size factor having a statistical significant loading in case of portfolios formed without sector restriction.

The value factor, HML, is a strategy of buying stocks of high book value to market value while shorting stocks of low book value to market value. The positive loading in most of the portfolios in Table 34 thus reflects a tendency of this strategy of buying stocks that are cheap — in the sense of having high book value relative to their market value. But value risk factor doesn't have any significant contribution towards returns generated by various portfolios. Thus, we fail to reject hypothesis (**H5**) that the returns generated from statistical arbitrage opportunities in Indian stock futures market cannot be attributed to value risk as per Fama-French three factor model.

Collectively, these three standard factors (market, size and value) do not explain much of the alpha in portfolios generating statistically significant returns as shown in Table 34. Because pairs trading's alpha cannot be explained by standard factors studied by academics, its success is considered a sign of its uniqueness. Hence in nutshell, pairs trading

strategy is able to provide positive excess returns net of transaction costs and these returns are because of the strategy itself, which has its roots in mean reversion strategy and law of one price.

4.2 Statistical Arbitrage in Stock Spot/ Cash Market

This section deals with statistical arbitrage opportunities when pairs are identified using spot prices and traded using stock spot prices. Inter-day naked short selling is not allowed in Indian equities cash segment. Shorting in the spot market has to be done on an intraday basis only. Inter-day short selling is possible only through Stock Lending and Borrowing Mechanism (SLBM), which is not very popular in India. Hence it is more of a theoretical study done using various assumptions. The pairs are formed with and without sector restriction. The empirical results presented in this section would cover various aspects, like, whether pairs trading is profitable after transaction costs, whether the strategy is generating any significant alpha, and does any trading strategy/portfolio is superior to others.

4.2.1 Pairs Trading Without Sector Restriction

In the following section, the summary statistics for various pairs trading strategies are provided when pairs are formed using stock spot prices without any sector restriction. Without sector restriction implies a stock can be paired with any other stock from the sample of stocks taken for the study. Portfolios formed without sector restriction are traded using different trading strategies – profit and loss approach (stop loss and take profit), standard deviation approach and combined approach (combination of profit and loss and standard deviation approaches)

4.2.1.1 Profit and Loss Approach (Stop Loss and Take Profit)

In this section, the results are reported when pairs are formed and traded using stock spot prices. As mentioned earlier, certain assumptions have been made to trade pairs especially to short stocks in spot market as naked inter-day short selling is not allowed in Indian spot market. Under profit and loss approach, the trade is entered when z-score for the pair crosses the threshold limits, which are set at +2 or -2. The trade is exited when returns reach any of pre-defined stop loss or take profit parameters. The Table 35 and Table 36 report the average six-monthly returns over various trading periods and key descriptive statistics respectively, before and after transaction costs when pairs portfolios are formed without sector restriction and traded using profit and loss approach. Pairs are formed using distance approach, also known as Gatev methodology (Gatev *et al* 2006) and cointegration approach.

The average returns are negative for most of the portfolios. Looking at the returns for various trading periods, top 5 pairs formed using distance approach are profitable for first three trading periods and after that there is negative trajectory of the returns. The portfolio of cointegrating pairs is showing positive profitability in majority of trading periods, but average six-monthly profitability is mere 2.55%, which is less than six-monthly risk-free return of 3.73%. After factoring in transaction costs, all portfolios are yielding negative average returns. Returns are lower and negative in this scenario as compared to portfolios formed and traded using future prices. One of the reasons for lower returns is assumption of high margin requirement in case of stock spot trading.

Table 35: Six-monthly returns of stock spot pairs without sector restriction from profit and loss approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointe-grated pairs	Distance approach			Cointe-grated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
	Profitability (%)							
2012H1	19.60	6.19	4.95	17.09	13.16	-3.07	-3.01	11.30
2012H2	5.30	3.94	2.67	-0.12	1.68	-1.51	-2.48	-7.02
2013H1	9.55	3.42	-3.75	6.21	4.42	-2.68	-10.76	0.87
2013H2	-1.37	-0.46	4.46	5.85	-19.59	-19.04	-12.00	-5.00
2014H1	5.28	8.26	9.00	2.54	-3.02	2.07	3.34	-2.40
2014H2	-3.03	-13.06	-4.52	-14.69	-13.48	-25.12	-14.58	-30.47
2015H1	-12.37	-10.61	-8.12	1.97	-22.00	-20.84	-16.13	-2.32
2015H2	-19.09	-19.22	-14.05	-6.36	-31.44	-32.57	-26.55	-19.03
2016H1	5.59	2.46	-0.01	1.02	-7.55	-7.14	-7.67	0.19
2016H2	-11.10	-0.98	-2.95	-8.05	-25.52	-11.59	-12.56	-20.74
2017H1	2.96	-1.13	0.35	-3.39	1.74	-2.95	-1.77	-8.44
2017H2	-3.27	-3.37	1.24	28.53	-11.35	-10.46	-6.68	24.48
Average	-0.16	-2.05	-0.89	2.55	-9.41	-11.24	-9.24	-4.88

Note: This table reports the six-monthly returns (in percent) when pairs are formed using stock spot prices without sector restriction and traded using profit and loss strategy over the twelve trading periods.

In Table 36, Shapiro-Wilk test has been used to check the normality of data. The non-significant Shapiro-Wilk test statistic implies normal distribution of data. The portfolios of top 5, top 10 and top 20 pairs formed using distance approach are generating statistically significant six-monthly average returns of -9.41%, -11.24% and -9.24% respectively, after considering transaction costs. All three significant portfolios are negatively skewed as well. The portfolio of cointegrating pairs is generating six-monthly average returns of 2.55% and -4.88% without and with transaction costs respectively.

Table 36: Descriptive statistics for six-monthly returns of stock spot pairs without sector restriction with profit and loss trading approach

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
Mean (%)	-0.16	-2.05	-0.89	2.55	-9.41**	-11.24***	-9.24***	-4.88
SD (%)	10.59	8.29	6.26	11.46	13.55	10.87	8.00	14.52
Skewness	-0.06	-0.82	-0.52	0.85	-0.03	-0.64	-0.51	0.19
Kurtosis	2.60	2.64	2.89	3.50	1.96	2.22	3.02	3.00
Min (%)	-19.09	-19.22	-14.05	-14.69	-31.44	32.57	-26.55	-30.47
Max (%)	19.60	8.26	9.00	28.53	13.16	2.07	3.34	24.48
SW Statistic	0.97 ^{NS}	0.91 ^{NS}	0.97 ^{NS}	0.93 ^{NS}	0.98 ^{NS}	0.92 ^{NS}	0.97 ^{NS}	0.96 ^{NS}

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using stock spot prices without sector restriction and traded using profit and loss strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

The following Figure 17 shows the graphical representation of six-monthly returns (with and without transaction costs) over various trading periods for portfolios formed and traded using stock spot prices. There are three portfolios made under distance approach and one portfolio of cointegrating pairs, which are traded using profit and loss (stop loss and take profit) approach.

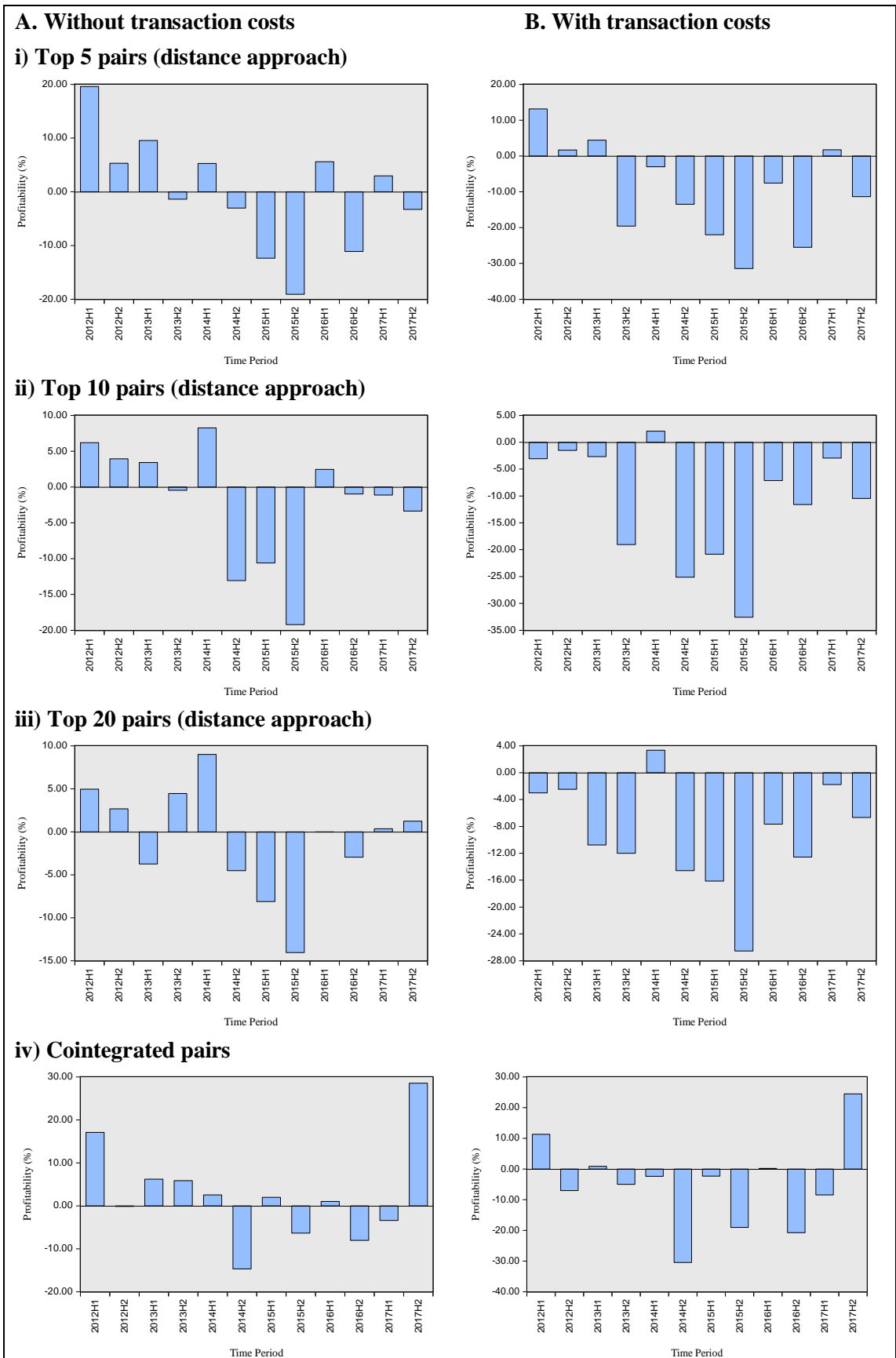


Figure 17: Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock spot prices without sector restriction and traded using profit and loss strategy over twelve trading periods

4.2.1.2 Standard Deviation Approach

Under standard deviation approach, positions are triggered when log of price series deviates more than two standard deviation from the mean of log of price ratio during formation period in either direction and squared off when log of price series comes down to one standard deviation of log of price ratio during formation period. In other words, threshold limits on z-score for entering the trade are +2 or -2 and for exiting the trade are +1 or -1.

Table 37 shows the average six-monthly returns over the twelve trading periods for various pairs portfolios formed from stock spot prices without sector restriction and traded using standard deviation approach. Portfolios are formed using distance method and cointegration method.

Table 37: Six-monthly returns of stock spot pairs without sector restriction from standard deviation approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
	Profitability (%)							
2012H1	19.49	8.24	6.75	19.70	13.86	3.81	3.12	14.43
2012H2	5.43	4.35	4.00	0.46	2.61	1.52	1.47	-2.44
2013H1	6.70	4.31	-0.68	5.79	4.35	1.62	-3.10	3.33
2013H2	-5.13	-2.48	2.60	3.79	-9.82	-6.50	-1.28	-0.09
2014H1	6.35	7.78	9.88	4.00	3.50	4.90	7.16	1.63
2014H2	-5.79	-17.06	-8.60	-19.56	-9.48	-19.96	-11.18	-22.37
2015H1	-11.74	-9.65	-7.46	3.96	-13.37	-11.46	-9.16	2.25
2015H2	-17.39	-18.14	-14.47	-1.35	-20.15	-20.70	-16.66	-3.58
2016H1	2.21	1.63	1.09	2.00	-0.14	-0.18	-0.69	1.19
2016H2	-17.98	-4.47	-4.38	-12.64	-20.38	-7.08	-6.77	-15.65
2017H1	2.47	-1.53	1.26	-7.23	2.05	-2.16	0.34	-8.30
2017H2	-1.98	-3.21	1.95	20.74	-5.25	-6.09	-1.07	16.67
Average	-1.45	-2.52	-0.67	1.64	-4.35	-5.19	-3.15	-1.08

Note: This table reports the six-monthly returns (in percent) when pairs are formed using stock spot prices without sector restriction and traded using standard deviation strategy over the twelve trading periods.

Table 37 shows that portfolios of top 5 and top 10 pairs are profitable till third trading period including transaction costs. But from forth trading period, it has shown consistently negative returns even before transaction costs. The portfolio of top 20 pairs formed using distance approach has varied six-monthly returns ranging from -14.47% to 9.88% before transaction costs, with net average six-monthly returns of -3.15%. The portfolio of cointegrating pairs has inconsistent returns with majority of trading periods generating positive returns, but after considering transaction costs, it is giving average six-monthly of -1.08%. In later trading periods, all portfolios are yielding negative returns, except portfolio of top 20 pairs formed using distance approach and portfolio of cointegrating pairs.

Table 38: Descriptive statistics for six-monthly returns of stock spot pairs without sector restriction with standard deviation trading approach

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointe-grated pairs	Distance approach			Cointe-grated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
Mean (%)	-1.45	-2.52	-0.67	1.64	-4.35	-5.19*	-3.15	-1.08
SD (%)	10.90	8.76	6.91	11.55	10.53	8.59	6.67	10.98
Skewness	0.06	-0.59	-0.50	-0.01	-0.10	-0.70	-0.55	-0.26
Kurtosis	2.48	2.29	2.54	2.73	2.10	2.34	2.63	2.81
Min (%)	-17.98	-18.14	-14.47	-19.56	-20.38	-20.70	-16.66	-22.37
Max (%)	19.49	8.24	9.88	20.74	13.86	4.90	7.16	16.67
SW Statistic	0.96 ^{NS}	0.92 ^{NS}	0.96 ^{NS}	0.94 ^{NS}	0.95 ^{NS}	0.90 ^{NS}	0.96 ^{NS}	0.95 ^{NS}

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using stock spot prices without sector restriction and traded using standard deviation strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

Table 38 depicts descriptive statistics of various portfolios traded using standard deviation trading strategy. Non-significance of Shapiro-Wilk test statistic implies normal distribution of data. All portfolios are generating negative net average six-monthly average returns. The portfolio of top 10 pairs formed using distance approach is yielding statistically significant (at 90% level of confidence) average six-monthly net returns of -5.19%.

The following Figure 18 shows the graphical representation of six-monthly returns (with and without transaction costs) for different portfolios formed from stock spot prices without sector restriction and traded using standard deviation strategy over various trading periods.

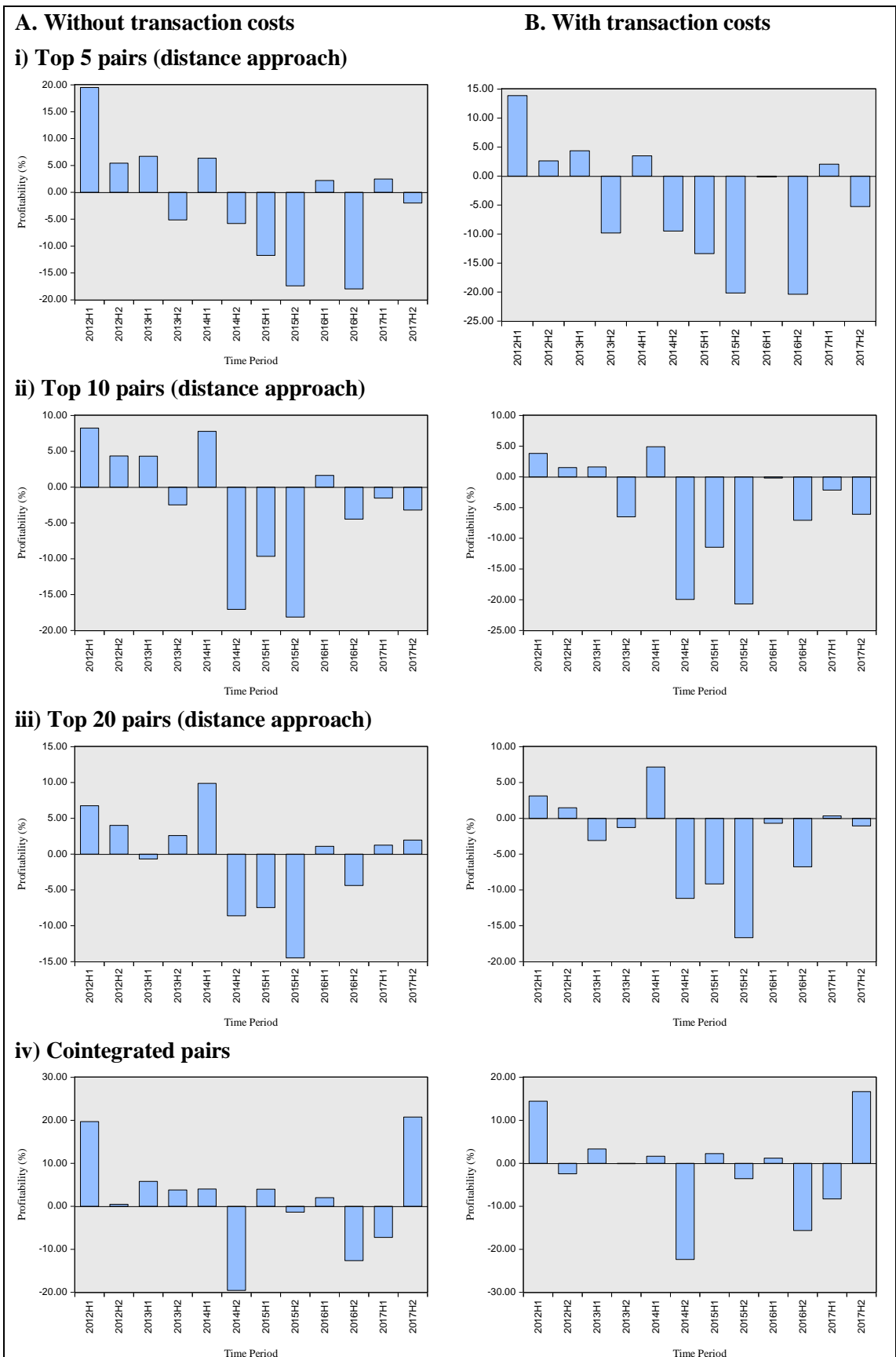


Figure 18: Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock spot prices without sector restriction and traded using standard deviation strategy over twelve trading periods

4.2.1.3 Combined Approach

Under combined approach, which is a combination of profit and loss (stop loss and take profit) and standard deviation trading strategies, positions are triggered when log of price series deviates more than two standard deviation from the mean of log of price ratio during formation period in either direction and squared off when either log of price series comes down to one standard deviation of log of price ratio during formation period or returns reach any of the pre-defined stop loss or take profit parameters. In other words, threshold limits on z-score for entering the trade are +2 or -2 and for exiting the trade the limits are +1 or -1 on z-score or returns hitting the stop loss or take profit limits (whichever happens first).

Table 39 shows the average six-monthly returns over the twelve trading periods for various pairs portfolios formed from stock spot prices without sector restriction and traded using combined approach.

Table 39: Six-monthly returns of stock spot pairs without sector restriction from combined trading approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
	Profitability (%)							
2012H1	16.80	6.82	5.64	15.12	9.96	-2.83	-2.60	8.84
2012H2	5.09	3.86	3.12	0.22	1.06	-1.78	-2.21	-7.12
2013H1	8.96	5.12	-3.17	7.48	3.81	-1.58	-10.48	1.59
2013H2	-3.79	-1.67	2.96	1.60	-22.83	-20.66	-13.80	-9.75
2014H1	5.28	8.05	8.90	2.97	-3.02	1.86	3.24	-2.20
2014H2	-1.97	-12.53	-4.26	-14.27	-12.82	-24.80	-14.41	-30.23
2015H1	-12.37	-10.61	-7.63	3.30	-22.00	-20.84	-15.74	-1.26
2015H2	-18.88	-18.48	-13.68	-6.55	-31.61	-32.23	-26.38	-19.37
2016H1	5.59	2.46	-0.02	0.99	-7.55	-7.14	-7.77	-0.22
2016H2	-11.99	-1.78	-3.62	-10.26	-26.40	-12.39	-13.22	-22.93
2017H1	2.96	-1.13	0.35	-3.39	1.74	-2.95	-1.77	-8.44
2017H2	-1.30	-3.01	0.97	20.74	-10.17	-10.50	-7.24	16.67
Average	-0.47	-1.91	-0.87	1.50	-9.99	-11.32	-9.36	-6.20

Note: This table reports the six-monthly returns (in percent) when pairs are formed using stock spot prices without sector restriction and traded using combined (profit and loss and standard deviation) trading strategy over the twelve trading periods.

Table 39 shows that all the portfolios formed from distance approach, that are, portfolios of top 5, top 10 and top 20 pairs are generating negative returns in majority of the trading periods both including and excluding transaction costs. The portfolio of cointegrating pairs yields some positive returns without transaction costs, but after including transaction costs, most of the returns in different trading periods have moved into negative territory. It is probably because of more number of trades entered into than in other portfolios, as more the number of trades, larger the transaction costs.

Table 40 focuses on the summary statistics of various portfolios traded using combined trading strategy. After factoring in transaction costs, portfolios of top 5, top 10 and top 20 pairs formed using distance method are yielding statistically significant (at 1% level of significance) average six-monthly returns of -9.99%, -11.32% and -9.36% respectively. The portfolio of cointegrating pairs is generating six-monthly average net return of -6.20%. The returns of all the portfolios considered after transaction costs are negatively skewed. This trading strategy is not able to protect even the base capital invested for the trading, let alone generating any positive returns.

Table 40: Descriptive statistics for six-monthly returns of stock spot pairs without sector restriction with combined trading approach

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
Mean (%)	-0.47	-1.91	-0.87	1.50	-9.99**	-11.32***	-9.36***	-6.20
SD (%)	10.12	8.21	6.09	9.88	13.34	10.94	8.04	13.26
Skewness	-0.26	-0.71	-0.48	0.36	-0.18	-0.57	-0.43	-0.19
Kurtosis	2.39	2.47	2.93	2.69	1.79	2.06	2.84	2.47
Min (%)	-18.88	-18.48	-13.68	-14.27	-31.61	-32.23	-26.38	-30.23
Max (%)	16.80	8.05	8.90	20.74	9.96	1.86	3.24	16.67
SW Statistic	0.97 ^{NS}	0.92 ^{NS}	0.97 ^{NS}	0.97 ^{NS}	0.95 ^{NS}	0.90 ^{NS}	0.96 ^{NS}	0.95 ^{NS}

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using stock spot prices without sector restriction and traded using combined trading (profit and loss and standard deviation) strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

The Figure 19 depicts the graphical representation of six-monthly returns over various trading periods for different portfolios formed from stock spot prices without sector restriction and traded using combined trading strategy.

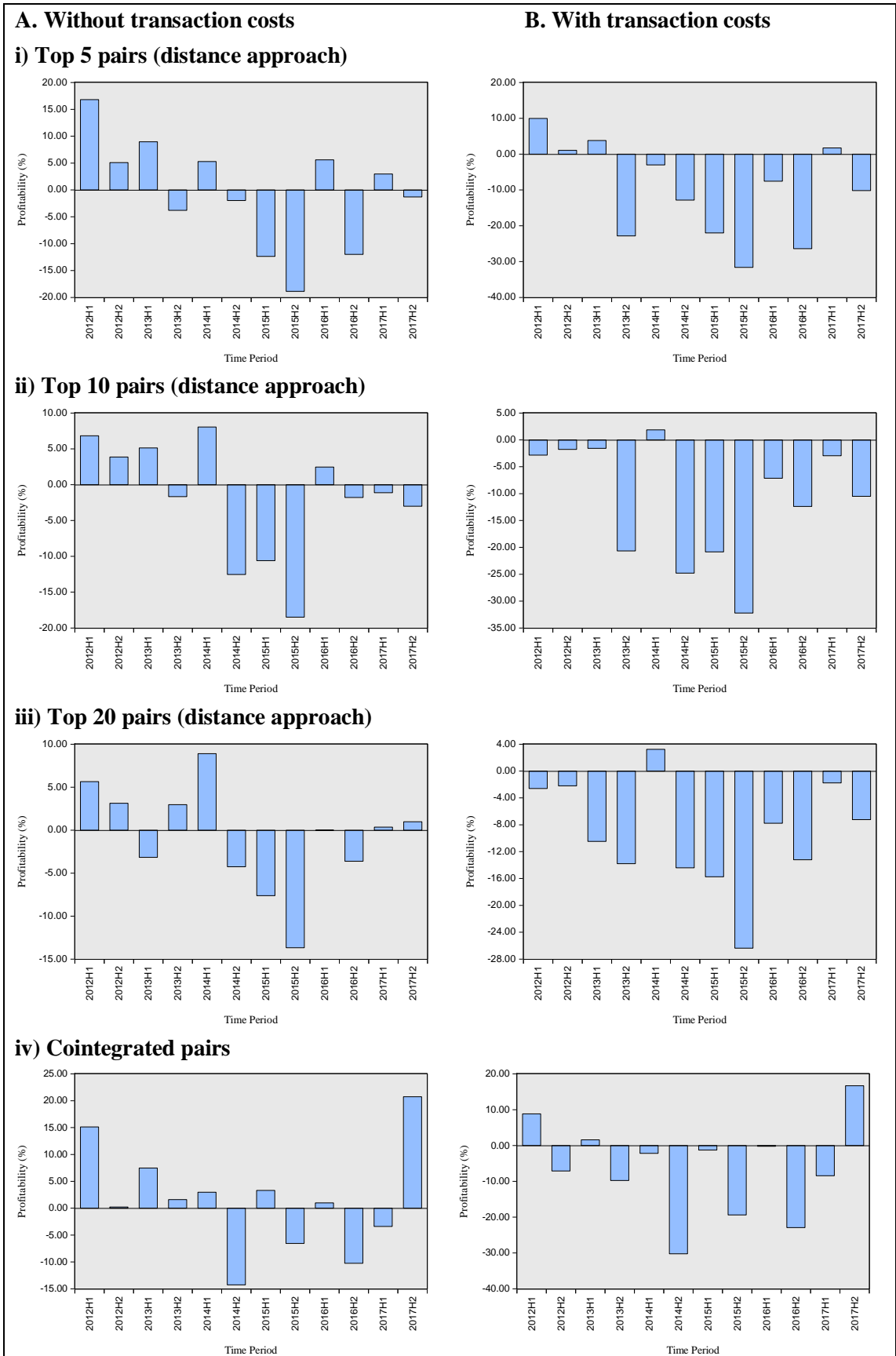


Figure 19: Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock spot prices without sector restriction and traded using combined strategy over twelve trading periods

4.2.2 Pairs Trading With Sector Restriction

This section exhibits the empirical results when pairs are formed from stock spot prices with sector restriction. It implies a stock belonging to a particular sector is matched with another stock from that particular sector only to form a pair. It means a stock from, say, automobile sector would be paired with another stock from automobile sector only. Various portfolios are formed using distance and cointegration approach, which are then traded using three different trading strategies.

4.2.2.1 Profit and Loss Approach (Stop Loss and Take Profit)

Table 41 and Table 42 below show the six-monthly returns over various trading periods and its summary statistics respectively, when pairs are formed with sector restriction from stock spot prices and trading using profit and loss approach.

Table 41: Six-monthly returns of stock spot pairs with sector restriction from profit and loss trading approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
	Profitability (%)							
2012H1	11.10	7.99	8.26	14.13	5.89	3.77	4.86	8.63
2012H2	4.75	6.05	5.67	5.84	1.93	3.42	1.12	3.38
2013H1	-2.56	-5.11	-9.14	2.87	-8.86	-11.44	-15.64	-1.54
2013H2	-3.33	5.08	9.24	6.79	-23.51	-12.66	-5.21	-10.63
2014H1	9.55	9.25	4.39	0.00	5.31	1.61	-2.61	0.00
2014H2	1.00	0.43	-4.80	-19.31	-8.19	-8.81	-15.75	-36.11
2015H1	-12.37	-10.71	-5.00	2.62	-22.00	-19.72	-13.20	-1.78
2015H2	-0.68	1.38	5.17	1.77	-6.61	-4.93	-0.96	-2.12
2016H1	5.59	0.81	0.75	5.07	-7.55	-10.60	-9.72	0.97
2016H2	-0.89	1.06	-0.73	1.31	-10.04	-6.10	-7.53	-6.57
2017H1	3.64	1.05	-0.75	0.00	1.61	-0.37	-4.71	0.00
2017H2	3.11	7.41	1.54	0.00	-1.40	1.29	-5.06	0.00
Average	1.58	2.06	1.22	1.76	-6.12	-5.38	-6.20	-3.82

Note: This table reports the six-monthly returns (in percent) when pairs are formed using stock spot prices with sector restriction and traded using profit and loss strategy over the twelve trading periods.

It can be observed from Table 41 that even though all the portfolios are generating positive returns in majority of the trading periods without transaction costs, the average return without transaction costs is meagre. It can be attributed to large negative returns in couple of trading periods. After inclusion of transaction costs, most of the positive portfolios' returns have turned negative in many trading periods. Number of trades entered into significantly impact the returns because of the rise in trading costs.

Table 42: Descriptive statistics for six-monthly returns of stock spot pairs with sector restriction with profit and loss trading approach

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
Mean (%)	1.58	2.06	1.22	1.76	-6.12**	-5.38**	-6.20***	-3.82
SD (%)	6.28	5.74	5.64	7.75	9.56	7.47	6.50	11.21
Skewness	-0.56	-0.82	-0.28	-1.47	-0.55	-0.35	-0.06	-2.12
Kurtosis	3.27	3.15	2.13	6.08	2.39	2.08	2.09	7.02
Min (%)	-12.37	-10.71	-9.14	-19.31	-23.51	-19.72	-15.75	-36.11
Max (%)	11.10	9.25	9.24	14.13	5.89	3.77	4.86	8.63
SW Statistic	0.96 ^{NS}	0.91 ^{NS}	0.97 ^{NS}	0.79***	0.91 ^{NS}	0.94 ^{NS}	0.96 ^{NS}	0.72***

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using stock spot prices with sector restriction and traded using profit and loss strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

Table 42 summarizes the results of pairs formed from stock spot prices with sector restriction and traded using profit and loss approach. The significant Shapiro-Wilk statistic in case of portfolio of cointegrating pairs implies non-normal distribution of data. The portfolio of top 5, top 10 and top 20 pairs formed using distance approach has generated statistically significant ($p < 0.05$) six-monthly average net returns (after transaction costs) of -6.12%, -5.38% and -6.20% respectively. The returns are negatively skewed as well.

The following Figure 20 presents the graphical representation of six-monthly returns (with and without transaction costs) for different portfolios formed with sector restriction and traded using profit and loss trading strategy over various trading periods.

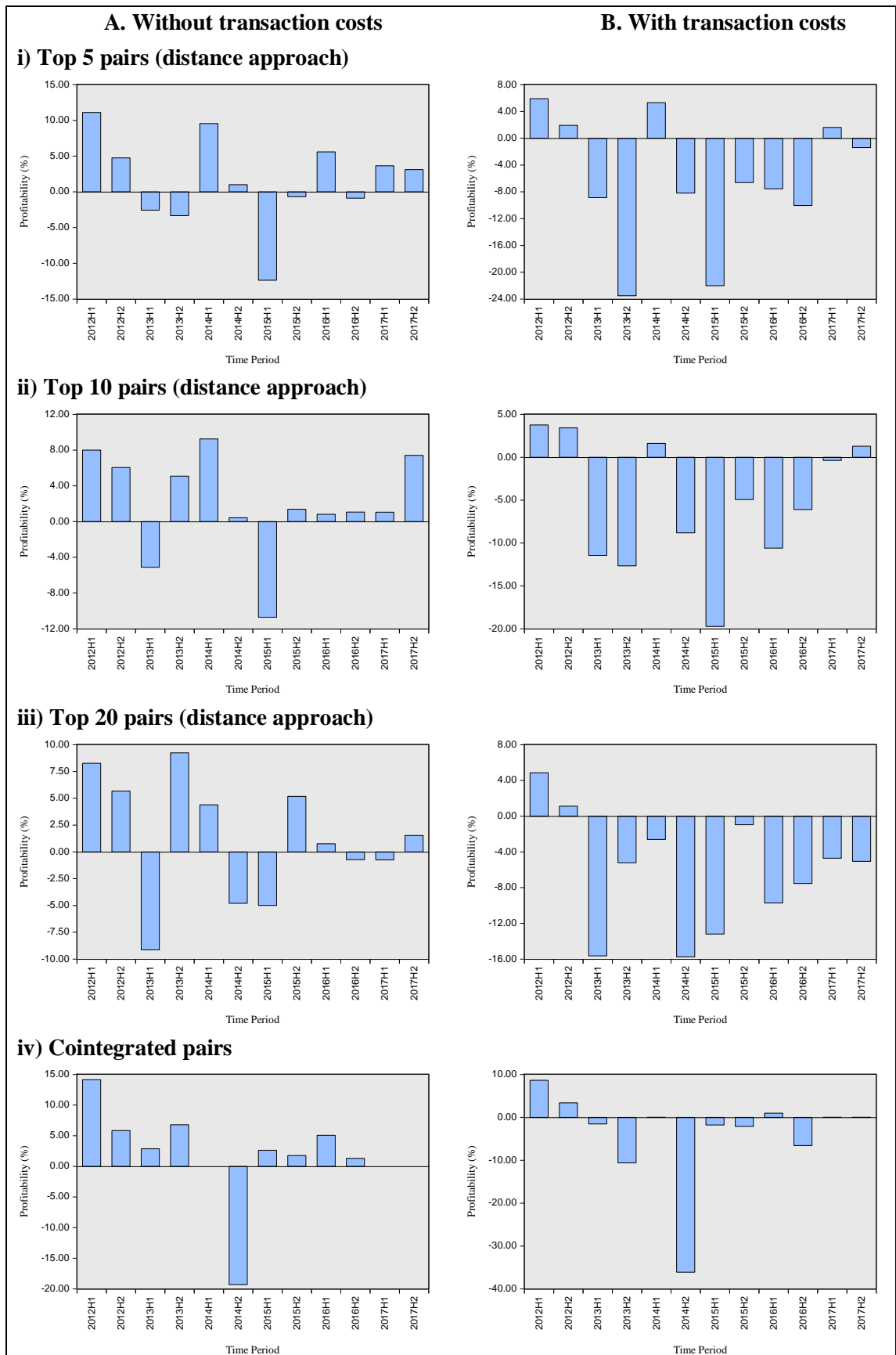


Figure 20: Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock spot prices with sector restriction and traded using profit and loss strategy over twelve trading periods

4.2.2.2 Standard Deviation Approach

Table 43 shows the average six-monthly returns over the twelve trading periods for various pairs portfolios formed from stock spot prices with sector restriction and traded using standard deviation approach. Portfolios are formed using distance method and cointegration method.

Table 43: Six-monthly returns of stock spot pairs with sector restriction from standard deviation trading approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
	Profitability (%)							
2012H1	11.86	9.10	9.15	13.76	8.23	6.09	6.65	9.76
2012H2	4.29	7.57	6.27	4.03	2.30	5.35	3.81	2.06
2013H1	0.60	-2.30	-5.52	2.37	-2.48	-4.82	-7.73	-0.01
2013H2	-7.98	2.34	7.75	2.45	-12.31	-2.46	3.89	-3.79
2014H1	11.11	15.39	6.76	0.00	9.22	12.28	4.11	0.00
2014H2	-2.55	-3.43	-7.54	-21.28	-5.76	-6.30	-9.81	-24.52
2015H1	-11.74	-7.75	-4.39	5.72	-13.37	-9.54	-6.59	3.73
2015H2	2.45	4.37	6.34	2.51	-0.65	1.91	4.15	-1.34
2016H1	2.21	0.71	0.09	9.98	-0.14	-1.33	-2.29	5.95
2016H2	-2.25	2.31	-0.29	-1.00	-5.02	-0.06	-2.30	-4.88
2017H1	3.15	0.85	-1.26	0.00	1.92	0.03	-2.72	0.00
2017H2	12.49	10.98	5.53	0.00	9.94	8.44	3.23	0.00
Average	1.97	3.34	1.91	1.55	-0.68	0.80	-0.47	-1.09

Note: This table reports the six-monthly returns (in percent) when pairs are formed using stock spot prices with sector restriction and traded using standard deviation strategy over the twelve trading periods.

It can be seen from Table 43 that all the portfolios are generating positive returns in majority of the trading periods when considered without transaction costs. However, after the inclusion of transaction costs, some of positive returns have also moved into negative territory, thus making the overall average returns negative when considered after transaction costs.

Table 44 provides the descriptive statistics when pairs are formed with sector restriction and traded using standard deviation strategy. The portfolio of top 10 pairs formed using distance approach is generating statistically significant (at 10% level of significance) six-monthly average return of 3.34%. After inclusion of transaction costs, average returns have turned negative except for the portfolio of top 10 pairs formed using distance approach. Though the portfolio of top 10 pairs formed using distance approach is generating positive return after transaction costs (0.80%) , the return generated is less than risk-free rate of return.

Table 44: Descriptive statistics for six-monthly returns of stock spot pairs with sector restriction with standard deviation trading approach

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointe-grated pairs	Distance approach			Cointe-grated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
Mean (%)	1.97	3.34*	1.91	1.55	-0.68	0.80	-0.47	-1.09
SD (%)	7.55	6.55	5.75	8.43	7.69	6.36	5.50	8.40
Skewness	-0.18	0.19	-0.32	-1.49	-0.19	0.19	-0.39	-1.79
Kurtosis	2.29	2.39	1.64	5.89	2.10	2.24	1.75	6.36
Min (%)	-11.74	-7.75	-7.54	-21.28	-13.37	-9.54	-9.81	-24.52
Max (%)	12.49	15.39	9.15	13.76	9.94	12.28	6.65	9.76
SW Statistic	0.95 ^{NS}	0.99 ^{NS}	0.90 ^{NS}	0.80***	0.95 ^{NS}	0.99 ^{NS}	0.89 ^{NS}	0.79***

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using stock spot prices with sector restriction and traded using standard deviation strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

The following Figure 21 presents the graphical representation of six-monthly returns (with and without transaction costs) over all the trading periods for various portfolios formed from stock spot prices with sector restriction and traded using standard deviation trading strategy.

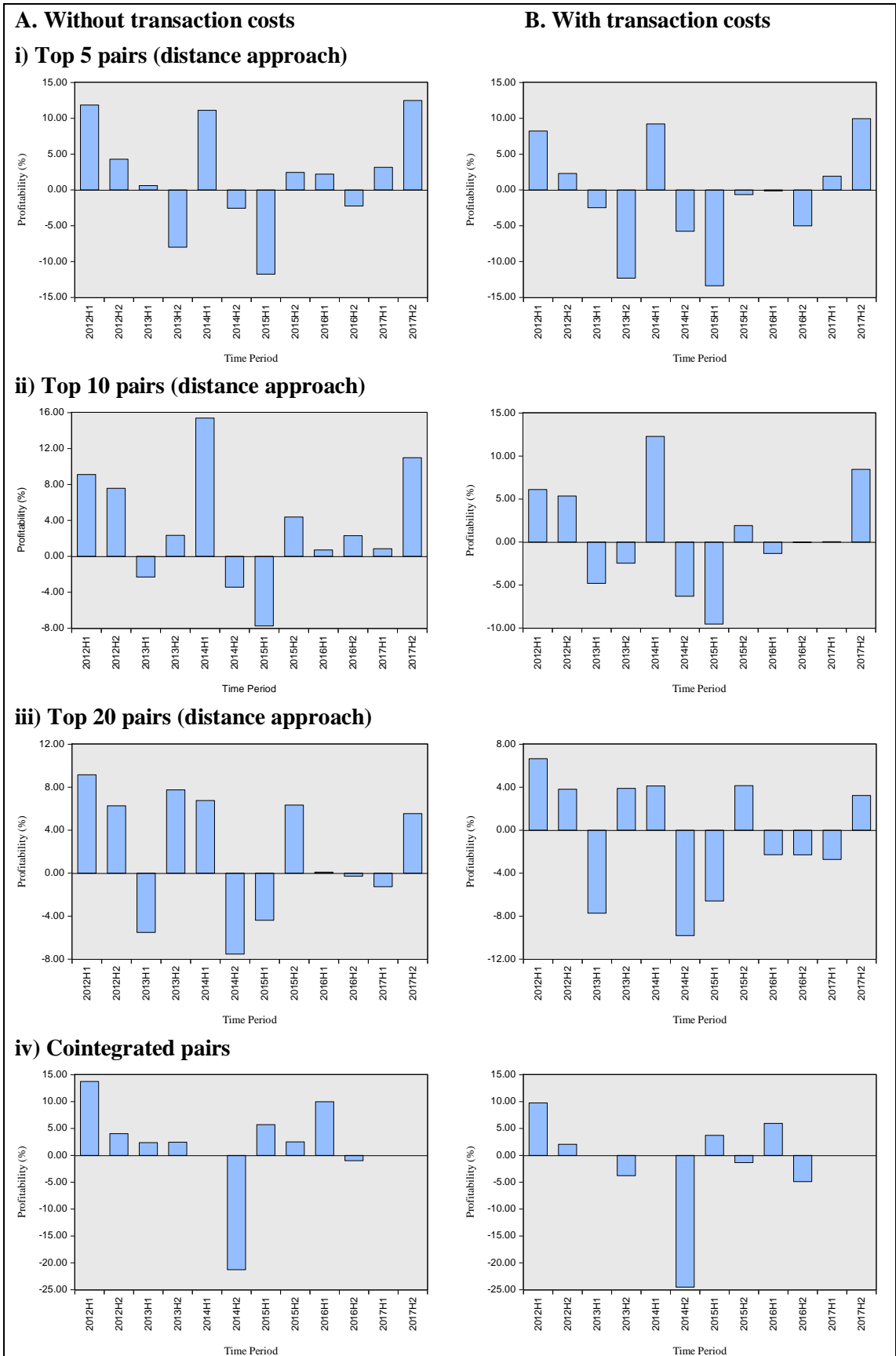


Figure 21: Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock spot prices with sector restriction and traded using standard deviation strategy over twelve trading periods

4.2.2.3 Combined Approach

The average six-monthly returns over the twelve trading periods for various pairs portfolios formed from stock spot prices with sector restriction and traded using combined approach are shown in Table 45. Returns of various portfolios formed using distance method and cointegration approach are computed both including and excluding transaction costs.

Table 45: Six-monthly returns of stock spot pairs with sector restriction from combined trading approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
	Profitability (%)							
2012H1	9.87	8.13	8.19	10.88	4.67	3.73	4.59	5.37
2012H2	3.88	6.75	5.52	3.86	1.08	3.93	0.87	1.38
2013H1	-0.83	-4.71	-9.03	3.00	-7.92	-11.42	-15.73	-1.88
2013H2	-4.68	3.02	7.78	-1.42	-25.69	-15.32	-6.97	-20.19
2014H1	9.55	9.25	4.80	0.00	5.31	1.61	-2.30	0.00
2014H2	2.06	0.95	-4.54	-18.89	-7.54	-8.48	-15.59	-36.09
2015H1	-12.37	-9.78	-4.62	4.49	-22.00	-18.98	-12.92	-0.30
2015H2	0.79	3.52	6.50	2.31	-5.92	-3.39	-0.13	-2.54
2016H1	5.59	0.81	0.62	4.97	-7.55	-10.60	-9.95	-1.10
2016H2	-1.92	0.54	-0.99	-3.89	-11.07	-6.62	-7.79	-11.75
2017H1	3.64	1.05	-1.16	0.00	1.61	-0.37	-5.12	0.00
2017H2	3.61	7.15	1.85	0.00	-1.29	0.84	-4.94	0.00
Average	1.60	2.22	1.24	0.44	-6.36	-5.42	-6.33	-5.59

Note: This table reports the six-monthly returns (in percent) when pairs are formed using stock spot prices with sector restriction and traded using combined (profit and loss and standard deviation) trading strategy over the twelve trading periods.

As seen in Table 45, all the portfolios are yielding negative returns after transaction costs in majority of the trading periods leading to overall average negative returns. Transaction costs play a big role in portfolios' returns as with inclusion of transaction costs, many of the returns that have been positive before transaction costs, are converted into negative returns after inclusion of transaction costs.

Table 46 provides the summary statistics of different portfolios. All the portfolios are yielding negative six-monthly average net returns (after transaction costs). The portfolios of

top 5, top 10 and top 20 pairs formed using distance approach are generating statistically significant ($p < 0.05$) six-monthly average returns of -6.36%, -5.42% and -6.33% respectively. All the portfolios have positive six-monthly average before transaction costs, but the returns are less than risk-free rate of return. The returns are negatively skewed in all the portfolios.

Table 46: Descriptive statistics for six-monthly returns of stock spot pairs with sector restriction with combined trading approach

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
Mean (%)	1.60	2.22	1.24	0.44	-6.36**	-5.42**	-6.33***	-5.59
SD (%)	6.14	5.49	5.51	7.16	9.76	7.66	6.48	11.74
Skewness	-0.77	-0.75	-0.35	-1.54	-0.73	-0.32	0.01	-1.72
Kurtosis	3.41	3.03	2.03	5.76	2.63	1.87	2.01	4.88
Min (%)	-12.37	-9.78	-9.03	-18.89	-25.69	-18.98	-15.73	-36.09
Max (%)	9.87	9.25	8.19	10.88	5.31	3.93	4.59	5.37
SW Statistic	0.94 ^{NS}	0.92 ^{NS}	0.95 ^{NS}	0.83**	0.91 ^{NS}	0.94 ^{NS}	0.97 ^{NS}	0.73***

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using stock spot prices with sector restriction and traded using combined trading (profit and loss and standard deviation) strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

The Figure 22 shows the graphical presentation of six-monthly returns over all the trading periods for various portfolios formed from stock spot prices with sector restriction and traded using combined trading (profit and loss and standard deviation) strategy.

The pairs trading strategy is not profitable when pairs are formed from stock spot prices both with and without sector restriction, and traded using various trading strategies. Even in the cases where returns are coming out to be positive, the returns generated are less than the risk-free rate of return.

In light of the above evidence, it can be summarized that there are statistical arbitrage opportunities present in Indian stock spot market as seen from various trading opportunities, but they are not profitable. Ergo, hypothesis (**H6**) that there are no statistical arbitrage opportunities in Indian stock spot market, is not accepted. On the other hand, we fail to reject the hypothesis (**H7**) that the statistical arbitrage opportunities in Indian stock spot market are not profitable. Therefore it can be established that though statistical arbitrage opportunities exist in Indian stock spot market but they are not profitable.

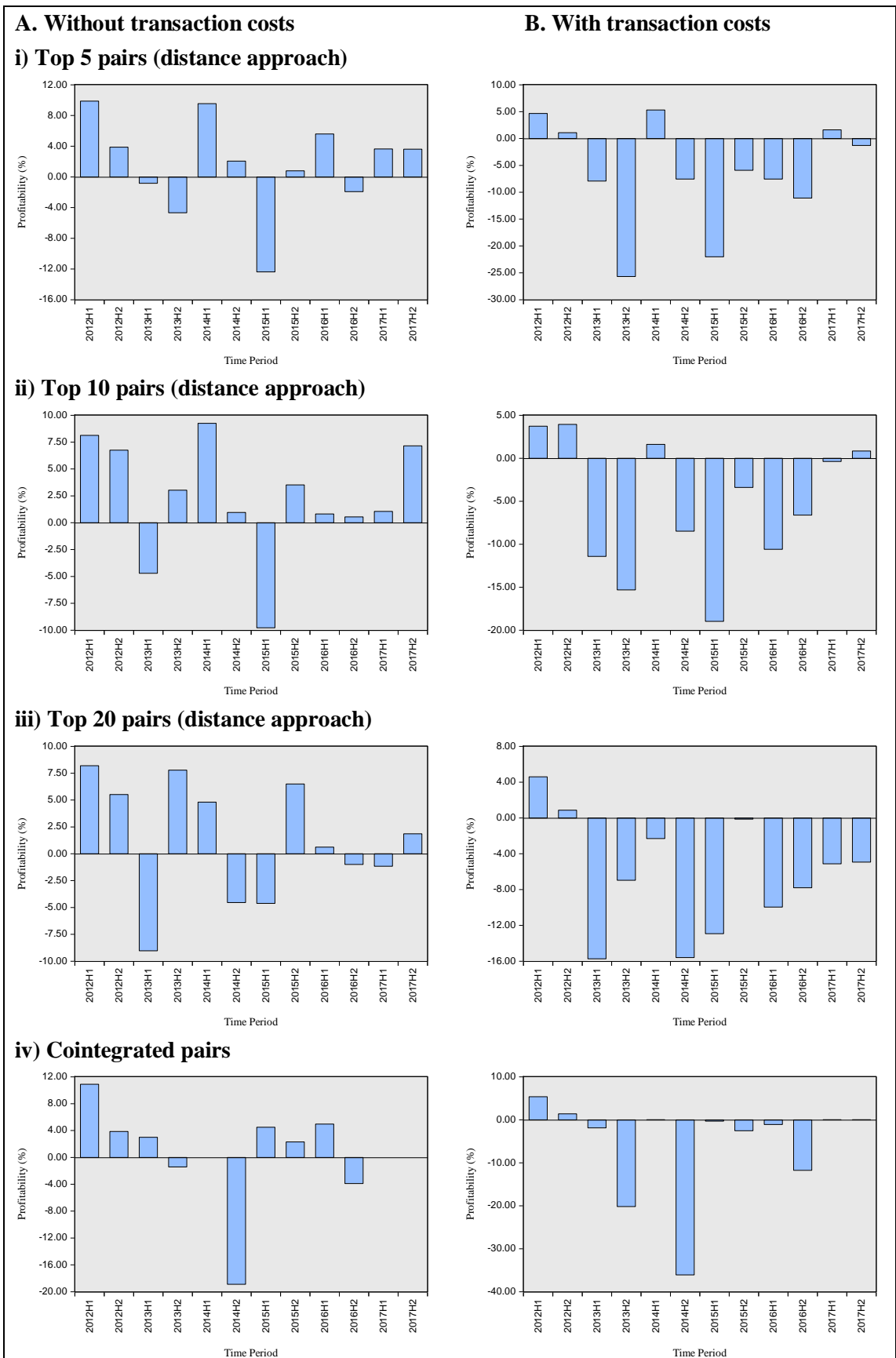


Figure 22: Graphical presentation of six-monthly returns of various portfolios of pairs formed using stock spot prices with sector restriction and traded using combined strategy over twelve trading periods

4.2.3 Returns' Attribution of Pairs Trading Strategies

This section deals with the risk characteristics of various pairs trading strategies which have been used to trade different portfolios of pairs. The Table 47 below compares twenty four different portfolios formed using stock spot prices both with and without sector restriction, and traded using various trading strategies (profit and loss, standard deviation and combined). The purpose is to analyse the portfolios considering both risk and return characteristics. Shape ratio and Fama-French (1993) asset pricing model have been used to calculate the risk-adjusted returns and attribute the returns to various risk factors to determine the source of returns, respectively.

As seen from Table 47, almost all the portfolios are generating negative returns after transaction costs. Before including transaction costs, the portfolios formed with sector restriction have six-monthly average positive returns, but these returns have turned negative once the transaction costs are factored in. Also, the positive returns generated are less than the average risk-free rate of return. Risk-adjusted returns which are calculated using Sharpe ratio are also negative in all the cases, which suggests that pairs trading in portfolios formed and traded using stock spot prices is not profitable and hence not advisable. The couple of points that differentiate pairs trading in stock spot from pairs trading in stock futures are that pairs trading in stock spot is studied using various assumptions because naked short-selling is not allowed in inter-day market in spot market. Also, the margin requirement and transaction costs are assumed to be higher in stock spot than in stock futures. The standard deviation of returns in stock spot pairs is considerably less than standard deviation in stock futures pairs.

Coming to attribution of returns using Fama-French three factor model, it can be observed that there is significant negative alpha generation (intercept value). It implies investor would not be compensated for taking higher risk. In line with the literature, the pairs trading strategy is market neutral: the exposure to the market factor is insignificant in majority of the cases. Hence, we fail to reject the hypothesis (**H8**) that the returns generated from statistical arbitrage opportunities in Indian stock spot market cannot be attributed to market risk as per Fama-French three factor model.

The size factor, SMB, is a strategy of going long small-capitalization stocks and short large-cap stocks. Hence, a positive loading on SMB reflects a tendency to buy small-cap stocks, so pairs trading strategy's negative loading reflects a tendency to buy large-cap stocks. The exposure to the size has predictable sign and is statistically significant when portfolios are formed without sector restriction but is statistically insignificant when portfolios are formed with sector restriction. The negative SMB implies large-cap stocks outperformed. Thus it is prudent to say that hypothesis (**H9**) that the returns generated from statistical arbitrage opportunities in Indian stock spot market cannot be attributed to size risk as per Fama-French three factor model is not accepted. The size factor has negative loading because majority of the stocks included in the sample for this study are large cap stocks.

Table 47: Stock spot portfolios with risk adjusted six-monthly returns and attribution of returns

Portfolio/Trading strategy		Without transaction costs		With transaction costs		Risk adjusted returns				
		AR (%)	SD (%)	AR (%)	SD (%)	Sharpe ratio	Fama-French (1993) Model			
							Intercept	Market	SMB	HML
Without sector restriction										
Profit and loss trading strategy										
Distance method	Top 5 pairs	-0.16	10.59	-9.41**	13.55	-0.37	-4.55	0.76**	-0.72***	-0.11
	Top 10 pairs	-2.05	8.29	-11.24***	10.87	-0.70	-6.24***	0.46*	-0.56***	0.18
	Top 20 pairs	-0.89	6.26	-9.24***	8.00	-0.74	-6.34***	0.52***	-0.32***	0.12
Cointegrated pairs		2.55	11.46	-4.88	14.52	-0.10	-1.78	0.31	-0.39	0.24
Standard deviation trading strategy										
Distance method	Top 5 pairs	-1.45	10.90	-4.35	10.53	-0.47	-6.67*	0.84*	-0.61**	-0.13
	Top 10 pairs	-2.52	8.76	-5.19*	8.59	-0.71	-6.70***	0.44	-0.55***	0.19
	Top 20 pairs	-0.67	6.91	-3.15	6.67	-0.64	-5.94***	0.53***	-0.38***	0.14
Cointegrated pairs		1.64	11.55	-1.08	10.98	-0.18	-2.50	0.13	-0.23	0.26
Combined trading strategy										
Distance method	Top 5 pairs	-0.47	10.12	-9.99**	13.34	-0.41	-5.03*	0.78**	-0.68***	-0.14
	Top 10 pairs	-1.91	8.21	-11.32***	10.94	-0.69	-5.97***	0.44*	-0.57***	0.16
	Top 20 pairs	-0.87	6.09	-9.36***	8.04	-0.75	-6.31***	0.53***	-0.31***	0.08
Cointegrated pairs		1.50	9.88	-6.20	13.26	-0.23	-2.64	0.30	-0.36	0.14

Contd....

Portfolio/Trading strategy		Without transaction costs		With transaction costs		Risk adjusted returns				
		AR (%)	SD (%)	AR (%)	SD (%)	Sharpe ratio	Fama-French (1993) Model			
							Intercept	Market	SMB	HML
With sector restriction										
Profit and loss trading strategy										
Distance method	Top 5 pairs	1.58	6.28	-6.12**	9.56	-0.34	-3.99*	0.39	-0.09	0.07
	Top 10 pairs	2.06	5.74	-5.38**	7.47	-0.29	-3.47**	0.22	-0.01	0.25*
	Top 20 pairs	1.22	5.64	-6.20***	6.50	-0.44	-3.80**	0.00	0.14	0.26*
Cointegrated pairs		1.76	7.75	-3.82	11.21	-0.25	-1.12	-0.17	-0.16	0.28
Standard deviation trading strategy										
Distance method	Top 5 pairs	1.97	7.55	-0.68	7.69	-0.23	-3.78	0.36	-0.06	0.15
	Top 10 pairs	3.34*	6.55	0.80	6.36	-0.06	-2.43	0.18	0.05	0.33**
	Top 20 pairs	1.91	5.75	-0.47	5.50	-0.32	-2.97*	-0.05	0.12	0.34**
Cointegrated pairs		1.55	8.43	-1.09	8.40	-0.26	-1.39	-0.15	-0.11	0.18
Combined trading strategy										
Distance method	Top 5 pairs	1.60	6.14	-6.36**	9.76	-0.35	-3.82*	0.34	-0.07	0.06
	Top 10 pairs	2.22	5.49	-5.42**	7.66	-0.27	-3.29**	0.19	0.05	0.22*
	Top 20 pairs	1.24	5.51	-6.33***	6.48	-0.45	-3.82**	-0.02	0.18	0.25*
Cointegrated pairs		0.44	7.16	-5.59	11.74	-0.46	-2.76	-0.10	-0.08	0.14

Note: This table reports the risk-adjusted six-monthly returns and coefficients of Fama-French three factor model of portfolios of stock spot formed both with and without sector restriction. AR, SD, Market, SMB and HML denote six-monthly average return, six-monthly standard deviation, market factor, size factor and value factor respectively. Superscripts ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively.

The value factor, HML, is a strategy of buying stocks of high book value to market value while shorting stocks of low book value to market value. The positive loading in most of the portfolios in Table 47 thus reflects a tendency of value stocks outperforming growth stocks. But value risk factor doesn't have any statistically significant contribution towards returns generated by various portfolios. Thus, we fail to reject hypothesis (*H10*) that the returns generated from statistical arbitrage opportunities in Indian stock spot market cannot be attributed to value risk as per Fama-French three factor model.

4.3 Spot-Future Statistical Arbitrage in Indian Stock Market

This section deals with the spot-future statistical arbitrage in stocks. Under this, a pair is identified as a stock in its respective spot market and future market. It is done for every stock in the sample. The intend here is to check whether spot-future statistical arbitrage exists in pairs and if it exists, whether it can be traded by applying the rules of pairs trading. There are two pairs portfolios, one, the portfolio of all pairs where each pair is comprised of a stock in its respective spot and future market, and second, the portfolio of cointegrating pairs where from all the pairs, only pairs that are cointegrated are selected. Then these pairs are traded using various guidelines and assumptions through various trading approaches, that are, profit and loss approach, standard deviation approach and combined approach. This section is again more of a theoretical study because inter-day naked short selling is not allowed in Indian spot market.

4.3.1 Profit and Loss Approach (Stop Loss and Take Profit)

Table 48 shows the six-monthly returns of two portfolios formed from stocks in their respective spot market and future market traded using profit and loss approach over the various trading periods. Table 49 presents the summary statistics of the traded portfolios.

It can be seen from Table 48 that both portfolios are generating positive returns in all trading periods before transaction costs. The returns generated are less than the risk-free rate of return of the respective trading period. The returns have slipped into negative zone once transaction costs are factored in. The magnitude of both positive and negative returns in terms of percentage is very less. One possible reason can be that stock spot-future arbitrage is generally considered as a near riskless strategy.

Table 49 presents the descriptive statistics of portfolios formed from stock spot-future pairs and traded using profit and loss approach. Portfolios of all pairs and cointegrated pairs when considered without transaction costs have normally distributed returns and are generating statistically significant ($p < 0.01$) six-monthly average returns of 1.30% and 1.29% respectively. The average returns have turned negative after inclusion of transaction costs. The returns of both portfolios are positively skewed, both with and without transaction costs.

Table 48: Six-monthly returns of stock spot-future pairs from profit and loss approach over various trading periods

Time Period	Portfolio			
	Without transaction costs		With transaction costs	
	All pairs	Cointegrated pairs	All pairs	Cointegrated pairs
	Profitability (%)			
2012H1	1.20	1.20	-0.33	-0.48
2012H2	2.05	1.97	1.21	1.17
2013H1	0.87	0.87	-0.04	-0.04
2013H2	1.83	1.83	-0.24	-0.24
2014H1	1.13	1.19	0.05	0.06
2014H2	1.56	1.65	0.23	0.24
2015H1	1.27	1.45	-0.47	-0.38
2015H2	1.04	1.03	-0.32	-0.31
2016H1	1.72	1.67	0.10	0.17
2016H2	0.63	0.63	-0.32	-0.32
2017H1	0.76	0.63	-0.45	-0.60
2017H2	1.49	1.32	-0.02	-0.10
Average	1.30	1.29	-0.05	-0.07

Note: This table reports the six-monthly returns (in percent) when pairs are formed using stocks in their respective spot and future market, and traded using profit and loss strategy over the twelve trading periods.

Table 49: Descriptive statistics for six-monthly returns of portfolios formed from stock spot-future pairs with profit and loss trading approach

Statistics	Portfolio			
	Without transaction costs		With transaction costs	
	All pairs	Cointegrated pairs	All pairs	Cointegrated pairs
Mean (%)	1.30***	1.29***	-0.05	-0.07
SD (%)	0.44	0.45	0.46	0.47
Skewness	0.15	-0.07	1.82	1.55
Kurtosis	1.95	1.88	5.94	5.21
Min (%)	0.63	0.63	-0.47	-0.60
Max (%)	2.05	1.97	1.21	1.17
SW Statistic	0.98 ^{NS}	0.96 ^{NS}	0.78***	0.85**

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using stocks in their respective spot and future market, and traded using profit and loss strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

The following Figure 23 shows the graphical representation of six-monthly returns (with and without transaction costs) over various trading periods for portfolios formed from stock spot-future pairs and traded using profit and loss (stop loss and take profit) approach.

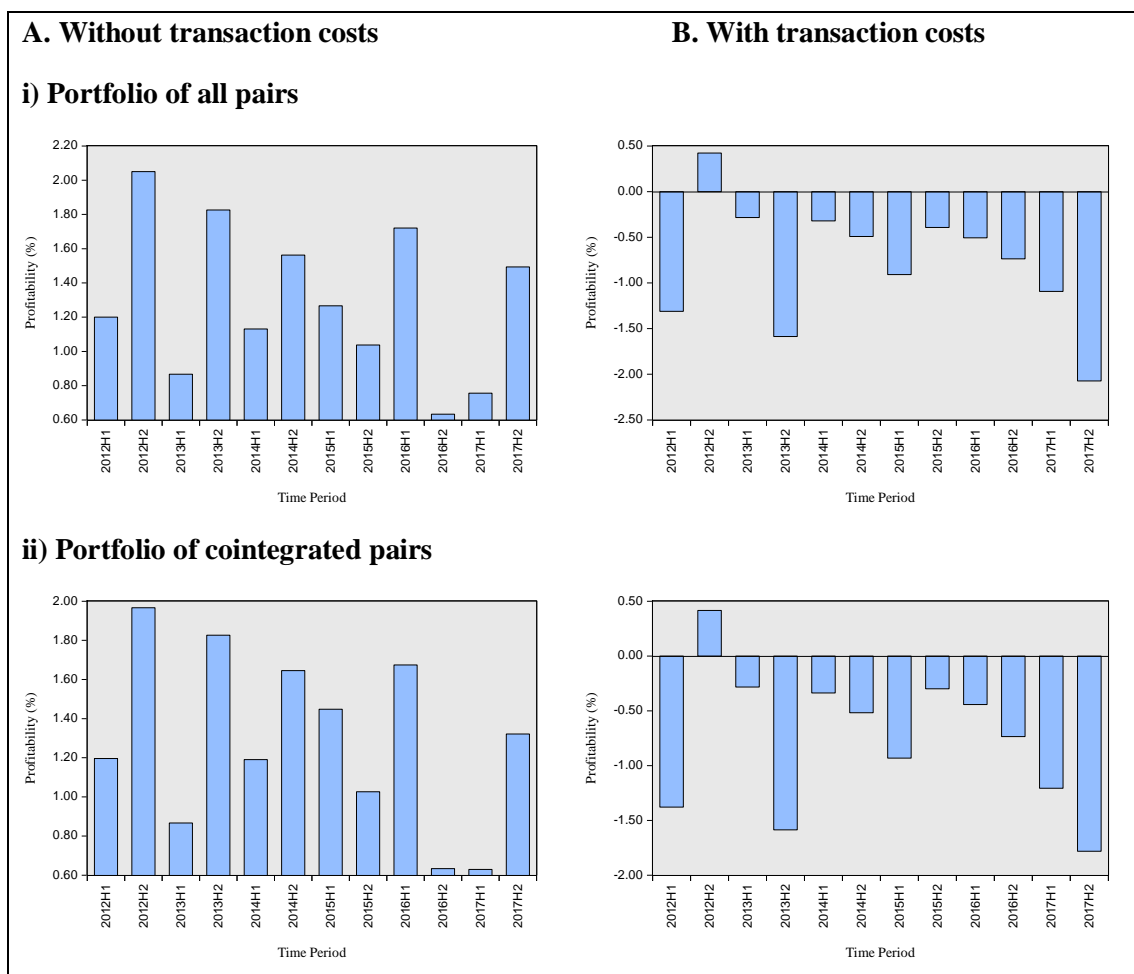


Figure 23: Graphical presentation of six-monthly returns of various portfolios formed using stock spot-future pairs and traded using profit and loss strategy over twelve trading periods

4.3.2 Standard Deviation Approach

Under standard deviation approach, positions are triggered when log of price series deviates more than two standard deviation from the mean of log of price ratio during formation period in either direction and squared off when log of price series comes down to one standard deviation of log of price ratio during formation period.

Table 50 shows the average six-monthly returns over the twelve trading periods for various pairs portfolios formed from stock spot-future pairs and traded using standard deviation approach. Portfolios are formed using all pairs and cointegrated pairs.

It can be seen from Table 50 that both portfolios are generating positive returns in all trading periods before transaction costs, though the returns generated are less than the risk-free rate of return of the respective trading period. Majority of the returns have slipped into negative zone once transaction costs are factored in. The magnitude of both positive and negative returns in terms of percentage is very less, except returns without transaction costs in first three trading periods.

Table 50: Six-monthly returns of stock spot-future pairs from standard deviation approach over various trading periods

Time Period	Portfolio			
	Without transaction costs		With transaction costs	
	All pairs	Cointegrated pairs	All pairs	Cointegrated pairs
	Profitability (%)			
2012H1	5.73	6.85	-1.31	-1.38
2012H2	1.48	1.44	0.42	0.42
2013H1	1.64	1.64	-0.28	-0.28
2013H2	6.47	6.47	-1.44	-1.44
2014H1	2.14	2.26	-0.32	-0.34
2014H2	2.66	2.80	-0.49	-0.52
2015H1	3.85	3.97	-0.91	-0.93
2015H2	2.41	2.38	-0.12	-0.01
2016H1	2.32	2.02	-0.68	-0.68
2016H2	1.72	1.72	-0.74	-0.74
2017H1	1.76	1.86	-0.97	-1.08
2017H2	2.68	2.28	-2.07	-1.78
Average	2.90	2.97	-0.74	-0.73

Note: This table reports the six-monthly returns (in percent) when pairs are formed using stocks in their respective spot and future market, and traded using standard deviation strategy over the twelve trading periods.

Table 51: Descriptive statistics for six-monthly returns of portfolios formed from stock spot-future pairs with standard deviation trading approach

Statistics	Portfolio			
	Without transaction costs		With transaction costs	
	All pairs	Cointegrated pairs	All pairs	Cointegrated pairs
Mean (%)	2.90***	2.97***	-0.74***	-0.73***
SD (%)	1.63	1.85	0.66	0.63
Skewness	1.31	1.37	-0.28	0.07
Kurtosis	3.33	3.34	2.82	2.29
Min (%)	1.48	1.44	-2.07	-1.78
Max (%)	6.47	6.85	0.42	0.42
SW Statistic	0.79***	0.74***	0.99 ^{NS}	0.99 ^{NS}

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using stocks in their respective spot and future market, and traded using standard deviation strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

Table 51 shows the descriptive statistics of standard deviation trading approach when portfolios are formed from stock spot-future pairs. The non-significant Shapiro-Wilk statistic implies the normal distribution of data. Both portfolios are generating statistically significant ($p < 0.01$) six-monthly average returns, both including and excluding transaction costs. Portfolios of all pairs and cointegrated pairs are generating statistically significant six-monthly average returns of -0.74% and -0.73% respectively after transaction costs. The returns are positively skewed in majority of the scenarios.

The following Figure 24 shows the graphical representation of six-monthly returns (with and without transaction costs) over various trading periods for portfolios formed from stock spot-future pairs and traded using standard deviation approach.

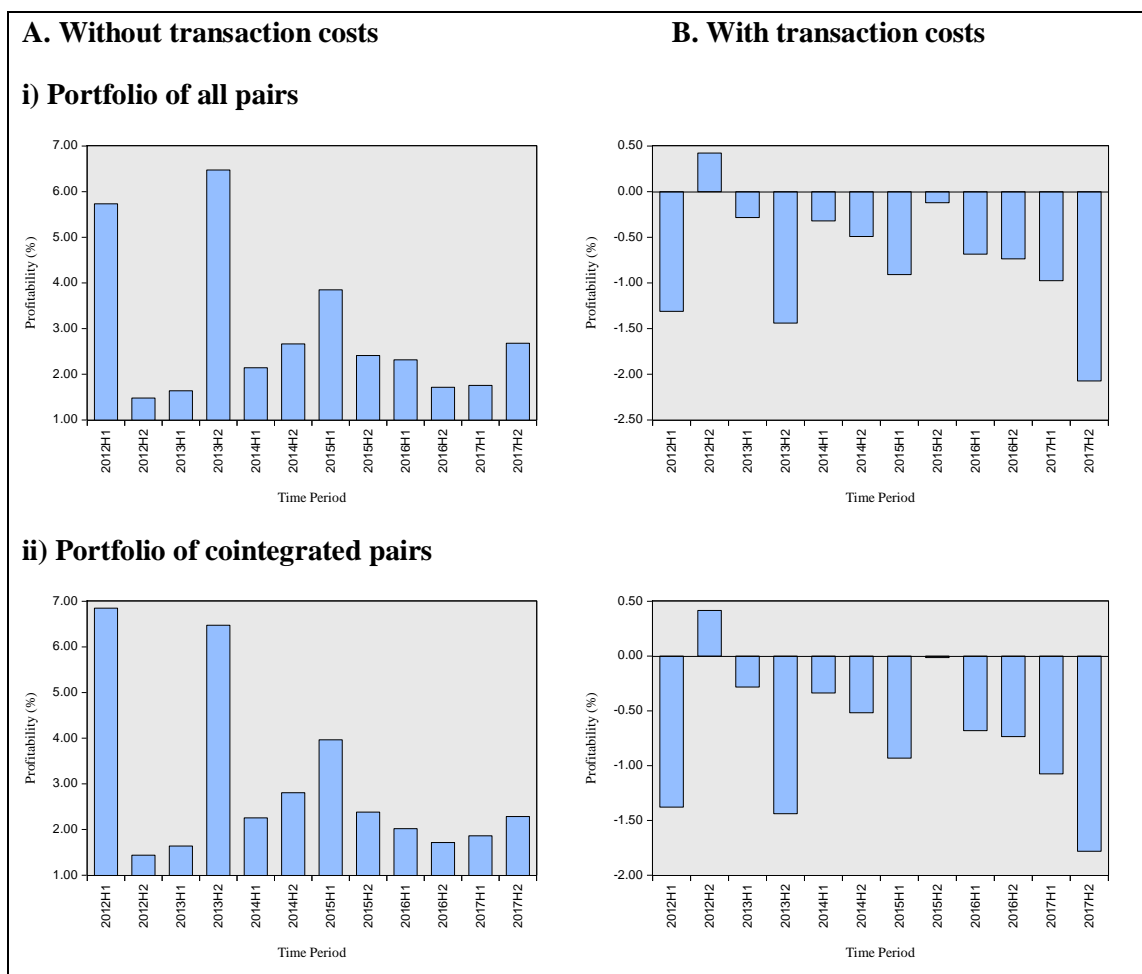


Figure 24: Graphical presentation of six-monthly returns of various portfolios formed using stock spot-future pairs and traded using standard deviation strategy over twelve trading periods

4.3.3 Combined Approach

The combined trading approach is a combination of profit and loss (stop loss and take profit) and standard deviation trading strategies. The average six-monthly returns over the twelve trading periods for pairs portfolios formed from stock spot-future prices and traded

using combined approach are shown in Table 52. Returns of both portfolios are computed both including and excluding transaction costs.

It can be seen from Table 52 that returns are on a declining trend. It can be because of exploitation of arbitrage opportunities by market participants as in later time periods, the returns have reduced to mere around 2% without transaction costs per trading period.

Table 52: Six-monthly returns of stock spot-future pairs from combined approach over various trading periods

Time Period	Portfolio			
	Without transaction costs		With transaction costs	
	All pairs	Cointegrated pairs	All pairs	Cointegrated pairs
	Profitability (%)			
2012H1	5.73	6.85	-1.31	-1.38
2012H2	1.48	1.44	0.42	0.42
2013H1	1.64	1.64	-0.28	-0.28
2013H2	6.41	6.41	-1.59	-1.59
2014H1	2.14	2.26	-0.32	-0.34
2014H2	2.66	2.80	-0.49	-0.52
2015H1	3.85	3.97	-0.91	-0.93
2015H2	2.23	2.19	-0.39	-0.30
2016H1	2.67	2.49	-0.51	-0.44
2016H2	1.72	1.72	-0.74	-0.74
2017H1	1.73	1.83	-1.09	-1.21
2017H2	2.68	2.28	-2.07	-1.78
Average	2.91	2.99	-0.77	-0.76

Note: This table reports the six-monthly returns (in percent) when pairs are formed using stocks in their respective spot and future market, and traded using combined (profit and loss and standard deviation) strategy over the twelve trading periods.

Table 53 shows the descriptive statistics of combined trading approach when portfolios are formed from stock spot-future pairs. The non-significant Shapiro-Wilk statistic implies the normal distribution of data. Both portfolios are generating statistically significant ($p < 0.01$) six-monthly average returns, both including and excluding transaction costs. Portfolios of all pairs and cointegrated pairs are generating statistically significant six-monthly average returns of 2.91% and 2.99% respectively before transaction costs. The returns are positively skewed when taken without transaction costs.

Table 53: Descriptive statistics for six-monthly returns of portfolios formed from stock spot-future pairs with combined trading approach

Time Period	Portfolio			
	Without transaction costs		With transaction costs	
	All pairs	Cointegrated pairs	All pairs	Cointegrated pairs
Mean (%)	2.91***	2.99***	-0.77***	-0.76***
SD (%)	1.62	1.83	0.67	0.64
Skewness	1.27	1.36	-0.29	-0.02
Kurtosis	3.26	3.33	2.74	2.25
Min (%)	1.48	1.44	-2.07	-1.78
Max (%)	6.41	6.85	0.42	0.42
SW Statistic	0.79***	0.75***	0.97 ^{NS}	0.96 ^{NS}

Note: This table reports the six-monthly returns of various portfolios when pairs are formed using stocks in their respective spot and future market, and traded using combined strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.

The following Figure 25 shows the graphical representation of six-monthly returns (with and without transaction costs) over various trading periods for portfolios formed from stock spot-future pairs and traded using combined (profit and loss and standard deviation) approach.

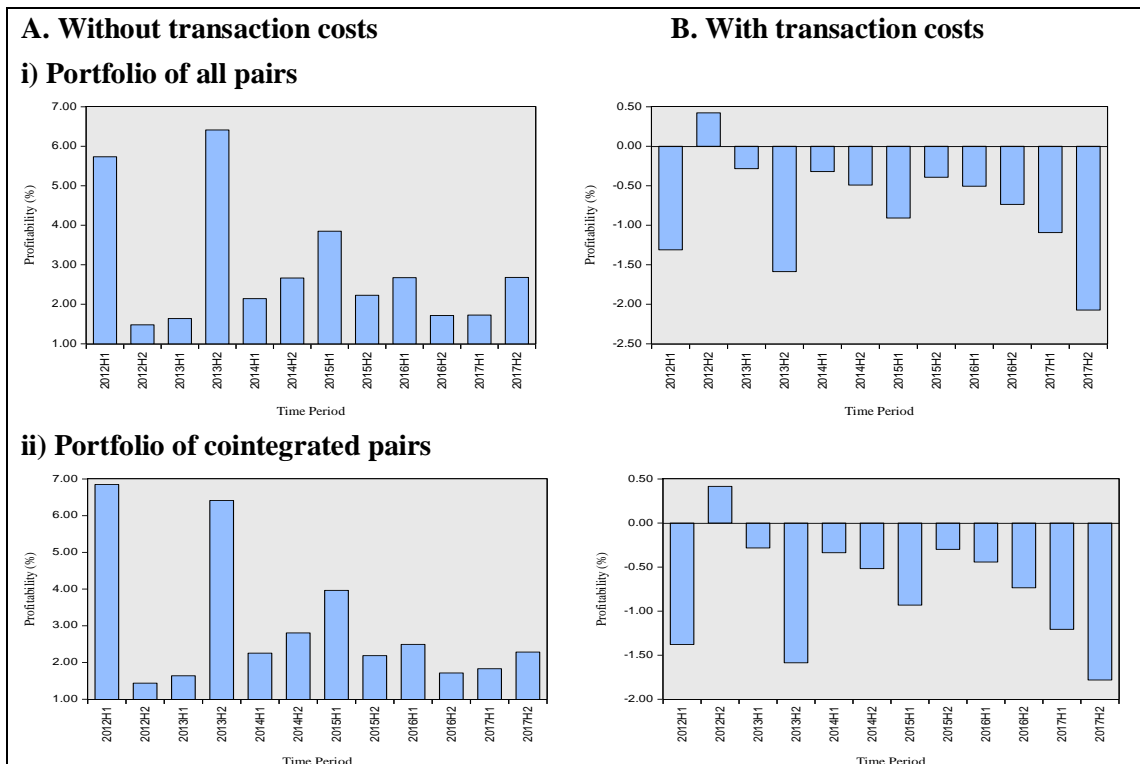


Figure 25: Graphical presentation of six-monthly returns of various portfolios formed using stock spot-future pairs and traded using combined strategy over twelve trading periods

Given the above analysis, it is safe to say that spot-future statistical arbitrage does exist in Indian stock market, but the opportunities are not necessarily profitable. Ergo, hypothesis (*H11*) that there is no spot-future statistical arbitrage present in Indian stock market, is not accepted. On the other hand, we fail to reject the hypothesis (*H12*) that the spot-future statistical arbitrage in Indian stock market is not profitable. These are near riskless opportunities which are mostly profitable without transaction costs but return generated is less than risk-free rate of return. Moreover, once the transaction costs are factored in, the returns have turned negative.

4.3.4 Returns' Attribution of Spot-Future Pairs Trading Strategies

This section deals with the risk characteristics of various pairs trading strategies which have been used to trade portfolios of stock spot-future pairs. The Table 54 below compares six different portfolios formed using stock spot-future pairs and traded using various trading strategies (profit and loss, standard deviation and combined). The purpose is to analyse the portfolios in terms of both risk and return characteristics. Shape ratio and Fama-French (1993) asset pricing model have been used to calculate the risk-adjusted returns and attribute the returns to various risk factors to determine the source of returns, respectively.

As seen from Table 54, almost all the portfolios are generating negative returns after transaction costs. Before including transaction costs, all the portfolios are generating positive returns, though the returns generated are less than risk-free rate of return. Risk-adjusted returns which are calculated using Sharpe ratio are also negative in all the cases, which suggests that pairs trading in portfolios formed from spot-future pairs and traded using various strategies is not profitable and hence not advisable. Some points to note are that trading in stock spot market is studied using various assumptions because naked short-selling is not allowed in inter-day market in Indian stock spot market. Also, the margin requirement and transaction costs are assumed to be higher in stock spot than in stock futures.

Coming to attribution of returns using Fama-French three factor model, it can be observed that there is significant ($p < 0.01$) negative alpha generation (intercept value). It implies investor would not be compensated for taking risk. In line with the literature, the pairs trading strategy is market neutral: the exposure to the market factor is insignificant in all of the cases. Hence, we fail to reject the hypothesis (*H13*) that the returns generated from spot-future statistical arbitrage in Indian stock market cannot be attributed to market risk as per Fama-French three factor model.

The size factor, SMB, is a strategy of going long small-capitalization stocks and short large-cap stocks. Hence, a positive loading on SMB reflects a tendency to buy small-cap stocks, so pairs trading strategy's negative loading reflects a tendency to buy large-cap stocks. The exposure to the size has predictable sign but it is statistically insignificant in all the cases.

Table 54: Stock spot-future portfolios with risk adjusted six-monthly returns and attribution of returns

Portfolio/Trading strategy	Without transaction costs		With transaction costs		Risk adjusted returns				
	AR (%)	SD (%)	AR (%)	SD (%)	Sharpe ratio	Fama-French (1993) Model			
						Intercept	Market	SMB	HML
Profit and loss trading strategy									
All pairs	1.30***	0.44	-0.05	0.46	-5.48	-2.43***	0.00	0.00	0.00
Cointegrated pairs	1.29***	0.45	-0.07	0.47	-5.48	-2.44***	0.00	0.00	-0.01
Standard deviation trading strategy									
All pairs	2.90***	1.63	-0.74***	0.66	-0.50	-0.86	0.01	-0.01	0.00
Cointegrated pairs	2.97***	1.85	-0.73***	0.63	-0.41	-0.84	0.03	-0.01	-0.02
Combined trading strategy									
All pairs	2.91***	1.62	-0.77***	0.67	-0.50	-0.82	0.04	-0.01	-0.02
Cointegrated pairs	2.99***	1.83	-0.76***	0.64	-0.40	-0.82	0.04	-0.01	-0.02

*Note: This table reports the risk-adjusted six-monthly returns and coefficients of Fama-French three factor model of portfolios of stock spot-future pairs which are traded using various strategies. AR, SD, Market, SMB and HML denote six-monthly average return, six-monthly standard deviation, market factor, size factor and value factor respectively. Superscripts ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively.*

Thus the hypothesis (*H14*) that the returns generated from spot-future statistical arbitrage in Indian stock market cannot be attributed to size risk as per Fama-French three factor model is not rejected. The size factor has negative loading because majority of the stocks included in the sample for this study are large cap stocks.

The value factor, HML, which reflects the strategy of buying stocks of high book value to market value while shorting stocks of low book value to market value, has statistically insignificant contribution towards returns generated by various portfolios. Thus, we fail to reject hypothesis (*H15*) that the returns generated from spot-future statistical arbitrage in Indian stock market cannot be attributed to value risk as per Fama-French three factor model.

4.4 Statistical Arbitrage in Commodity Futures

This section deals with statistical arbitrage opportunities in Indian commodity futures market using pairs trading. The commodities listed and traded in futures market are used to form and trade pairs for the study and not the commodities in the spot market because there is a basic difference between a commodity spot market and a commodity future market. Delivery of a commodity is compulsory in the spot market. So it is not feasible to trade using arbitrage opportunities in commodity spot market. Also, spot markets tend to be more limited to geographies, while commodity futures are largely region agnostic.

The pairs of the commodities are formed with and without sector restriction. Each category has been further analysed including and excluding transaction costs. The pairs formation has already been explained in research methodology. Their empirical results are presented in this section. The intent is to examine whether pairs trading generate profits without transaction costs and if they do generate profits, then are these profits robust to transaction costs. It also involves knowing if one portfolio or one trading strategy dominates the others and finally whether pairs trading outperforms the market?

4.4.1 Pairs Trading Without Sector Restriction

This section exhibits empirical results for the pairs trading strategy when pairs are formed without sector restriction. Without sector restriction, a commodity can be paired with any other commodity from the entire sample. Various trading strategies have been deployed to trade different portfolios, that are, profit and loss (stop loss and take profit) approach, standard deviation approach and combined approach.

4.4.1.1 Profit and Loss Approach (Stop Loss and Take Profit)

Under profit and loss trading approach, positions are triggered when log of price ratio series deviates more than two standard deviation from the mean of log of price ratio during formation period in either direction and squared off when returns reach either the stop loss or take profit parameters.

Table 55 shows the average six-monthly returns over the twelve trading periods for the pairs portfolios formed without sector restriction and traded using profit and loss approach. Portfolios are formed using distance method and cointegration method. In distance approach, portfolios of top 5, top 10 and top 20 pairs are formed according to least distance criterion. Cointegration approach involves the portfolio of cointegrating pairs. The pairs are traded according to rules and assumptions stated in Chapter 3. Further returns are reported including and excluding transaction costs.

Table 55: Six-monthly returns of commodity futures' pairs without sector restriction from profit and loss trading approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointe-grated pairs	Distance approach			Cointe-grated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
	Profitability (%)							
2012H1	-0.97	-1.45	22.44	80.60	-4.66	-4.02	19.36	68.17
2012H2	26.55	10.17	19.29	40.20	24.63	8.73	17.41	39.40
2013H1	-44.49	-33.59	0.30	0.00	-49.75	-37.57	-2.77	0.00
2013H2	-22.46	0.09	42.53	118.06	-24.56	-2.09	39.01	110.54
2014H1	-27.48	14.87	7.40	42.22	-30.35	11.43	4.44	36.59
2014H2	26.04	11.08	-23.92	41.36	23.82	8.21	-27.50	38.15
2015H1	28.59	-2.28	9.91	-4.38	24.28	-9.41	2.49	-21.13
2015H2	-8.30	18.81	2.91	12.82	-9.74	17.12	0.80	9.61
2016H1	-7.17	19.24	6.27	25.46	-9.93	14.47	2.31	23.79
2016H2	-9.24	-0.97	42.57	0.00	-11.80	-5.48	38.31	0.00
2017H1	-18.12	17.90	20.47	0.00	-20.02	14.97	18.80	0.00
2017H2	40.85	26.31	-10.66	14.59	39.23	22.52	-16.10	12.01
Average	-1.35	6.68	11.63	30.91	-4.07	3.24	8.05	26.43

Note: This table reports the six-monthly returns (in percent) when pairs are formed using commodity future prices without sector restriction and traded using profit and loss strategy over the twelve trading periods.

It can be seen from Table 55 that portfolio of top 5 pairs formed using distance approach is generating negative returns in majority of the trading periods, both with and without transaction costs. Remaining portfolios, that are, portfolios of top 10 and top 20 pairs formed using distance approach and portfolio of cointegrating pairs, are largely generating positive returns in most of the time periods.

Table 56: Descriptive statistics for six-monthly returns of commodity futures' pairs without sector restriction with profit and loss trading approach

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
Mean (%)	-1.35	6.68	11.63*	30.91***	-4.07	3.24	8.05	26.43**
SD (%)	26.32	15.91	19.49	37.08	26.73	16.33	19.77	35.78
Skewness	0.16	-1.27	0.04	1.20	0.11	-1.25	0.00	1.04
Kurtosis	1.93	4.43	2.55	3.58	2.04	4.22	2.44	3.62
Min (%)	-44.49	-33.59	-23.92	-4.38	-49.75	-37.57	-27.50	-21.13
Max (%)	40.85	26.31	42.57	118.06	39.23	22.52	39.01	110.54
SW Statistic	0.94 ^{NS}	0.87 ^{NS}	0.96 ^{NS}	0.85	0.94 ^{NS}	0.88 ^{NS}	0.95 ^{NS}	0.91 ^{NS}

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using commodity future prices without sector restriction and traded using profit and loss strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

The Table 56 shows the summary statistics for different pairs portfolios formed without sector restriction which are traded using profit and loss strategy. The non-significant Shapiro-Wilk statistic implies the normal distribution of data. The portfolio of cointegrating pairs has six-monthly average return of 30.91% (statistically significant at 5% level) when traded using profit and loss approach without considering the transaction costs. Even after factoring in transaction costs, the portfolio of cointegrating pairs is yielding statistically significant six-monthly average return of 26.43%.

The following Figure 26 shows the graphical representation of six-monthly returns (with and without transaction costs) over all the trading periods for various portfolios formed without sector restriction and traded using profit and loss trading strategy.

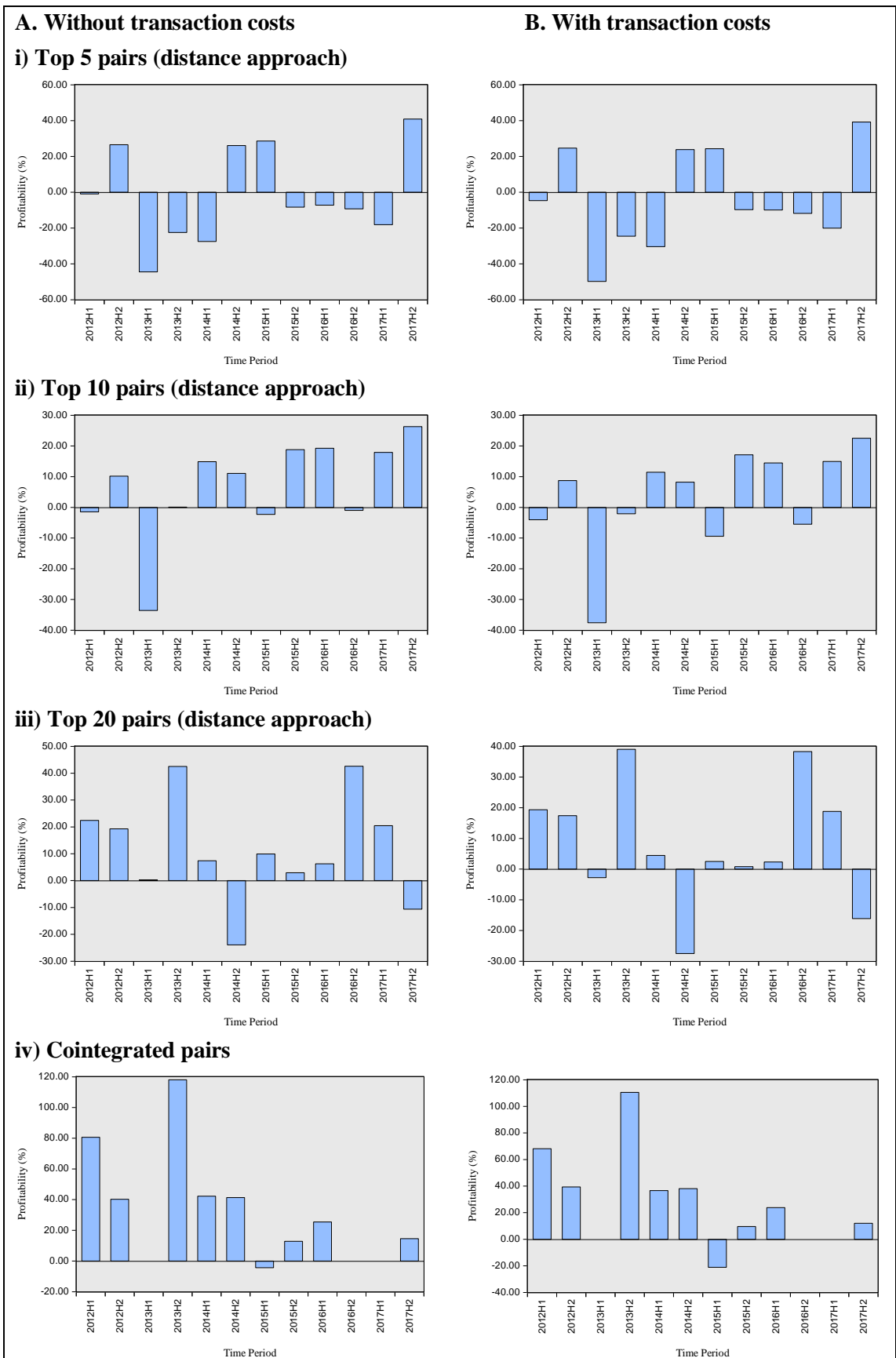


Figure 26: Graphical presentation of six-monthly returns of various portfolios of pairs formed using commodity future prices without sector restriction and traded using profit and loss strategy over twelve trading periods

4.4.1.2 Standard Deviation Approach

Under standard deviation trading approach, positions are triggered when log of price series deviate more than two standard deviation of the mean of log of price ratio during formation period in either direction and squared off when log of price series comes down to one standard deviation of log of price ratio during formation period. Table 57 shows the average six-monthly returns over the twelve trading periods for various pairs portfolios formed without sector restriction and traded using standard deviation approach. Portfolios are formed using distance method and cointegration method.

Table 57: Six-monthly returns of commodity futures' pairs without sector restriction from standard deviation trading approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
	Profitability (%)							
2012H1	0.33	-1.57	15.84	0.92	-1.11	-2.46	14.97	0.52
2012H2	38.38	12.72	25.98	15.29	37.28	11.92	25.07	14.50
2013H1	-36.61	-24.92	-10.88	0.00	-38.03	-26.18	-12.03	0.00
2013H2	-6.17	23.28	33.21	3.71	-7.33	21.80	31.86	2.59
2014H1	-33.54	-10.53	-4.33	6.35	-34.34	-11.57	-5.17	5.53
2014H2	12.30	1.25	-24.34	28.22	11.04	0.15	-25.28	25.81
2015H1	19.62	15.59	5.75	-20.63	18.68	14.47	4.70	-21.34
2015H2	-10.18	44.10	16.72	9.82	-10.98	43.05	15.76	8.21
2016H1	-7.02	12.33	11.65	23.20	-8.03	11.15	10.64	22.34
2016H2	-16.84	0.30	44.31	0.00	-17.47	-0.68	43.01	0.00
2017H1	-15.15	28.60	29.19	0.00	-15.62	27.82	28.60	0.00
2017H2	48.52	29.22	-17.04	9.03	46.58	27.27	-18.81	7.89
Average	-0.53	10.86	10.50	6.33	-1.61	9.73	9.44	5.50

Note: This table reports the six-monthly returns (in percent) when pairs are formed using commodity future prices without sector restriction and traded using standard deviation strategy over the twelve trading periods.

From Table 57, it can be observed that for portfolios of top 10 and top 20 pairs formed using distance approach, returns are mostly consistent through various trading periods, and have performed better than other portfolios, both including and excluding

transaction costs. Six-monthly returns are largely negative for portfolio of top 5 pairs formed using distance approach. The portfolio of cointegrating pairs is generating positive returns in various trading periods with lack of existence of cointegrating pairs in three trading periods.

Table 58: Descriptive statistics for six-monthly returns of commodity futures' pairs without sector restriction with standard deviation trading approach

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
Mean (%)	-0.53	10.86*	10.50	6.33	-1.61	9.73*	9.44	5.50
SD (%)	26.16	19.15	21.29	12.60	25.96	19.10	21.35	12.19
Skewness	0.51	-0.12	-0.15	-0.21	0.49	-0.13	-0.17	-0.32
Kurtosis	2.39	2.47	1.96	3.35	2.38	2.51	1.94	3.50
Min (%)	-36.61	-24.92	-24.34	-20.63	-38.03	-26.18	-25.28	-21.34
Max (%)	48.52	44.10	44.31	28.22	46.58	43.05	43.01	25.81
SW Statistic	0.95 ^{NS}	0.99 ^{NS}	0.97 ^{NS}	0.94 ^{NS}	0.95 ^{NS}	0.99 ^{NS}	0.97 ^{NS}	0.92 ^{NS}

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using commodity future prices without sector restriction and traded using standard deviation strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

Table 58 shows the descriptive statistics of standard deviation trading approach applied to various portfolios formed without sector restriction. The portfolio of the ten best pairs using distance approach has six-monthly average return of 10.86% (statistically significant at 10% level) without considering the transaction costs. However, after considering the transaction costs, the average six-monthly returns are reduced to 9.73%.

The following Figure 27 shows the graphical representation of six-monthly returns (with and without transaction costs) over all the trading periods for various portfolios formed without sector restriction and traded using standard deviation trading strategy.

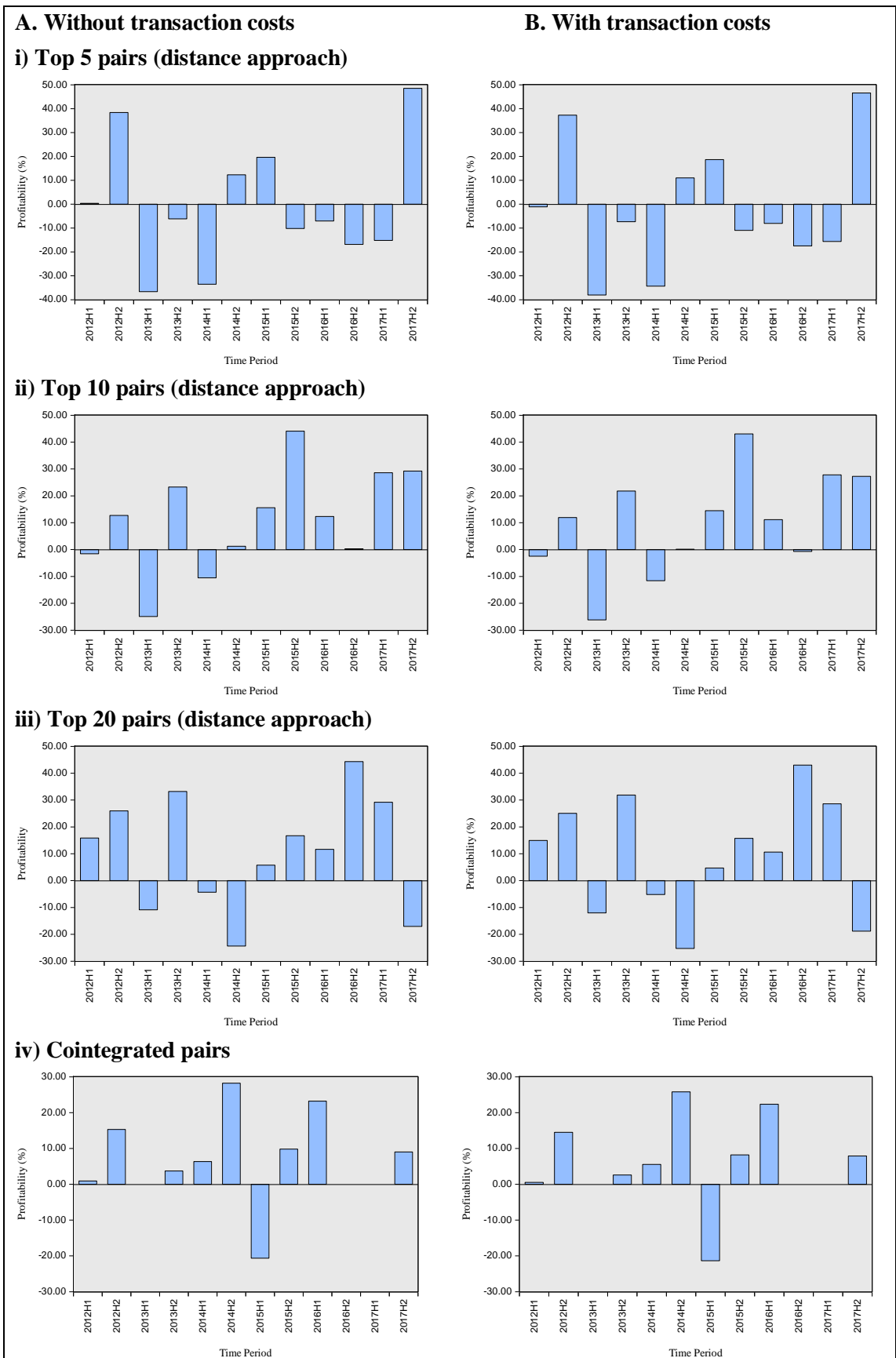


Figure 27: Graphical presentation of six-monthly returns of various portfolios of pairs formed using commodity future prices without sector restriction and traded using standard deviation strategy over twelve trading periods

4.4.1.3 Combined Approach

The combined trading approach combines the characteristics of both profit and loss and standard deviation trading approaches. In this case, positions are triggered when log of price series deviate more than two standard deviation of the mean of log of price ratio during formation period in either direction and squared off when either log of price series comes down to one standard deviation of log of price ratio during formation period, or returns reach any of the SL or TP parameters.

Table 59 shows the average six-monthly returns over the twelve trading periods for various pairs portfolios formed without sector restriction and traded using combined approach.

Table 59: Six-monthly returns of commodity futures' pairs without sector restriction from combined trading approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointe-grated pairs	Distance approach			Cointe-grated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
	Profitability (%)							
2012H1	8.85	3.46	22.85	80.60	4.68	0.65	19.65	68.17
2012H2	21.57	6.12	17.75	15.29	19.65	4.67	15.84	14.50
2013H1	-32.08	-22.77	7.69	0.00	-38.15	-27.23	4.22	0.00
2013H2	-12.52	10.59	45.95	118.06	-14.78	8.17	42.28	110.54
2014H1	-31.69	11.20	4.57	42.22	-34.57	7.67	1.57	36.59
2014H2	26.37	11.82	-23.55	36.63	23.98	8.79	-27.21	33.42
2015H1	22.53	-7.16	7.46	-4.38	18.23	-14.29	0.05	-21.13
2015H2	-10.41	17.76	0.26	27.92	-12.01	15.99	-1.90	24.31
2016H1	-2.63	20.13	6.72	25.46	-5.39	15.37	2.76	23.79
2016H2	-9.24	-0.97	41.00	0.00	-11.80	-5.48	36.74	0.00
2017H1	-18.12	17.64	20.34	0.00	-20.02	14.71	18.67	0.00
2017H2	44.75	28.26	-9.68	5.33	42.49	24.15	-15.29	2.43
Average	0.61	8.01	11.78	28.93	-2.31	4.43	8.12	24.39

Note: This table reports the six-monthly returns (in percent) when pairs are formed using commodity future prices without sector restriction and traded using combined (profit and loss and standard deviation) strategy over the twelve trading periods.

As seen in Table 59, portfolio of cointegrating pairs has performed better than other portfolios. It is profitable both including and excluding transaction costs. The portfolio of top 5 pairs formed using distance approach is generating negative returns in majority of the time periods. The returns are otherwise consistent in portfolios of top 10 and top 20 pairs formed using distance approach and portfolio of cointegrating pairs.

Table 60: Descriptive statistics for six-monthly returns of commodity futures' pairs without sector restriction with combined trading approach

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	Top 20		Top 5	Top 10	Top 20	
Mean (%)	0.61	8.01*	11.78*	28.93**	-2.31	4.43	8.12	24.39**
SD (%)	24.24	13.68	19.56	37.20	24.57	14.32	19.86	35.68
Skewness	0.29	-0.80	0.14	1.33	0.25	-0.89	0.09	1.21
Kurtosis	2.03	3.30	2.65	3.83	2.12	3.14	2.51	3.94
Min (%)	-32.08	-22.77	-23.55	-4.38	-38.15	-27.23	-27.21	-21.13
Max (%)	44.75	28.26	45.95	118.06	42.49	24.15	42.28	110.54
SW Statistic	0.95 ^{NS}	0.95 ^{NS}	0.97 ^{NS}	0.82	0.96 ^{NS}	0.93 ^{NS}	0.97 ^{NS}	0.88 ^{NS}

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using commodity future prices without sector restriction and traded using combined (profit and loss and standard deviation) strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

Table 60 shows the descriptive statistics of combined trading approach applied to various portfolios formed without sector restriction. The portfolio of the cointegrating pairs has average six-monthly return of 28.93% (statistically significant at 5% level). The average six-monthly return increases with the inclusion of more pairs in the portfolio under distance approach, from 0.61% with 5 pairs to 11.78% when a portfolio consists of 20 pairs.

The following Figure 28 shows the graphical representation of six-monthly returns (with and without transaction costs) over all the trading periods for various portfolios formed without sector restriction and traded using combined (profit and loss and standard deviation) trading strategy.

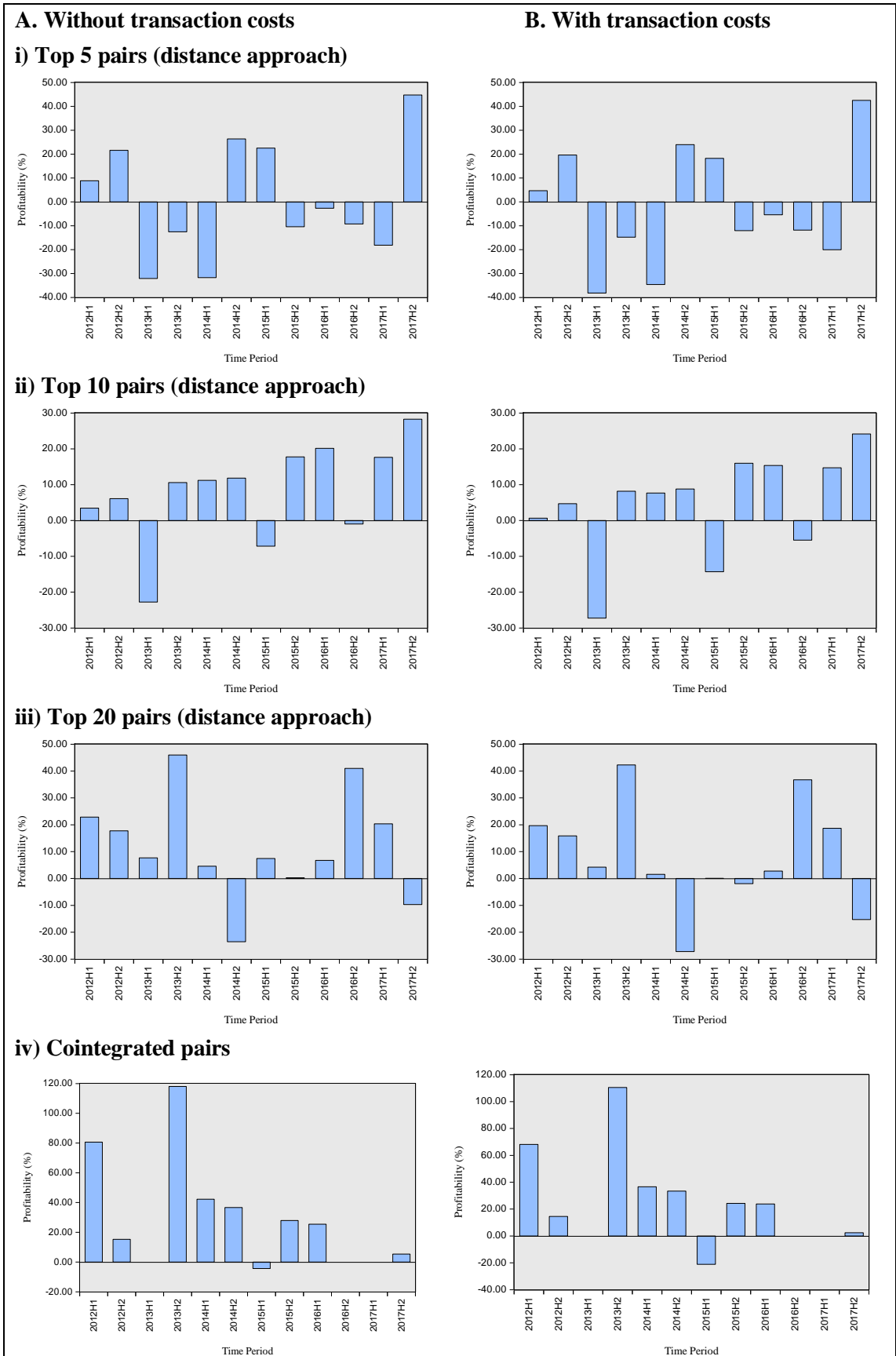


Figure 28: Graphical presentation of six-monthly returns of various portfolios of pairs formed using commodity future prices without sector restriction and traded using combined strategy over twelve trading periods

4.4.2 Pairs Trading With Sector Restriction

In the following section, returns on pairs trading are examined where commodities are matched only within the four sector groupings, viz., Agricultural (Agro) Commodities, Base Metals, Bullion and Energy. With sector restriction, the number of possible pairs are 15. Hence portfolios of top 5 and top 10 pairs are formed from those 15 pairs using least distance criterion. The other two portfolios considered for analysis are portfolios of all 15 pairs and portfolio of cointegrating pairs with sector restriction.

Tables 61 to 66 exhibit the six-monthly returns generated for various trading periods along with summarizing the average six-monthly returns for the pairs portfolios with sector restriction. Different trading strategies have been employed to trade various portfolios, that are, profit and loss (stop loss and take profit) approach, standard deviation approach and combined approach. The pairs are traded according to rules and assumptions stated in Chapter 3. Further returns are reported including and excluding transaction costs.

4.4.2.1 Profit and Loss Approach (Stop Loss and Take Profit)

Table 61 shows the average six-monthly returns over the twelve trading periods for the pairs portfolios formed with sector restriction and traded using profit and loss approach. Portfolios are formed using distance method and cointegration method.

Table 61: Six-monthly returns of commodity futures' pairs with sector restriction from profit and loss trading approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	All pairs		Top 5	Top 10	All pairs	
Profitability (%)								
2012H1	16.06	13.69	28.48	0.00	14.14	12.57	25.75	0.00
2012H2	45.80	24.56	30.93	40.20	44.68	23.35	29.64	40.20
2013H1	-15.34	17.20	19.56	0.00	-16.59	16.01	18.34	0.00
2013H2	-22.46	-8.56	5.05	12.44	-24.56	-10.41	2.53	12.44
2014H1	-4.43	14.92	16.75	193.97	-6.18	11.07	13.00	193.97
2014H2	-11.37	-12.39	18.36	0.00	-13.27	-14.77	15.55	0.00
2015H1	-28.81	8.11	18.12	0.00	-33.15	5.13	15.22	0.00
2015H2	-10.14	-12.96	41.05	-68.40	-12.69	-15.58	37.81	-68.40
2016H1	-7.17	14.56	55.74	25.46	-9.93	12.53	53.05	25.46
2016H2	1.16	16.36	27.00	0.00	-2.55	12.98	23.44	0.00
2017H1	-19.74	-9.87	4.91	0.00	-22.44	-11.22	3.53	0.00
2017H2	40.85	-16.74	-30.19	11.74	39.23	-19.72	-33.21	9.05
Average	-1.30	4.07	19.65	17.95	-3.61	1.83	17.05	17.73

Note: This table reports the six-monthly returns (in percent) when pairs are formed using commodity future prices with sector restriction and traded using profit and loss strategy over the twelve trading periods.

In distance approach, portfolios of top 5 and top 10 are formed according to least distance criterion. Portfolio of all pairs include all possible 15 pairs with sector restriction. Cointegration approach involves the portfolio of cointegrating pairs. Table 61 shows portfolios formed with sector restriction are generating more consistent returns than portfolios formed without sector restriction, though magnitude of returns are higher in portfolios formed without sector restriction. After factoring in transaction costs, portfolio of cointegrating pairs is giving highest six-monthly returns among all portfolios.

Table 62 reports key descriptive statistics for return time series, both before and after trading costs, generated by four different portfolios, as described earlier. It summarizes the results when pairs are formed with the sector restriction and are traded using profit and loss trading approach (with stop loss and take profit parameters). The non-significant Shapiro-Wilk statistic implies the normal distribution of data. The pairs portfolio of all pairs formed using distance approach has positive average six-monthly return of 19.65% (statistically significant at 1%). Even after factoring in transaction costs, the portfolio is giving significant positive average return of 17.05% over a six-month period.

Table 62: Descriptive statistics for six-monthly returns of commodity futures' pairs with sector restriction with profit and loss trading approach

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	All pairs		Top 5	Top 10	All pairs	
Mean (%)	-1.30	4.07	19.65***	17.95	-3.61	1.83	17.05**	17.73
SD (%)	23.87	14.85	21.21	61.05	24.38	15.01	21.20	61.08
Skewness	1.00	-0.20	-0.70	2.00	0.99	-0.18	-0.74	2.01
Kurtosis	2.78	1.37	4.02	7.26	2.81	1.44	4.10	7.27
Min (%)	-28.81	-16.74	-30.19	-68.40	-33.15	-19.72	-33.21	-68.40
Max (%)	45.80	24.56	55.74	193.97	44.68	23.35	53.05	193.97
SW Statistic	0.87 ^{NS}	0.86	0.93 ^{NS}	0.67	0.87 ^{NS}	0.88 ^{NS}	0.93 ^{NS}	0.67

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using commodity future prices with sector restriction and traded using profit and loss strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

The following Figure 29 shows the graphical representation of six-monthly returns (with and without transaction costs) over all the trading periods for various portfolios formed with sector restriction and traded using profit and loss trading strategy.

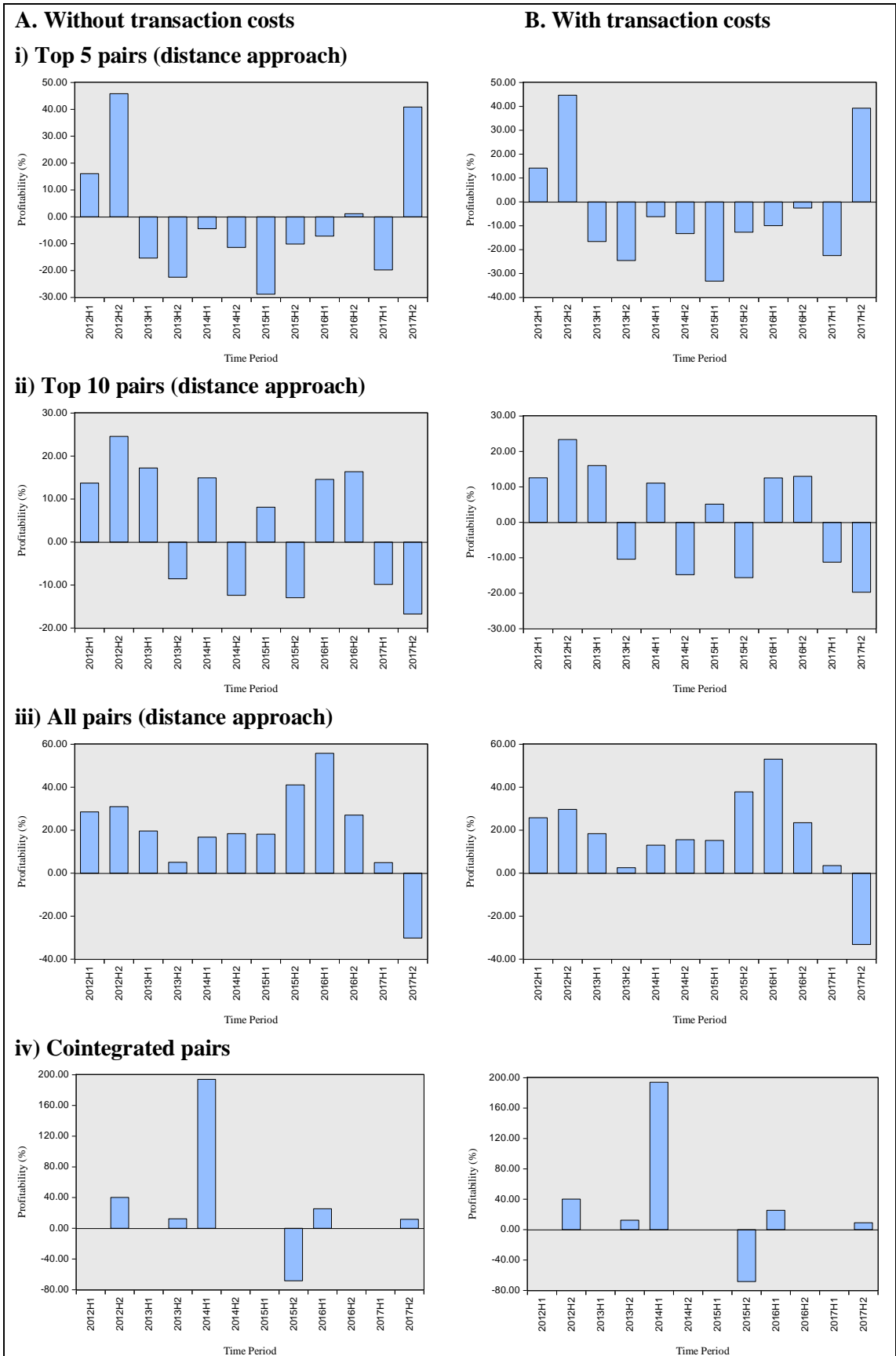


Figure 29: Graphical presentation of six-monthly returns of various portfolios of pairs formed using commodity future prices with sector restriction and traded using profit and loss strategy over twelve trading periods

4.4.2.2 Standard Deviation Approach

Table 63 shows the average six-monthly returns over the twelve trading periods for various pairs portfolios formed from commodity future prices with sector restriction and traded using standard deviation approach. Portfolios are formed using distance method and cointegration method.

Table 63: Six-monthly returns of commodity futures' pairs with sector restriction from standard deviation trading approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	All pairs		Top 5	Top 10	All pairs	
	Profitability (%)							
2012H1	18.90	14.53	43.36	0.00	17.46	13.65	42.53	0.00
2012H2	51.03	24.79	41.63	15.29	50.08	23.83	40.67	14.50
2013H1	6.29	14.23	20.87	0.00	4.71	13.04	19.81	0.00
2013H2	-6.17	4.66	4.25	57.77	-7.33	3.52	3.27	56.06
2014H1	-7.26	-19.03	-5.99	-21.71	-8.37	-20.08	-6.90	-23.36
2014H2	-7.71	-20.26	0.05	0.00	-8.50	-20.89	-0.57	0.00
2015H1	26.32	26.83	41.65	0.00	24.70	25.54	40.42	0.00
2015H2	2.75	-9.49	13.47	-44.79	1.64	-10.52	12.37	-46.41
2016H1	-7.02	15.99	57.01	23.20	-8.03	15.00	55.91	22.34
2016H2	14.16	8.70	2.79	0.00	13.35	7.81	2.02	0.00
2017H1	-13.81	-6.91	14.79	0.00	-14.60	-7.30	14.22	0.00
2017H2	48.52	-6.01	-17.34	16.96	46.58	-7.23	-18.38	15.34
Average	10.50	4.00	18.05	3.89	9.31	3.03	17.11	3.21

Note: This table reports the six-monthly returns (in percent) when pairs are formed using commodity future prices with sector restriction and traded using standard deviation strategy over the twelve trading periods.

It can be seen from Table 63 that all the portfolios are generating positive returns in majority of the trading periods both including and excluding transaction costs. The portfolio of all pairs is generating highest returns among all the portfolios both with and without transaction costs. The portfolio of top 5 pairs formed using distance approach which has been generating negative returns when formed without sector restriction, is now yielding considerably higher positive returns when formed with sector restriction.

Table 64 provides the descriptive statistics when pairs are formed with sector restriction and traded using standard deviation strategy. The standard deviation trading approach is generating statistically significant positive results even after factoring in transaction costs. The returns are positively skewed as well. The pairs portfolio of all pairs formed using distance approach has six-monthly average return of 17.11% after transaction costs (statistically significant at 5%).

Table 64: Descriptive statistics for six-monthly returns of commodity futures' pairs with sector restriction with standard deviation trading approach

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointe-grated pairs	Distance approach			Cointe-grated pairs
	Top 5	Top 10	All pairs		Top 5	Top 10	All pairs	
Mean (%)	10.50	4.00	18.05**	3.89	9.31	3.03	17.11**	3.21
SD (%)	22.00	16.11	23.14	24.67	21.80	16.01	23.07	24.61
Skewness	0.80	-0.14	0.24	0.22	0.81	-0.14	0.23	0.11
Kurtosis	2.37	1.75	1.88	3.93	2.39	1.74	1.89	3.93
Min (%)	-13.81	-20.26	-17.34	-44.79	-14.60	-20.89	-18.38	-46.41
Max (%)	51.03	26.83	57.01	57.77	50.08	25.54	55.91	56.06
SW Statistic	0.87 ^{NS}	0.94 ^{NS}	0.95 ^{NS}	0.90 ^{NS}	0.87 ^{NS}	0.93 ^{NS}	0.95 ^{NS}	0.89 ^{NS}

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using commodity future prices with sector restriction and traded using standard deviation strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

The following Figure 30 shows the graphical representation of six-monthly returns (with and without transaction costs) over all the trading periods for various portfolios formed with sector restriction and traded using standard deviation trading strategy.

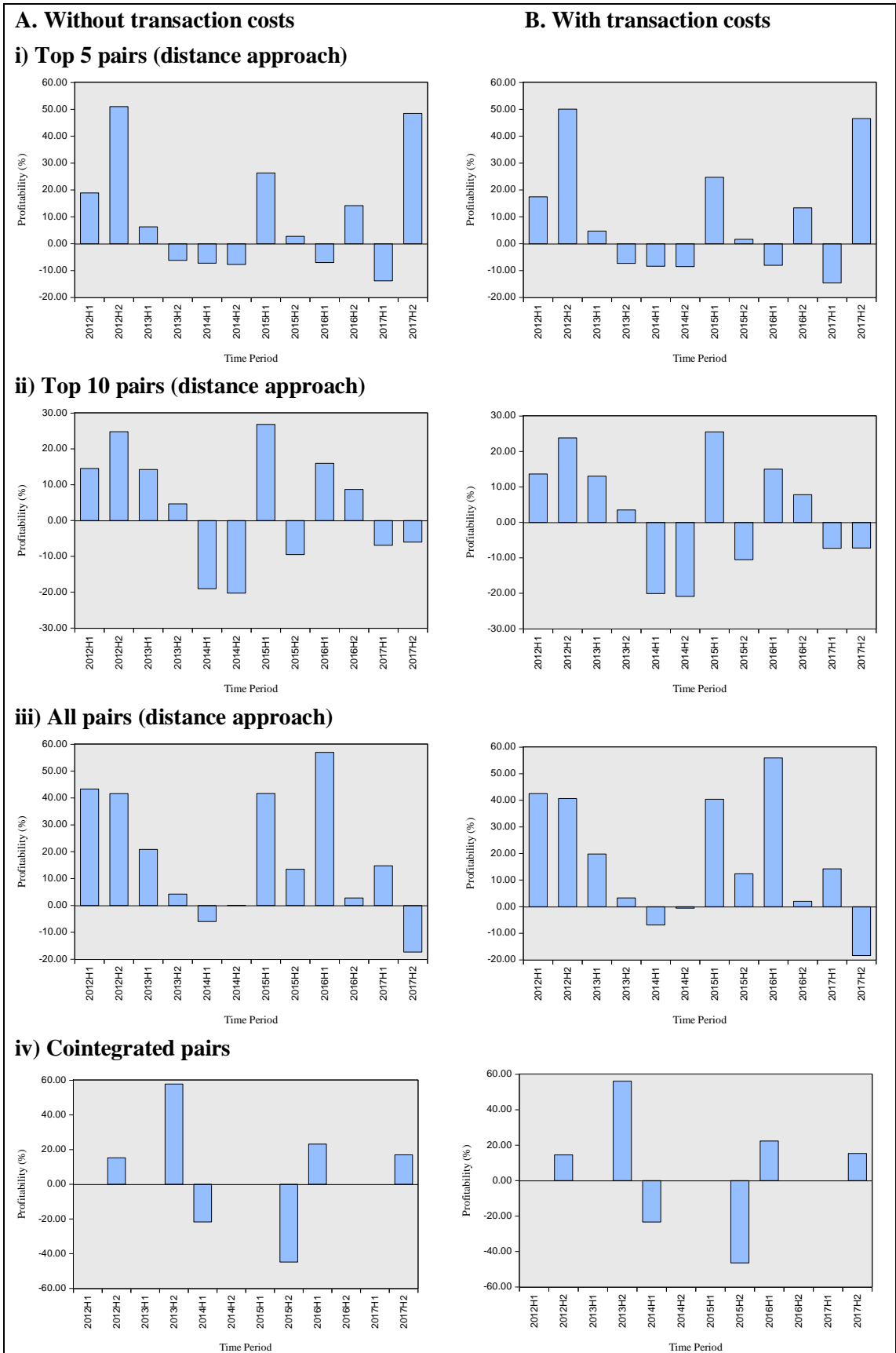


Figure 30: Graphical presentation of six-monthly returns of various portfolios of pairs formed using commodity future prices with sector restriction and traded using standard deviation strategy over twelve trading periods

4.4.2.3 Combined Approach

The average six-monthly returns over the twelve trading periods for various pairs portfolios formed from commodity future prices with sector restriction and traded using combined approach are shown in Table 65. Returns of various portfolios formed using distance method and cointegration approach are computed both including and excluding transaction costs.

Table 65: Six-monthly returns of commodity futures' pairs with sector restriction from combined trading approach over various trading periods

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	All pairs		Top 5	Top 10	All pairs	
	Profitability (%)							
2012H1	25.88	18.02	31.37	0.00	23.48	16.66	28.48	0.00
2012H2	40.82	21.49	31.46	15.29	39.70	20.21	30.07	14.50
2013H1	6.30	29.01	26.60	0.00	4.08	27.25	25.01	0.00
2013H2	-12.52	-1.94	9.47	12.44	-14.78	-3.95	6.84	7.62
2014H1	-10.22	11.22	14.75	193.97	-12.14	7.29	10.95	181.90
2014H2	-10.09	-11.75	18.79	0.00	-12.16	-14.22	15.92	0.00
2015H1	-33.96	9.51	19.05	0.00	-38.30	6.45	16.11	0.00
2015H2	-12.24	-15.48	39.37	-40.98	-14.95	-18.19	36.07	-45.01
2016H1	-2.63	14.18	55.49	25.46	-5.39	12.16	52.80	23.79
2016H2	1.16	15.16	26.20	0.00	-2.55	11.78	22.64	0.00
2017H1	-20.27	-10.13	4.73	0.00	-22.97	-11.48	3.36	0.00
2017H2	44.75	-14.79	-28.89	-3.69	42.49	-18.09	-32.12	-6.90
Average	1.41	5.38	20.70	16.87	-1.12	2.99	18.01	14.66

Note: This table reports the six-monthly returns (in percent) when pairs are formed using commodity future prices with sector restriction and traded using combined (profit and loss and standard deviation) strategy over the twelve trading periods.

As seen in Table 65, portfolio of all pairs and portfolio of cointegrating pairs are generating highest returns among all the portfolios. The portfolio of top 5 pairs is yielding negative returns in majority of the trading periods. The portfolio of top 10 pairs is generating mix of positive and negative returns with net average return less than risk-free rate of return.

Table 66 provides the descriptive statistics when pairs are formed with sector restriction and traded using combined (profit and loss and standard deviation) strategy. All the

portfolios formed under distance approach and cointegration approach and traded using combined approach are generating positive six-monthly returns without transaction costs. The portfolio of all pairs formed with distance approach has six-monthly return of 18.01% (statistically significant at 1%) after transaction costs.

Table 66: Descriptive statistics for six-monthly returns of commodity futures' pairs with sector restriction with combined trading approach

Time Period	Portfolio							
	Without transaction costs				With transaction costs			
	Distance approach			Cointegrated pairs	Distance approach			Cointegrated pairs
	Top 5	Top 10	All pairs		Top 5	Top 10	All pairs	
Mean (%)	1.41	5.38	20.70***	16.87	-1.12	2.99	18.01***	14.66
SD (%)	24.19	15.47	20.75	57.95	24.68	15.70	20.83	55.12
Skewness	0.63	-0.13	-0.81	2.60	0.61	-0.09	-0.84	2.52
Kurtosis	2.37	1.60	4.14	8.76	2.41	1.66	4.21	8.55
Min (%)	-33.96	-15.48	-28.89	-40.98	-38.30	-18.19	-32.12	-45.01
Max (%)	44.75	29.01	55.49	193.97	42.49	27.25	52.80	181.90
SW Statistic	0.91 ^{NS}	0.91 ^{NS}	0.93 ^{NS}	0.56	0.91 ^{NS}	0.93 ^{NS}	0.93 ^{NS}	0.58 ^{NS}

*Note: This table reports the six-monthly returns of various portfolios when pairs are formed using commodity future prices with sector restriction and traded using combined (profit and loss and standard deviation) strategy. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.*

The Figure 31 shows the graphical representation of six-monthly returns (with and without transaction costs) over all the trading periods for various portfolios formed with sector restriction and traded using combined (profit and loss and standard deviation) trading strategy.

The pairs trading strategy is more profitable when pairs are formed with the sector restriction in case of distance approach. The portfolios of cointegrating pairs and of top 10 and all pairs under distance approach have sufficient returns that even after factoring in transaction costs, they remain fairly profitable. Portfolios formed using cointegration approach have given adequate positive average returns including transaction costs (statistically significant), both when pairs are formed without sector restriction and with sector restriction, and traded using various approaches. The average annualized return is 71.37% excluding transaction costs when portfolio is composed of cointegrating pairs formed without sector restriction. Even after including transaction costs, returns can rise up to 59.85% on annualized basis (statistically significant at 5%). The returns are superior to the average annualized index return of 0.51%.

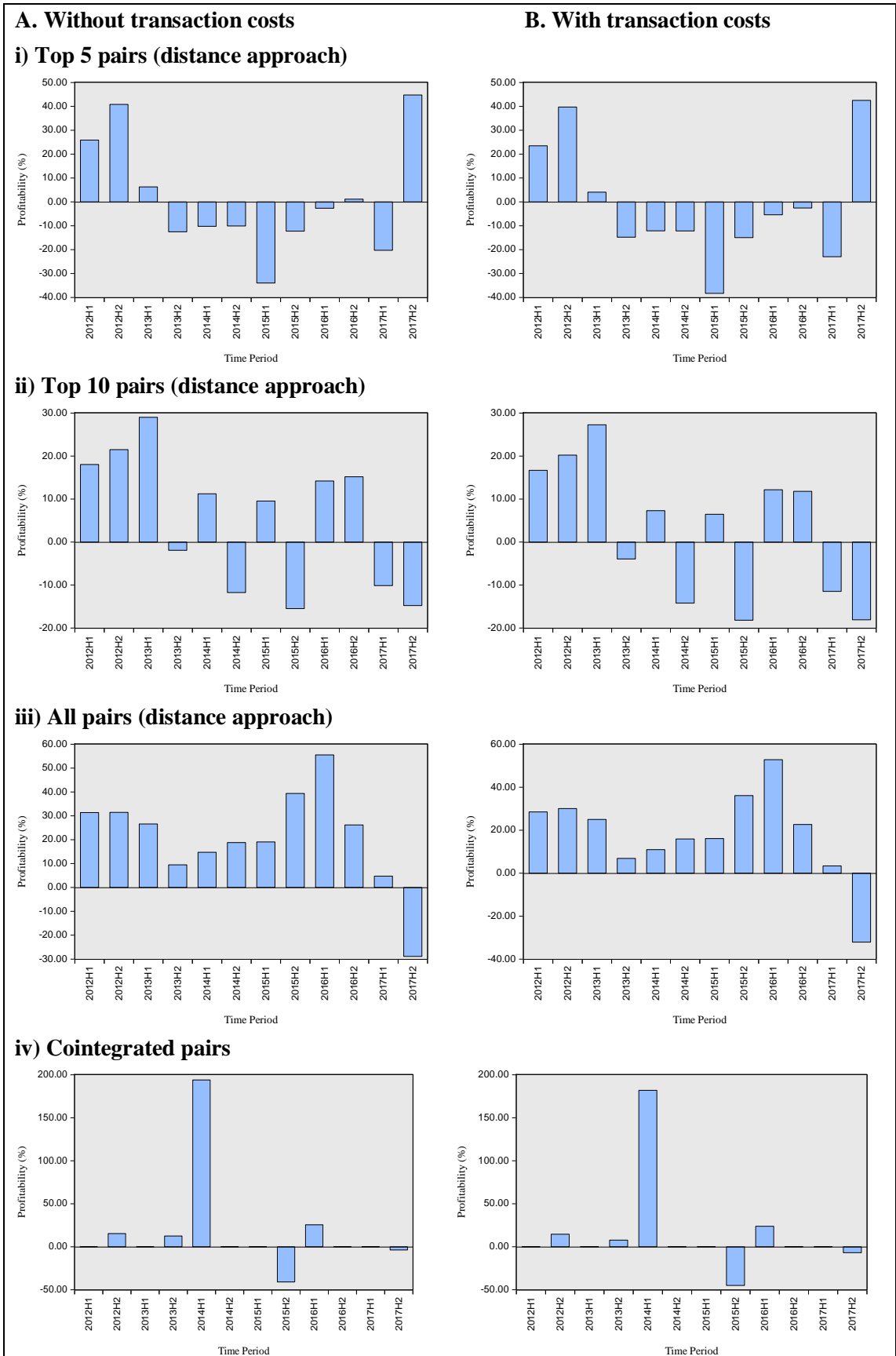


Figure 31: Graphical presentation of six-monthly returns of various portfolios of pairs formed using commodity future prices with sector restriction and traded using combined strategy over twelve trading periods

The results of presented in this section verify the profitability of different pairs selection and pairs trading techniques for the Indian commodity futures market. Ergo, in light of the above evidence, the null hypotheses (*H16 and H17*) that there are no statistical arbitrage opportunities present in Indian commodity futures market and the statistical arbitrage opportunities in Indian commodity futures market are not profitable, respectively, are not accepted. We fail to accept hypotheses (*H16 and H17*) and therefore it can be established that statistical arbitrage opportunities exist in Indian commodity futures market and that they are profitable.

4.4.3 Returns' Attribution of Pairs Trading Strategies (Risk Characteristics of Pairs Trading)

In this section, an attempt has been made to choose the trading strategy that is most profitable for the investor with least risk involved. Sharpe ratio has been used to calculate risk-adjusted returns. To explore the value added by the strategy, single index model has been applied. The Table 67 below presents the risk-adjusted returns for all the portfolios formed without and with sector restriction respectively.

As seen in Table 67, the portfolio of cointegrating pairs formed without sector restriction and traded using profit and loss approach has generated highest statistically significant returns, both excluding and including transaction costs (average six-monthly return of 30.91% and 26.43% respectively). It also has highest Sharpe ratio among all the portfolios formed without sector restriction. The significant intercept value (alpha) of 27.73% signifies the value added by the strategy over and above the index return (average six-monthly return of 0.26%).

However, after considering standard deviation and Sharpe ratio, the pairs trading strategy is more profitable (risk-adjusted returns) when pairs are formed with the sector restriction. The portfolios of pairs under distance approach have sufficient returns that even after factoring in transaction costs, they remain fairly profitable (statistically significantly average six-monthly return of 18.01% at 1% level of significance). The strategy is generating significant positive risk-adjusted alpha over and above the market risk, which implies that the returns are because of the strategy itself.

In line with the literature, the pairs trading strategy is market neutral: the exposure to the market factor is insignificant in almost all the cases. Hence, we fail to reject the hypothesis (*H18*) that the returns generated from statistical arbitrage opportunities in Indian commodity futures market cannot be attributed to market risk as per Single Index model.

Table 67: Commodity futures' portfolios with risk adjusted six-monthly returns and attribution of returns

Portfolio/ Trading strategy		Without transaction costs		With transaction costs		Risk adjusted returns		
						Sharpe ratio	Single Index Model	
		AR (%)	SD (%)	AR (%)	SD (%)		Intercept	Market
Without sector restriction								
Profit and loss trading strategy								
Distance method	Top 5 pairs	-1.35	26.32	-4.07	26.73	-0.19	-4.54	0.15
	Top 10 pairs	6.68	15.91	3.24	16.33	0.19	3.57	0.18
	Top 20 pairs	11.63*	19.49	8.05	19.77	0.41	9.69	0.51
Cointegrated pairs		30.91**	37.08	26.43**	35.78	0.73	27.73**	0.16
Standard deviation trading strategy								
Distance method	Top 5 pairs	-0.53	26.16	-1.61	25.96	-0.16	-2.65	0.46
	Top 10 pairs	10.86*	19.15	9.73*	19.10	0.37	7.49	0.10
	Top 20 pairs	10.50	21.29	9.44	21.35	0.32	8.09	0.38
Cointegrated pairs		6.33	12.60	5.50	12.19	0.21	2.32	-0.08
Combined trading strategy								
Distance method	Top 5 pairs	0.61	24.24	-2.31	24.57	-0.13	-2.26	0.24
	Top 10 pairs	8.01*	13.68	4.43	14.32	0.31	5.01	0.21
	Top 20 pairs	11.78*	19.56	8.12	19.86	0.41	9.92	0.54
Cointegrated pairs		28.93**	37.20	24.39**	35.68	0.68	25.05*	-0.04

Contd....

Portfolio/ Trading strategy		Without transaction costs		With transaction costs		Risk adjusted returns		
		AR (%)	SD (%)	AR (%)	SD (%)	Sharpe ratio	Single Index Model	
							Intercept	Market
With sector restriction								
Profit and loss trading strategy								
Distance method	Top 5 pairs	-1.30	23.87	-3.61	24.38	-0.21	-2.95	0.60
	Top 10 pairs	4.07	14.85	1.83	15.01	0.02	1.53	0.34
All pairs		19.65***	21.21	17.05**	21.20	0.75	15.25**	-0.19
Cointegrated pairs		17.95	61.05	17.73	61.08	0.23	17.99	1.08
Standard deviation trading strategy								
Distance method	Top 5 pairs	10.50	22.00	9.31	21.80	0.31	8.84	0.60
	Top 10 pairs	4.00	16.11	3.03	16.01	0.02	2.32	0.59
All pairs		18.05**	23.14	17.11**	23.07	0.62	15.46*	0.33
Cointegrated pairs		3.89	24.67	3.21	24.61	0.01	4.12	1.14**
Combined trading strategy								
Distance method	Top 5 pairs	1.41	24.19	-1.12	24.68	-0.10	-0.02	0.66
	Top 10 pairs	5.38	15.47	2.99	15.70	0.11	2.89	0.36
All pairs		20.70***	20.75	18.01***	20.83	0.82	16.36**	-0.18
Cointegrated pairs		16.87	57.95	14.66	55.12	0.23	15.40	0.65

*Note: This table reports the risk-adjusted six-monthly returns and coefficients of Single Index model of portfolios of commodity futures formed both with and without sector restriction. AR, SD and Index denote six-monthly average return, six-monthly standard deviation and market factor respectively. Superscripts ***, ** and * represent statistical significance at 1, 5 and 10 percent levels, respectively.*

4.5 Statistical Arbitrage in Currencies Market

In the realm of currency trading in India, only currency pairs that are benchmarked against INR can be traded. Also, foreign currency cannot be traded from India. So, RBI allows investors to trade in the following INR currency pairs: USD/INR, EUR/INR, GBP/INR and JPY/INR. Hence there are total six possible pairs for the purpose of pairs trading in currencies, that are, USD/INR – EUR/INR, USD/INR – GBP/INR, USD/INR – JPY/INR, EUR/INR – GBP/INR, EUR/INR – JPY/INR and GBP/INR – JPY/INR. Henceforth, only one portfolio (of all six possible pairs) is traded under different scenarios using various trading strategies. The portfolio of currency pairs is traded using profit and loss approach, standard deviation approach and combined approach.

Under profit and loss approach, the trade is entered when z-score for the pair crosses the threshold limits, which are set at +2 or –2. The trade is exited when returns reach any of pre-defined stop loss or take profit parameters. Under standard deviation approach, threshold limits on z-score for entering the trade are +2 or -2 and for exiting the trade are +1 or -1. Under combined approach, which is a combination of profit and loss (stop loss and take profit) and standard deviation trading strategies, threshold limits on z-score for entering the trade are +2 or -2 and for exiting the trade the limits are +1 or -1 on z-score or returns hitting the stop loss or take profit limits.

The returns are computed both including and excluding transaction costs. The trading assumptions and guidelines are stated in Chapter 3. The empirical results are presented under three scenarios, viz., futures market, spot market and spot-future statistical arbitrage. An attempt has been made to check whether statistical arbitrage opportunities exist under different scenarios and if they exist, whether they are profitable.

4.5.1 Statistical Arbitrage in Currencies Futures

In the following section, returns over various trading periods and its summary statistics are provided when portfolio of currency pairs is traded using currency future prices. Three different trading strategies have been deployed to trade the portfolio of currency pairs. Currency futures are traded on platforms offered by exchanges like the NSE (National Stock Exchange of India), BSE (formerly, Bombay Stock Exchange), MSE (Metropolitan Stock Exchange), USE (United Stock Exchange of India). All possible pairs are traded using currency future prices. The Table 68 and Table 69 report the average six-monthly returns over various trading periods and key descriptive statistics respectively, before and after transaction costs when portfolio is traded using currency future prices.

It can be seen from Table 68 that portfolio of currency pairs when traded using future prices is generating positive returns in only half of the trading periods. The negative returns in other half of the trading periods are larger than positive returns thus leading to overall negative returns. Table 69 reports key descriptive statistics for return time series, both before and after trading costs, generated by the portfolio of currency pairs.

Table 68: Six-monthly returns of currency futures' pairs over various trading periods

Time Period	Trading Strategy					
	Without transaction costs			With transaction costs		
	P&L	Standard deviation	Combined	P&L	Standard deviation	Combined
	Profitability (%)					
1	13.96	23.75	24.35	12.08	21.89	21.96
2	37.54	20.30	20.68	35.93	18.96	19.07
3	-94.06	-96.03	-88.54	-98.10	-97.92	-92.83
4	-8.64	-26.08	-26.37	-10.25	-27.41	-27.97
5	5.28	12.95	12.95	3.95	11.36	11.36
6	-69.36	-70.49	-69.36	-71.49	-71.81	-71.49
7	-53.76	-45.73	-42.95	-57.76	-47.59	-47.21
8	45.37	30.66	30.66	44.83	30.11	30.11
9	-211.13	-187.95	-178.84	-216.22	-189.83	-184.19
10	27.89	27.84	22.46	24.72	26.28	19.30
11	27.72	11.36	11.36	27.45	11.10	11.10
12	-29.48	-15.50	-16.01	-31.35	-17.10	-18.15
Average	-25.72	-26.24	-24.97	-28.02	-27.66	-27.41

Note: This table reports the six-monthly returns (in percent) when pairs are formed and traded using currency future prices under different trading strategies (profit and loss, standard deviation and combined) over the twelve trading periods.

Table 69: Descriptive statistics for six-monthly returns of currency futures' pairs traded using different strategies

Statistics	Trading Strategy					
	Without transaction costs			With transaction costs		
	P&L	Standard deviation	Combined	P&L	Standard deviation	Combined
Mean (%)	-25.72	-26.24	-24.97	-28.02	-27.66	-27.41
SD (%)	73.46	65.54	62.31	74.66	65.78	63.5
Skewness	-1.38	-1.34	-1.33	-1.38	-1.34	-1.33
Kurtosis	4.32	4.01	4.01	4.31	4.00	4.01
Min (%)	-211.13	-187.95	-178.84	-216.22	-189.83	-184.19
Max (%)	45.37	30.66	30.66	44.83	30.11	30.11
SW Statistic	0.85***	0.83***	0.83***	0.85***	0.83***	0.83***

Note: This table reports the six-monthly returns of currency pairs' portfolio when pairs are traded using currency future prices under various trading strategies. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.

From Table 69, it can be seen that six-monthly average returns are negative, though insignificant. Shapiro-Wilk test statistic is statistically significant in all cases, which implies non-normal distribution of returns. Returns are negatively skewed as well. The following Figure 32 shows graphical representation of returns after transaction costs over various trading periods and traded using different strategies.

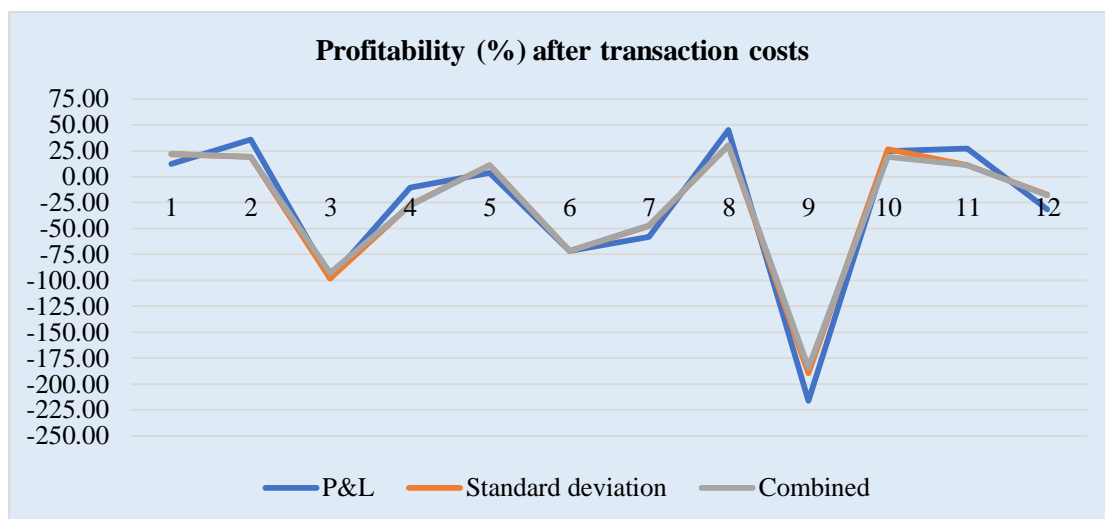


Figure 32: Graphical presentation of six-monthly returns of currency futures’ pairs over twelve trading periods and traded using different strategies

Given the above statistics, it can be established that though statistical arbitrage opportunities are present in Indian currency futures market, it is not profitable. Ergo, hypothesis (*H19*) that there are no statistical arbitrage opportunities present in Indian currency futures market, is not accepted. On the other hand, we fail to reject the hypothesis (*H20*) that the statistical arbitrage opportunities in Indian currency futures market are not profitable.

4.5.2 Statistical Arbitrage in Currencies Spot

In the following section, returns over various trading periods and its summary statistics are provided when portfolio of currency pairs is traded using currency spot prices. Till recently, it wasn’t possible to trade in currency spot market in India but in August 2019, the Clearing Corporation of India Ltd (CCIL) launched a centralised electronic forex trading platform (FX-Retail) for individual and small and medium enterprise customers. The facility is currently available only for USD/INR pair, but more currencies are expected to be added gradually. The study is done in currency spot market to provide the currency trader an idea about pairs trading when eventually all the currency pairs would be allowed to trade in the spot market. The Table 70 and Table 71 report the average six-monthly returns over various trading periods and key descriptive statistics respectively, before and after transaction costs when portfolio of currency pairs is traded using currency spot prices.

Table 70: Six-monthly returns of currency spot pairs over various trading periods

Time Period	Trading Strategy					
	Without transaction costs			With transaction costs		
	P&L	Standard deviation	Combined	P&L	Standard deviation	Combined
	Profitability (%)					
1	0.54	0.82	0.83	0.52	0.80	0.80
2	0.73	0.26	0.29	0.71	0.24	0.26
3	-2.29	-2.39	-2.19	-2.34	-2.41	-2.24
4	-0.20	-0.65	-0.68	-0.22	-0.67	-0.70
5	-0.01	0.25	0.25	-0.03	0.23	0.23
6	-1.74	-1.87	-1.74	-1.76	-1.88	-1.76
7	-1.39	-0.94	-0.92	-1.44	-0.96	-0.96
8	1.15	0.89	0.89	1.14	0.88	0.88
9	-5.32	-5.11	-4.71	-5.38	-5.13	-4.78
10	1.32	1.13	1.20	1.29	1.11	1.17
11	0.94	0.51	0.51	0.93	0.51	0.51
12	-0.90	-0.73	-0.77	-0.93	-0.75	-0.79
Average	-0.60	-0.65	-0.59	-0.63	-0.67	-0.61

Note: This table reports the six-monthly returns (in percent) when pairs are formed and traded using currency spot prices under different trading strategies (profit and loss, standard deviation and combined) over the twelve trading periods.

Table 71: Descriptive statistics for six-monthly returns of currency spot pairs traded using different strategies

Statistics	Trading Strategy					
	Without transaction costs			With transaction costs		
	P&L	Standard deviation	Combined	P&L	Standard deviation	Combined
Mean (%)	-0.60	-0.65	-0.59	-0.63	-0.67	-0.62
SD (%)	1.90	1.79	1.68	1.92	1.79	1.70
Skewness	-1.27	-1.33	-1.23	-1.27	-1.33	-1.24
Kurtosis	4.09	4.17	3.96	4.08	4.17	3.98
Min (%)	-5.32	-5.11	-4.71	-5.38	-5.13	-4.78
Max (%)	1.32	1.13	1.20	1.29	1.11	1.17
SW Statistic	0.87*	0.86**	0.88*	0.87*	0.86**	0.87*

Note: This table reports the six-monthly returns of currency pairs' portfolio when pairs are traded using currency spot prices under various trading strategies. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.

It can be seen from Table 70 that portfolio of currency pairs when traded using spot prices is generating positive returns in only half of the trading periods. The negative returns in other half of the trading periods are larger than the positive returns, thus leading to overall negative returns, though the magnitude of negative returns in this case is considerably less than when portfolio is traded using currency future prices.

Table 71 reports key descriptive statistics for return time series, both before and after trading costs, generated by the portfolio of currency pairs when traded using currency spot prices. From Table 71, it can be seen that six-monthly average returns are negative both before and after transaction costs, though statistically insignificant. Shapiro-Wilk test statistic is statistically significant in all cases, which implies non-normal distribution of returns. Returns are negatively skewed as well. The following Figure 33 shows graphical representation of returns after transaction costs over various trading periods and traded using different strategies.

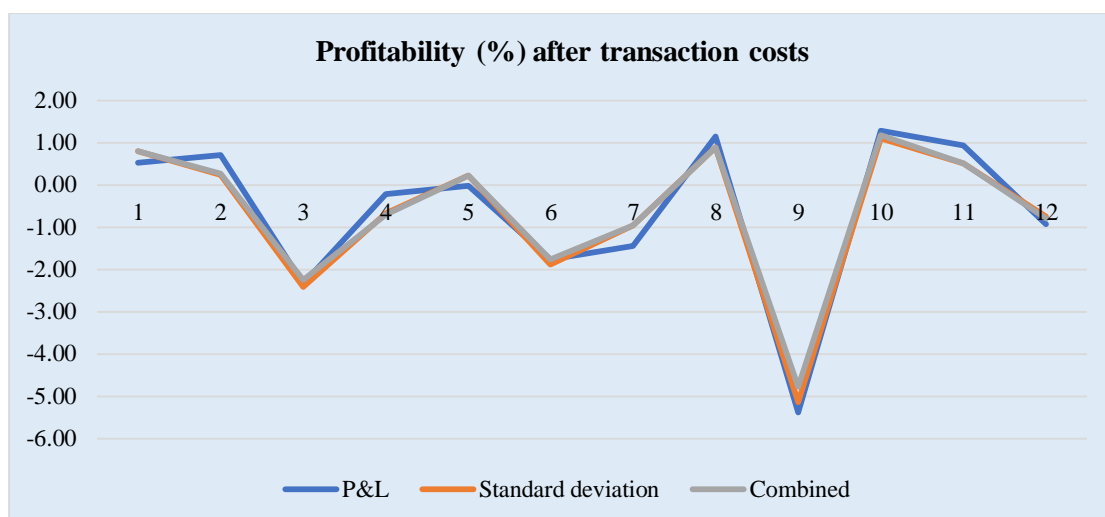


Figure 33: Graphical presentation of six-monthly returns of currency spot pairs over twelve trading periods and traded using different strategies

Given the above statistics, it can be established that though statistical arbitrage opportunities are present in Indian currency spot market, it is not profitable. Ergo, hypothesis (*H21*) that there are no statistical arbitrage opportunities present in Indian currency spot market, is not accepted. On the other hand, we fail to reject the hypothesis (*H22*) that the statistical arbitrage opportunities in Indian currency spot market are not profitable.

4.5.3 Spot-Future Statistical Arbitrage in Indian Currencies Market

Under spot-future statistical arbitrage, a pair is identified as a currency pair in its respective spot market and future market. It is done for every currency pair in the sample. The Table 72 and Table 73 report the average six-monthly returns over various trading periods and key descriptive statistics respectively, before and after transaction costs when portfolio of currency pairs is traded using currency spot and future prices simultaneously to discover whether spot-future statistical arbitrage exist in Indian currency market.

Table 72: Six-monthly returns of currency spot-future pairs over various trading periods

Time Period	Trading Strategy					
	Without transaction costs			With transaction costs		
	P&L	Standard deviation	Combined	P&L	Standard deviation	Combined
	Profitability (%)					
1	1.04	3.97	3.97	0.96	3.61	3.61
2	0.61	2.08	2.08	0.54	1.88	1.88
3	0.7	11.9	11.9	0.63	11.15	11.15
4	0.73	9.94	9.94	0.66	9.19	9.19
5	0.68	1.01	1.01	0.65	0.95	0.95
6	0.7	1.76	1.76	0.65	1.61	1.61
7	0.64	11.21	11.21	0.57	10.41	10.41
8	0.8	5.61	5.61	0.73	5.13	5.13
9	1.45	6.82	6.82	1.38	6.27	6.27
10	0.92	6.21	6.21	0.85	5.8	5.8
11	0.99	3.45	3.45	0.92	3.2	3.2
12	0.71	2.49	2.49	0.66	2.3	2.3
Average	0.83	5.54	5.54	0.77	5.13	5.13

Note: This table reports the six-monthly returns (in percent) when pairs are formed and traded using currency prices in their respective spot and future market under different trading strategies (profit and loss, standard deviation and combined) over the twelve trading periods.

Table 73: Descriptive statistics for six-monthly returns of currency spot-future pairs traded using different strategies

Statistics	Trading Strategy					
	Without transaction costs			With transaction costs		
	P&L	Standard deviation	Combined	P&L	Standard deviation	Combined
Mean (%)	0.83***	5.54***	5.54***	0.77***	5.13***	5.13***
SD (%)	0.24	3.78	3.78	0.23	3.53	3.53
Skewness	1.55	0.53	0.53	1.58	0.54	0.54
Kurtosis	4.70	1.91	1.91	4.89	1.94	1.94
Min (%)	0.61	1.01	1.01	0.54	0.95	0.95
Max (%)	1.45	11.90	11.90	1.38	11.15	11.15
SW Statistic	0.80***	0.91 ^{NS}	0.91 ^{NS}	0.80***	0.91 ^{NS}	0.91 ^{NS}

Note: This table reports the six-monthly returns of currency pairs' portfolio when pairs are traded using currency prices in their respective spot and future market under various trading strategies. SD, min, max denote standard deviation, minimum and maximum return. SW statistic represents Shapiro-Wilk test statistic to check the normality of returns. Superscripts NS, ***, ** and * represent non-significant and statistical significance at 1, 5 and 10 percent levels, respectively.

It can be seen from Table 72 that portfolio of currency pairs when traded using spot-future prices is generating positive returns in all of the trading periods. It is near riskless arbitrage scenario. Returns are considerably higher when traded using standard deviation and combined approaches than traded using profit and loss approach. Table 73 reports key descriptive statistics for return time series, both before and after trading costs, generated by the portfolio of currency pairs when traded using currency spot and future prices simultaneously.

From Table 73, it can be seen that six-monthly average returns are positive and statistically significant ($p < 0.01$) in all scenarios both before and after transaction costs. Non-significant Shapiro-Wilk test statistic implies normal distribution of returns. The portfolio of currency pairs is generating statistically significant six-monthly average return of 5.13% after transaction costs when traded using combined approach. Returns are positively skewed as well. The following Figure 34 shows graphical representation of returns after transaction costs over various trading periods and traded using different strategies.

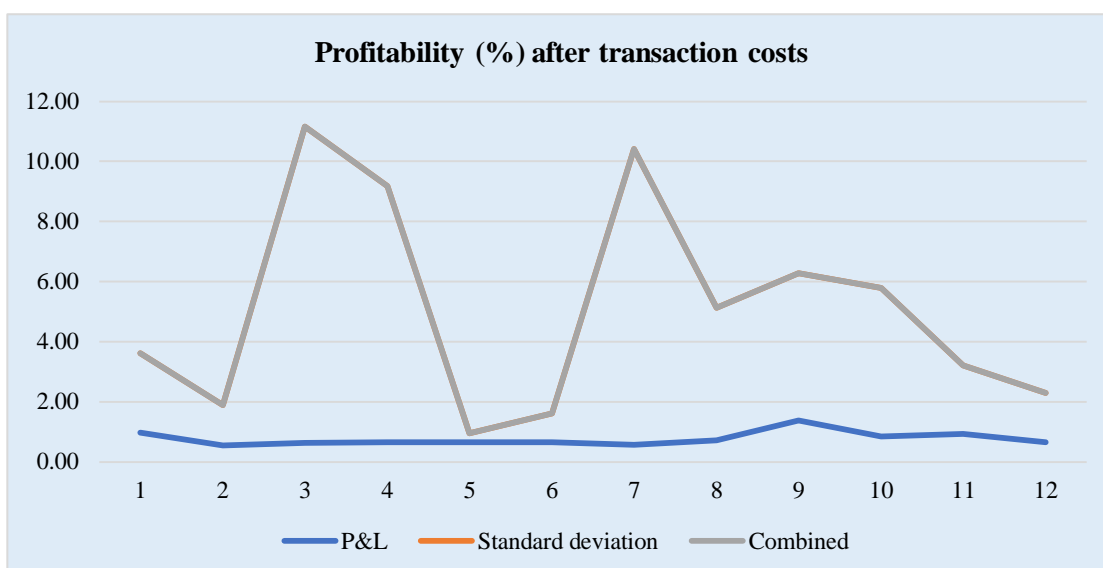


Figure 34: Graphical presentation of six-monthly returns of currency spot-future pairs over twelve trading periods and traded using different strategies

The portfolio of currency pairs is generating annualized return of 10.52% when traded using combined (profit and loss and standard deviation) approach. Ergo, in view of the above statistics and evidence, the null hypotheses (*H23 and H24*) that there is no spot-future statistical arbitrage present in Indian currency market and the spot-future statistical arbitrage in Indian currency market is not profitable, respectively, are not accepted. We fail to accept hypotheses (*H23 and H24*) and therefore it can be established that spot-future statistical arbitrage exists in Indian currency market and that they are profitable.

CHAPTER V

SUMMARY

This chapter summarizes the present study. It discusses the findings, implications and limitations of the study. It concludes by offering some suggestions and directions for future research.

In most basic terms, arbitrage refers to a trade opportunity which entails exploiting an inefficiency in the securities market by simultaneously buying and selling a security for a profit (Ehrman 2006). It is an opportunity of making a profit in securities market without risk and without net investment of capital (Delbean and Schachermayer 2006). These opportunities in the present age of information era seems farfetched, but in the past, such situations have the huge potential to be capitalized by a select group of individuals with vast resources. At present, however, with limitless power of computing, simple arbitrage has almost become extinct.

Even though a few market inefficiencies still exist, most of the arbitrage in the present is done on the basis of anticipated or implied or perceived pricing flaws than the real ones. The pricing flaws occur not because of the information failure, but these are based on individual's perception that relation between two securities has diverged from its past average (norm) in a statistically significant manner. Statistical arbitrage represents statistically significant deviations from historically identified average price relationships. It is taking counteracting positions in securities that are historically or mathematically associated, but taking these positions at times when their inter-relationship has been temporarily askewed. Over time, these relationships fluctuate around an average, moving away and then back to a mathematically determined midpoint.

The concept of statistical arbitrage forms the prerequisite to understand pairs trading because it is considered essentially as the same thing or categorised as a form of pairs trading. The foundation of pairs trading is based on the principle of prices moving/converging to the expected values. Ehrman (2006) defined pairs trading as, "a nondirectional, relative-value investment strategy that seeks to identify two companies with similar characteristics whose equity securities are currently trading at a price relationship that is outside their historical trading range. This investment strategy entails buying the undervalued security while short-selling the overvalued security, thereby maintaining market neutrality". Thus, it is fundamentally a market neutral strategy, which obtains its returns from the inter-relation between the performance of its long position and short position. Basically, the performance of the strategy is governed by the relative performance and not by the absolute performance of the securities involved.

India is a strong emerging economy. Huge investment and trading activities from all over the world are directed to Indian securities market. Global hedge funds are now

prioritizing Indian securities market for their emerging market investments. Many strategies and algorithms are now implemented and tested in Indian securities market and statistical arbitrage has been a profitable quantitative strategy. There are many platforms available in India where one can trade using statistical arbitrage techniques. These platforms do not provide any documented evidence of profitability. Thus, this research aimed at studying the statistical arbitrage opportunities that are present in Indian securities market through pairs trading and how profitable they are for the investors. The following objectives were set to understand whether statistical arbitrage opportunities exist in India, so as to gather a more practical view of the markets as against theories that specify market efficiency. Further, the objectives were framed to get to know to what extent these opportunities are profitable and their risk-return pay-off.

- 1) To study statistical arbitrage opportunities present in Indian securities market.
- 2) To study the profitability of statistical arbitrage opportunities in Indian securities market.
- 3) To attribute the returns generated from statistical arbitrage to different risk factors.

The study is a comprehensive one, covering three asset classes, viz., stocks/equities, commodities and currencies. The study involved a systematic process, starting with the identification of pairs for the pairs trading; then forming the trading rules and trading it in real case scenario; and measuring performance with the help of various risk-adjusted measures. The study also used the Fama and French model of asset pricing to attribute the returns to various risk factors.

Pairs trading involves identifying two assets that enjoy a long-term relationship and taking long-short positions in case of divergence from the relationship. The methodology closely followed the work of Gatev *et al* (2006) where in pairs trading was carried out over two periods – a pairs portfolio formation period, immediately followed by trading period. To cover all the major asset classes, the sample for the study was stocks traded on NSE futures segment, commodities listed on MCX futures segment and currency pairs allowed to trade in Indian market. The study was conducted over a time-period of Jan 1, 2011 to Dec 31, 2017. There was a formation period (training period) of 12 months in which pairs were identified and traded over next six-month period (trading period) on a rolling basis.

The methodology used was concerned with three major points: identifying two securities for pairs trading, how to trigger a long/short market neutral position and performance measurement (Desai *et al* 2012).

The pairs were formed using two criteria; distance approach (popularly known as Gatev methodology) and cointegration approach. Under distance approach, portfolios of top

5, top 10 and top 20 pairs were formed according to least distance criterion. The pairs were formed with and without sector restriction. The pairs were traded using three different trading strategies, viz., profit and loss (stop loss and take profit) approach, standard deviation approach and combined approach. The pairs were formed and traded using some assumptions and guidelines in different scenarios of the underlying assets involved, viz., stock futures market, stock spot market, stock spot-future statistical arbitrage, commodity futures market, currency futures market, currency spot market and currency spot-future statistical arbitrage.

This chapter which summarizes the whole study has been divided into following sections. Section 5.1 presents the findings of the study with regard to existence of statistical arbitrage opportunities in Indian securities market and its profitability. Section 5.2 discusses the implications of the study. The risks and limitations of the study are discussed in Section 5.3. Further, Section 5.4 offers some suggestions and Section 5.5 presents the directions for future research.

5.1 Findings of the Study

The study was conducted for three asset classes under different scenarios. The major findings of the study are presented in this section.

5.1.1 Stock Futures Market

The pairs portfolio of top 10 pairs formed with sector restriction under distance approach and traded using standard deviation approach produced the highest returns (statistically significant at 5%), both excluding and including transaction costs (average six-monthly return of 17.14% and 15.75% respectively). However, after considering standard deviation and Sharpe ratio, the pairs portfolio of top 10 pairs formed with sector restriction and traded using stop loss and take profit approach generated the highest risk-adjusted returns excluding transaction costs (average six-monthly return of 14.25%).

This leads to conclusion that pairs trading was profitable with every trading strategy when pairs were formed with sector restriction, though only the portfolios of top 5 and top 10 pairs formed using distance approach were significantly profitable. The returns are large in an economical and statistical sense, and suggest that pairs trading is profitable. The average annualized return was 37.22% excluding transaction costs when portfolio was composed of top 10 pairs formed with sector restriction using distance approach. Even after including transaction costs, 34% returns on annualized basis (statistically significant at 5%) were generated. The returns were superior to the average annualized market return of 19.32%.

The findings confirming the profitability of pairs trading corroborates with previous researches in the area, such as those carried out by Gatev *et al* (2006), Nath (2003), Do and Faff (2010), Broussard and Vaihekoski (2012), Aggarwal and Gupta (2015).

The application of Fama and French (1993) asset pricing model further implied that systematic market risk, size risk or the value risk were not helpful in explaining these returns. The study also showed that pairs trading returns were sensitive to the key parameters like the trading strategy used or composition of portfolios. The pairs trading was in essence a contrarian investment strategy which bets on the convergence of diverged prices (short term price reversal).

5.1.2 Stock Spot Market

This study was more from theoretical perspective as inter-day naked short selling is not allowed in Indian stock spot/cash market. The pairs trading strategy was not profitable when pairs were formed from stock spot prices both with and without sector restriction, and traded using various trading strategies. Even in the cases where returns were coming out to be positive, the returns generated were less than the risk-free rate of return. After factoring in transaction costs, only the portfolio of top 10 pairs formed with sector restriction using distance approach was generating six-monthly average positive return of 0.80%. Thus, it can be summarized that there were statistical arbitrage opportunities present in Indian stock spot market as seen from various trading opportunities, but they were not profitable.

Risk-adjusted returns which were calculated using Sharpe ratio was also negative in all the cases, which suggested that pairs trading in portfolios formed and traded using stock spot prices was not profitable and hence not advisable. There was statistically significant negative alpha generation (intercept value) as per Fama-French three factor model.

5.1.3 Stock Spot-Future Statistical Arbitrage

Under this, a pair was identified as a stock in its respective spot market and future market. Almost all the portfolios generated negative returns after transaction costs. Before including transaction costs, all the portfolios were generating positive returns, though the returns generated were less than risk-free rate of return. Risk-adjusted returns which were calculated using Sharpe ratio were also negative in all the cases, which suggested that pairs trading in portfolios formed from spot-future pairs and traded using various strategies was not profitable and hence not advisable. Even in this case, trading in stock spot market was studied using various assumptions because naked short-selling is not allowed in inter-day market in Indian stock spot market. Also, the margin requirement and transaction costs were assumed to be higher in stock spot than in stock futures.

There was significant ($p < 0.01$) negative alpha generation (intercept value) using Fama-French three factor model. It implied that investor would not be compensated for taking risk. In line with the literature, the pairs trading strategy was market neutral: the exposure to the market factor was insignificant in all of the cases.

5.1.4 Commodity Futures Market

The portfolio of cointegrating pairs formed without sector restriction and traded using profit and loss approach generated the highest statistically significant returns, both excluding and including transaction costs (average six-monthly return of 30.91% and 26.43% respectively). It also had the highest Sharpe ratio among all the portfolios formed without sector restriction. The significant intercept value (alpha) of 27.73% signified the value added by the strategy over and above the index return (average six-monthly return of 0.26%).

However, after considering standard deviation and Sharpe ratio, the pairs trading strategy was more profitable (risk-adjusted returns) when pairs were formed with the sector restriction. The portfolios of pairs under distance approach had sufficient returns that even after factoring in transaction costs, they remained fairly profitable (statistically significantly average six-monthly return of 18.01% at 1% level of significance).

The average annualized return was 71.37% excluding transaction costs when portfolio was composed of cointegrating pairs formed without sector restriction. Even after including transaction costs, 59.85% returns were generated on annualized basis (statistically significant at 5%). The returns were superior to the average annualized index return of 0.51%. On more conservative side, the portfolio of all pairs formed with sector restriction and traded using combined approach could also be considered (statistically significant average annualized of 39.26% including transaction costs). The results of this study verify the profitability of different pairs selection and pairs trading techniques for the Indian commodity futures market.

The above results corroborated with the research of Bianchi *et al* (2009) in U.S. commodities which revealed that pairs trading in similarly related commodity futures earned statistically significant excess returns with commensurate volatility. The profits generated were also supported by the results of Ungever (2015) and Yang *et al* (2017) who studied the profitability of pairs trading in U.S. and Chinese commodity markets, respectively.

The strategy generated significant positive risk-adjusted alpha over and above the market risk, which implied that the returns were because of the strategy itself. Also, market risk factor was insignificant implying the market neutrality of pairs trading strategy. The study also showed that pairs trading returns were sensitive to the key parameters like the trading strategy used or composition of portfolios.

5.1.5 Currency Futures Market

In the realm of currency trading in India, only currency pairs that were benchmarked against INR could be traded. Portfolio of currency pairs when traded using future prices generated positive returns in only half of the trading periods. The negative returns in other

half of the trading periods were larger than positive returns thus leading to overall neagive returns. It could be concluded that though statistical arbitrage opportunities were present in Indian currency futures market, it was not profitable.

5.1.6 Currency Spot Market

Till recently, it wasn't possible to trade in currency spot market in India but in August 2019, the Clearing Corporation of India Ltd (CCIL) launched a centralised electronic forex trading platform (FX-Retail) for individual and small and medium enterprise customers. The facility is currently available only for USD/INR pair, but more currencies are expected to be added gradually. The study was done in currency spot market to provide the currency trader an idea about pairs trading when eventually all the currency pairs would be allowed to trade in the spot market.

Portfolio of currency pairs when traded using spot prices genearted positive returns in only half of the trading periods. The negative returns in other half of the trading periods were larger than positive returns thus leading to overall neagive returns. It can be established that though statistical arbitrage opportunities were present in Indian currency spot market, it was not profitable.

5.1.7 Currency Spot-Future Statistical Arbitrage

Under spot-future statistical arbitrage, a pair was identified as a currency pair in its respective spot market and future market. Portfolio of currency pairs when traded using spot-future prices generated positive returns in all of the trading periods. It was near riskless arbitrage scenario. Returns were considerably higher when traded using standard deviation and combined approaches than traded using profit and loss approach. The portfolio of currency pairs generated statistically significant annualized return of 10.52% ($p < 0.01$) when traded using combined (profit and loss and standard deviation) approach. Ergo, it can be concluded that near riskless arbitrage exists in currency spot-future portfolio and it is profitable.

5.2 Implications

Futures markets in India are gaining prominence because of the participation by the diverse financial players that include investment banks, merchant banks, swap dealers, insurance companies, hedge funds, mutual funds, private equity funds, pension funds and other large institutional investors. Such participation has led to increased use of quantitative trading strategies to generate statistical arbitrage profits. Indian financial markets are maturing and are attracting sizable retail and institutional investments. Advanced applications like the one presented in this study are of significance for the investors and investment consultants so that they can benefit from the different trading strategies as researched in this study.

The profits from this statistical arbitrage strategy denied the securities market to be in any economic equilibrium, a crucial imperative for an efficient market (Jarrow, 1988). It seems to be a paradox, ipso facto that the market exhibited efficiency on the one hand and yet had arbitrage opportunities. The plausible explanation is that investors and traders who sought arbitrage opportunities are themselves the reason for the existence of efficient markets. By pursuing and exploiting market inefficiencies, they essentially exclude these inefficiencies in the mechanism by enabling prices to reach their appropriate level. Although the market is broadly efficient, there is generally a time lag in this efficiency which explained the existence of arbitrage opportunities. Therefore, it is not necessary to resolve the paradox.

Emerging economies like India have arbitrage opportunities because of lack of traders in futures market to exploit them. In other countries, stock lending has taken off in a big way and hence short selling is feasible in both spot and futures market. In India, Stock Lending and Borrowing Mechanism (SLBM) is not that popular. At the same time, ban on naked short selling in inter-day spot market and high transaction costs by margin provide for weaker arbitrage opportunities in Indian futures market. This unique environment provides for the possibility to generate significant positive returns using pairs trading.

Exploitation of statistical arbitrage opportunities using market neutral pairs trading is still one of the widely used trading strategies by hedge funds and traders all over the world. One example that can be quoted here is JPMorgan Research Market Neutral Fund. The fund enters into long and short positions in various securities. The securities are selected from the whole range of mid to large capitalization stocks that have characteristics similar to the stocks present in the Russell 1000 and/or Standard & Poor's 500 (S&P 500) indices. It is done with the intention to protect and neutralize the performance of the fund from the movements in the general stock market. The fund has realised the return of 13.02% over the past year, 5.09% over the past three years, 3.06% over the past five years, and 1.30% over the past decade.

There are multiple platforms available to traders for pairs trading. One such platform is ArbitrageLab by Hudson and Thames. It is a collection of algorithms from the best academic journals and graduate-level textbooks, which focuses on pairs trading. It performs deep literature review and code up (python) all of the landmark papers and the latest developments in the field of statistical arbitrage. There are numerous other examples as well. Hence it can be said that the statistical arbitrage opportunities exist and there is still lot to explore on exploiting these opportunities.

5.3 Risks and Limitations

Every study has some limitations and every trading strategy has some risks involved. Even investing in government securities involve volatility risk and interest rate risk. The limitations of the study include:

- i) There is a survivorship bias in the study as only those stocks and commodities have been selected that have been in trading in the futures segment for the entire trading period.
- ii) The study is confined to select stocks, currencies and commodities.
- iii) The study is limited to only top quintile of stocks listed in F&O section of NSE.
- iv) Moreover in terms of time the study is limited to a time period between Jan 1, 2011 and Dec 31, 2017.

Further, statistical arbitrage strategies have resulted in huge profits for quantitative trading firms, but still these strategies have their own set of risks which are following:

- i) The strategy heavily relies on the mean reversion of prices to their historical or predicted normal. This may not necessarily happen in some cases and the prices can continue to drift away from the historical normal.
- ii) Financial markets are in a continuous flux and evolve based on events occurring across the world. Hence, there is no guarantee of profit from statistical arbitrage all the times. In other words, losses may also be incurred in certain situations.
- iii) These strategies generally do not work for small investors or very large investors. Small investors would be stymied both by transaction costs and execution problems. Very large investors would quickly drive arbitrage to parity and eliminate excess returns.

5.4 Suggestions

- i) Leading agencies like NSE and SEBI (Securities and Exchange Board of India) should promote and make SLBM more convenient to encourage arbitrage strategies in both spot and futures market. In its Investor Awareness Program, NSE should provide training in arbitrage trading. Indian stock markets are mature and big enough to provide space for pairs trading and hence its awareness should be increased. The overall quality of the underlying market needs to be sufficiently robust for various arbitrage strategies to work. Hence, SEBI should make sure that underlying markets remain transparent, prices are readily available, counterparties are easily accessible and volumes are sufficiently high.
- ii) An important area to be looked into is the transaction costs. They are seen to be of such a significant magnitude that they are literally turning a positive return into a negative one. Technology should be leveraged to the best possible extent to cut down on the transaction costs.
- iii) Professional organizations should provide information about less risky pairs trading options. Organizations like Sharekhan, Geojit Financials, moneycontrol.com should provide a robust database of the risk-return profile of the stocks not only on stand-alone basis but also on the basis of pairs, within and without sector restrictions.

5.5 Scope for future research

This study examines the statistical arbitrage opportunities using daily future and spot prices in stocks, commodities and currencies. Technological advancements in the computational modeling have also paved the way for the use of statistical arbitrage in high frequency trading and with the so-called machine learning methods, such as neural networks and genetic algorithms (see Brogaard *et al* 2014, Chaboud *et al* 2014, Ortega *et al* 2015). The same can be implemented using intraday data with five minutes' interval (tick-by-tick data). It can further be extended by including comparison with international stock indices in other emerging economies. It can also be extended to other securities class. In more recent years, statistical arbitrage has seen renewed interest in emerging areas as well such as bitcoin (Brandvold *et al* 2015, Lintilhac and Tourin 2016), big data (McAfee and Brynjolfsson 2012, Nardo *et al* 2016) and factor investing (Maeso and Martellini 2017).

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ANNEXURE I

List of all feasible pairs

1. Stocks

1A. Without sector restriction

No.	Pairs	No.	Pairs
1	Ashok Leyland Ltd. and Bajaj Auto Ltd.	96	Axis Bank Ltd. and Jindal Steel & Power Ltd.
2	Ashok Leyland Ltd. and Hero Motocorp Ltd.	97	Axis Bank Ltd. and Steel Authority Of India Ltd.
3	Ashok Leyland Ltd. and Mahindra & Mahindra Ltd.	98	Axis Bank Ltd. and Tata Steel Ltd.
4	Ashok Leyland Ltd. and Maruti Suzuki India Ltd.	99	Axis Bank Ltd. and Vedanta Ltd.
5	Ashok Leyland Ltd. and Axis Bank Ltd.	100	H D F C Bank Ltd. and I D B I Bank Ltd.
6	Ashok Leyland Ltd. and H D F C Bank Ltd.	101	H D F C Bank Ltd. and State Bank Of India
7	Ashok Leyland Ltd. and I D B I Bank Ltd.	102	H D F C Bank Ltd. and Yes Bank Ltd.
8	Ashok Leyland Ltd. and State Bank Of India	103	H D F C Bank Ltd. and N T P C Ltd.
9	Ashok Leyland Ltd. and Yes Bank Ltd.	104	H D F C Bank Ltd. and Petronet L N G Ltd.
10	Ashok Leyland Ltd. and N T P C Ltd.	105	H D F C Bank Ltd. and Power Grid Corpn. Of India Ltd.
11	Ashok Leyland Ltd. and Petronet L N G Ltd.	106	H D F C Bank Ltd. and Reliance Industries Ltd.
12	Ashok Leyland Ltd. and Power Grid Corpn. Of India Ltd.	107	H D F C Bank Ltd. and Reliance Infrastructure Ltd.
13	Ashok Leyland Ltd. and Reliance Industries Ltd.	108	H D F C Bank Ltd. and Hindalco Industries Ltd.
14	Ashok Leyland Ltd. and Reliance Infrastructure Ltd.	109	H D F C Bank Ltd. and Jindal Steel & Power Ltd.
15	Ashok Leyland Ltd. and Hindalco Industries Ltd.	110	H D F C Bank Ltd. and Steel Authority Of India Ltd.
16	Ashok Leyland Ltd. and Jindal Steel & Power Ltd.	111	H D F C Bank Ltd. and Tata Steel Ltd.
17	Ashok Leyland Ltd. and Steel Authority Of India Ltd.	112	H D F C Bank Ltd. and Vedanta Ltd.
18	Ashok Leyland Ltd. and Tata Steel Ltd.	113	I D B I Bank Ltd. and State Bank Of India
19	Ashok Leyland Ltd. and Vedanta Ltd.	114	I D B I Bank Ltd. and Yes Bank Ltd.
20	Bajaj Auto Ltd. and Hero Motocorp Ltd.	115	I D B I Bank Ltd. and N T P C Ltd.
21	Bajaj Auto Ltd. and Mahindra & Mahindra Ltd.	116	I D B I Bank Ltd. and Petronet L N G Ltd.

ii:

No.	Pairs	No.	Pairs
22	Bajaj Auto Ltd. and Maruti Suzuki India Ltd.	117	I D B I Bank Ltd. and Power Grid Corpn. Of India Ltd.
23	Bajaj Auto Ltd. and Axis Bank Ltd.	118	I D B I Bank Ltd. and Reliance Industries Ltd.
24	Bajaj Auto Ltd. and H D F C Bank Ltd.	119	I D B I Bank Ltd. and Reliance Infrastructure Ltd.
25	Bajaj Auto Ltd. and I D B I Bank Ltd.	120	I D B I Bank Ltd. and Hindalco Industries Ltd.
26	Bajaj Auto Ltd. and State Bank Of India	121	I D B I Bank Ltd. and Jindal Steel & Power Ltd.
27	Bajaj Auto Ltd. and Yes Bank Ltd.	122	I D B I Bank Ltd. and Steel Authority Of India Ltd.
28	Bajaj Auto Ltd. and N T P C Ltd.	123	I D B I Bank Ltd. and Tata Steel Ltd.
29	Bajaj Auto Ltd. and Petronet L N G Ltd.	124	I D B I Bank Ltd. and Vedanta Ltd.
30	Bajaj Auto Ltd. and Power Grid Corpn. Of India Ltd.	125	State Bank Of India and Yes Bank Ltd.
31	Bajaj Auto Ltd. and Reliance Industries Ltd.	126	State Bank Of India and N T P C Ltd.
32	Bajaj Auto Ltd. and Reliance Infrastructure Ltd.	127	State Bank Of India and Petronet L N G Ltd.
33	Bajaj Auto Ltd. and Hindalco Industries Ltd.	128	State Bank Of India and Power Grid Corpn. Of India Ltd.
34	Bajaj Auto Ltd. and Jindal Steel & Power Ltd.	129	State Bank Of India and Reliance Industries Ltd.
35	Bajaj Auto Ltd. and Steel Authority Of India Ltd.	130	State Bank Of India and Reliance Infrastructure Ltd.
36	Bajaj Auto Ltd. and Tata Steel Ltd.	131	State Bank Of India and Hindalco Industries Ltd.
37	Bajaj Auto Ltd. and Vedanta Ltd.	132	State Bank Of India and Jindal Steel & Power Ltd.
38	Hero Motocorp Ltd. and Mahindra & Mahindra Ltd.	133	State Bank Of India and Steel Authority Of India Ltd.
39	Hero Motocorp Ltd. and Maruti Suzuki India Ltd.	134	State Bank Of India and Tata Steel Ltd.
40	Hero Motocorp Ltd. and Axis Bank Ltd.	135	State Bank Of India and Vedanta Ltd.
41	Hero Motocorp Ltd. and H D F C Bank Ltd.	136	Yes Bank Ltd. and N T P C Ltd.
42	Hero Motocorp Ltd. and I D B I Bank Ltd.	137	Yes Bank Ltd. and Petronet L N G Ltd.
43	Hero Motocorp Ltd. and State Bank Of India	138	Yes Bank Ltd. and Power Grid Corpn. Of India Ltd.
44	Hero Motocorp Ltd. and Yes Bank Ltd.	139	Yes Bank Ltd. and Reliance Industries Ltd.
45	Hero Motocorp Ltd. and N T P C Ltd.	140	Yes Bank Ltd. and Reliance Infrastructure Ltd.
46	Hero Motocorp Ltd. and Petronet L N G Ltd.	141	Yes Bank Ltd. and Hindalco Industries Ltd.

iii:

No.	Pairs	No.	Pairs
47	Hero Motocorp Ltd. and Power Grid Corpn. Of India Ltd.	142	Yes Bank Ltd. and Jindal Steel & Power Ltd.
48	Hero Motocorp Ltd. and Reliance Industries Ltd.	143	Yes Bank Ltd. and Steel Authority Of India Ltd.
49	Hero Motocorp Ltd. and Reliance Infrastructure Ltd.	144	Yes Bank Ltd. and Tata Steel Ltd.
50	Hero Motocorp Ltd. and Hindalco Industries Ltd.	145	Yes Bank Ltd. and Vedanta Ltd.
51	Hero Motocorp Ltd. and Jindal Steel & Power Ltd.	146	N T P C Ltd. and Petronet L N G Ltd.
52	Hero Motocorp Ltd. and Steel Authority Of India Ltd.	147	N T P C Ltd. and Power Grid Corpn. Of India Ltd.
53	Hero Motocorp Ltd. and Tata Steel Ltd.	148	N T P C Ltd. and Reliance Industries Ltd.
54	Hero Motocorp Ltd. and Vedanta Ltd.	149	N T P C Ltd. and Reliance Infrastructure Ltd.
55	Mahindra & Mahindra Ltd. and Maruti Suzuki India Ltd.	150	N T P C Ltd. and Hindalco Industries Ltd.
56	Mahindra&Mahindra Ltd. and Axis Bank Ltd.	151	N T P C Ltd. and Jindal Steel & Power Ltd.
57	Mahindra&Mahindra Ltd. and H D F C Bank Ltd.	152	N T P C Ltd. and Steel Authority Of India Ltd.
58	Mahindra&Mahindra Ltd. and I D B I Bank Ltd.	153	N T P C Ltd. and Tata Steel Ltd.
59	Mahindra & Mahindra Ltd. and State Bank Of India	154	N T P C Ltd. and Vedanta Ltd.
60	Mahindra & Mahindra Ltd. and Yes Bank Ltd.	155	Petronet L N G Ltd. and Power Grid Corpn. Of India Ltd.
61	Mahindra&Mahindra Ltd. and N T P C Ltd.	156	Petronet L N G Ltd. and Reliance Industries Ltd.
62	Mahindra&Mahindra Ltd. and Petronet L N G Ltd.	157	Petronet L N G Ltd. and Reliance Infrastructure Ltd.
63	Mahindra & Mahindra Ltd. and Power Grid Corpn. Of India Ltd.	158	Petronet L N G Ltd. and Hindalco Industries Ltd.
64	Mahindra & Mahindra Ltd. and Reliance Industries Ltd.	159	Petronet L N G Ltd. and Jindal Steel & Power Ltd.
65	Mahindra & Mahindra Ltd. and Reliance Infrastructure Ltd.	160	Petronet L N G Ltd. and Steel Authority Of India Ltd.
66	Mahindra&Mahindra Ltd. and HindalcoIndustries Ltd.	161	Petronet L N G Ltd. and Tata Steel Ltd.
67	Mahindra & Mahindra Ltd. and Jindal Steel & Power Ltd.	162	Petronet L N G Ltd. and Vedanta Ltd.
68	Mahindra & Mahindra Ltd. and Steel Authority Of India Ltd.	163	Power Grid Corpn. Of India Ltd. and Reliance Industries Ltd.
69	Mahindra&Mahindra Ltd. and Tata Steel Ltd.	164	Power Grid Corpn. Of India Ltd. and Reliance Infrastructure Ltd.
70	Mahindra&Mahindra Ltd. and Vedanta Ltd.	165	Power Grid Corpn. Of India Ltd. and Hindalco Industries Ltd.
71	Maruti Suzuki India Ltd. and Axis Bank Ltd.	166	Power Grid Corpn. Of India Ltd. and Jindal Steel & Power Ltd.

No.	Pairs	No.	Pairs
72	Maruti Suzuki India Ltd. and H D F C Bank Ltd.	167	Power Grid Corpn. Of India Ltd. and Steel Authority Of India Ltd.
73	Maruti Suzuki India Ltd. and I D B I Bank Ltd.	168	Power Grid Corpn. Of India Ltd. and Tata Steel Ltd.
74	Maruti Suzuki India Ltd. and State Bank Of India	169	Power Grid Corpn. Of India Ltd. and Vedanta Ltd.
75	Maruti Suzuki India Ltd. and Yes Bank Ltd.	170	Reliance Industries Ltd. and Reliance Infrastructure Ltd.
76	Maruti Suzuki India Ltd. and N T P C Ltd.	171	Reliance Industries Ltd. and Hindalco Industries Ltd.
77	Maruti Suzuki India Ltd. and Petronet L N G Ltd.	172	Reliance Industries Ltd. and Jindal Steel & Power Ltd.
78	Maruti Suzuki India Ltd. and Power Grid Corpn. Of India Ltd.	173	Reliance Industries Ltd. and Steel Authority Of India Ltd.
79	Maruti Suzuki India Ltd. and Reliance Industries Ltd.	174	Reliance Industries Ltd. and Tata Steel Ltd.
80	Maruti Suzuki India Ltd. and Reliance Infrastructure Ltd.	175	Reliance Industries Ltd. and Vedanta Ltd.
81	Maruti Suzuki India Ltd. and Hindalco Industries Ltd.	176	Reliance Infrastructure Ltd. and Hindalco Industries Ltd.
82	Maruti Suzuki India Ltd. and Jindal Steel & Power Ltd.	177	Reliance Infrastructure Ltd. and Jindal Steel & Power Ltd.
83	Maruti Suzuki India Ltd. and Steel Authority Of India Ltd.	178	Reliance Infrastructure Ltd. and Steel Authority Of India Ltd.
84	Maruti Suzuki India Ltd. and Tata Steel Ltd.	179	Reliance Infrastructure Ltd. and Tata Steel Ltd.
85	Maruti Suzuki India Ltd. and Vedanta Ltd.	180	Reliance Infrastructure Ltd. and Vedanta Ltd.
86	Axis Bank Ltd. and H D F C Bank Ltd.	181	Hindalco Industries Ltd. and Jindal Steel & Power Ltd.
87	Axis Bank Ltd. and I D B I Bank Ltd.	182	Hindalco Industries Ltd. and Steel Authority Of India Ltd.
88	Axis Bank Ltd. and State Bank Of India	183	Hindalco Industries Ltd. and Tata Steel Ltd.
89	Axis Bank Ltd. and Yes Bank Ltd.	184	Hindalco Industries Ltd. and Vedanta Ltd.
90	Axis Bank Ltd. and N T P C Ltd.	185	Jindal Steel & Power Ltd. and Steel Authority Of India Ltd.
91	Axis Bank Ltd. and Petronet L N G Ltd.	186	Jindal Steel & Power Ltd. and Tata Steel Ltd.
92	Axis Bank Ltd. and Power Grid Corpn. Of India Ltd.	187	Jindal Steel & Power Ltd. and Vedanta Ltd.
93	Axis Bank Ltd. and Reliance Industries Ltd.	188	Steel Authority Of India Ltd. and Tata Steel Ltd.
94	Axis Bank Ltd. and Reliance Infrastructure Ltd.	189	Steel Authority Of India Ltd. and Vedanta Ltd.
95	Axis Bank Ltd. and Hindalco Industries Ltd.	190	Tata Steel Ltd. and Vedanta Ltd.

1B. With sector restriction

No.	Pairs	No.	Pairs
1	Hindalco Industries Ltd. and Tata Steel Ltd.	21	N T P C Ltd. and Power Grid Corpn. Of India Ltd.
2	Hindalco Industries Ltd. and Vedanta Ltd.	22	Bajaj Auto Ltd. and Mahindra & Mahindra Ltd.
3	Tata Steel Ltd. and Vedanta Ltd.	23	Bajaj Auto Ltd. and Maruti Suzuki India Ltd.
4	Hindalco Industries Ltd. and Steel Authority Of India Ltd.	24	Ashok Leyland Ltd. and Hero Motocorp Ltd.
5	Steel Authority Of India Ltd. and Vedanta Ltd.	25	Ashok Leyland Ltd. and Maruti Suzuki India Ltd.
6	Steel Authority Of India Ltd. and Tata Steel Ltd.	26	Ashok Leyland Ltd. and Bajaj Auto Ltd.
7	Petronet L N G Ltd. and Power Grid Corpn. Of India Ltd.	27	N T P C Ltd. and Petronet L N G Ltd.
8	Petronet L N G Ltd. and Reliance Industries Ltd.	28	I D B I Bank Ltd. and Yes Bank Ltd.
9	State Bank Of India and Yes Bank Ltd.	29	N T P C Ltd. and Reliance Industries Ltd.
10	Jindal Steel & Power Ltd. and Tata Steel Ltd.	30	Reliance Industries Ltd. and Reliance Infrastructure Ltd.
11	H D F C Bank Ltd. and Yes Bank Ltd.	31	Axis Bank Ltd. and I D B I Bank Ltd.
12	H D F C Bank Ltd. and State Bank Of India	32	Axis Bank Ltd. and H D F C Bank Ltd.
13	Hindalco Industries Ltd. and Jindal Steel & Power Ltd.	33	Axis Bank Ltd. and Yes Bank Ltd.
14	Jindal Steel & Power Ltd. and Steel Authority Of India Ltd.	34	I D B I Bank Ltd. and State Bank Of India
15	Power Grid Corpn. Of India Ltd. and Reliance Industries Ltd.	35	Mahindra & Mahindra Ltd. and Maruti Suzuki India Ltd.
16	Bajaj Auto Ltd. and Hero Motocorp Ltd.	36	N T P C Ltd. and Reliance Infrastructure Ltd.
17	Hero Motocorp Ltd. and Maruti Suzuki India Ltd.	37	Power Grid Corpn. Of India Ltd. and Reliance Infrastructure Ltd.
18	Hero Motocorp Ltd. and Mahindra & Mahindra Ltd.	38	Petronet L N G Ltd. and Reliance Infrastructure Ltd.
19	Jindal Steel & Power Ltd. and Vedanta Ltd.	39	Axis Bank Ltd. and State Bank Of India
20	Ashok Leyland Ltd. and Mahindra & Mahindra Ltd.	40	H D F C Bank Ltd. and I D B I Bank Ltd.

2. Commodities

2A. Without sector restriction

No.	Pairs	No.	Pairs
1	Cardamom and CPO	34	Aluminium and Zinc
2	Cardamom and Mentha Oil	35	Aluminium and Gold
3	Cardamom and Aluminium	36	Aluminium and Silver
4	Cardamom and Copper	37	Aluminium and Crude Oil
5	Cardamom and Lead	38	Aluminium and Natural Gas
6	Cardamom and Nickel	39	Copper and Lead
7	Cardamom and Zinc	40	Copper and Nickel
8	Cardamom and Gold	41	Copper and Zinc
9	Cardamom and Silver	42	Copper and Gold
10	Cardamom and Crude Oil	43	Copper and Silver
11	Cardamom and Natural Gas	44	Copper and Crude Oil
12	CPO and Mentha Oil	45	Copper and Natural Gas
13	CPO and Aluminium	46	Lead and Nickel
14	CPO and Copper	47	Lead and Zinc
15	CPO and Lead	48	Lead and Gold
16	CPO and Nickel	49	Lead and Silver
17	CPO and Zinc	50	Lead and Crude Oil
18	CPO and Gold	51	Lead and Natural Gas
19	CPO and Silver	52	Nickel and Zinc
20	CPO and Crude Oil	53	Nickel and Gold
21	CPO and Natural Gas	54	Nickel and Silver
22	Mentha Oil and Aluminium	55	Nickel and Crude Oil
23	Mentha Oil and Copper	56	Nickel and Natural Gas
24	Mentha Oil and Lead	57	Zinc and Gold
25	Mentha Oil and Nickel	58	Zinc and Silver
26	Mentha Oil and Zinc	59	Zinc and Crude Oil
27	Mentha Oil and Gold	60	Zinc and Natural Gas
28	Mentha Oil and Silver	61	Gold and Silver
29	Mentha Oil and Crude Oil	62	Gold and Crude Oil
30	Mentha Oil and Natural Gas	63	Gold and Natural Gas
31	Aluminium and Copper	64	Silver and Crude Oil
32	Aluminium and Lead	65	Silver and Natural Gas
33	Aluminium and Nickel	66	Crude Oil and Natural Gas

2B. With sector restriction

No.	Pairs
1	Cardamom and CPO
2	Cardamom and Mentha Oil
3	Aluminium and Copper
4	Aluminium and Lead
5	Aluminium and Nickel
6	Aluminium and Zinc
7	Copper and Lead
8	Copper and Nickel
9	Copper and Zinc
10	CPO and Mentha Oil
11	Crude Oil and Natural Gas
12	Gold and Silver
13	Lead and Nickel
14	Lead and Zinc
15	Nickel and Zinc

3. Currencies

No.	Pairs
1	USDINR and EURINR
2	USDINR and GBPINR
3	USDINR and JPYINR
4	EURINR and GBPINR
5	EURINR and JPYINR
6	GBPINR and JPYINR

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