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# Energy Price Uncertainty and Investment: Firm Level Evidence from Indian Manufacturing Sector

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**ABSTRACT**

Uncertainty whatsoever has undoubtedly been deemed to be malevolent to the interests of investors. Theories of partial irreversibility of investment argue that uncertainty at the micro level negatively impacts the firm's investment and thereby, at least, slow the process of capital accumulation. Therefore, the present study, empirically analyzes how energy price uncertainty affects investment decisions of manufacturing firms in India. A variety of panel data models are estimated using generalized method of moments with data pertaining to Indian manufacturing firms over the period 1992-1993-2013-2014. Results are consistent with irreversible investment literature on the supply side of production, which shows that energy uncertainty has a negative effect on the capital accumulation in the manufacturing sector and this effect transpires in the form of firm's inability to adjust its actual capital stock to match up to its potential desired capital stock as proposed by the investment theories.

**Keywords:** Energy Price Uncertainty, Irreversible Investment, Energy Intensity
**JEL Classifications:** C23, D80, E20, Q41

## 1. INTRODUCTION

In the real world, contrary to the propositions of the perfect frictionless market models, firms will have to deal with various types of imperfections and uncertainties such as unforeseen changes in the output or input prices or non-availability of adequate amount of energy products at affordable prices and consequent business setbacks. There exist plenty of theoretical and empirical studies about the nature of the link between uncertainty and investment in the literature[1]. According to these studies, most of the investments are at least partially irreversible in the sense that they are sunk costs that cannot be recovered once capital is committed should unforeseen uncertainties hit the market. Therefore, the cost of investing includes an opportunity cost of committing resources rather than waiting for the arrival of new information (Caballero and Pindyck, 1996). And they generally concluded that the potential business uncertainty brought about by changing market conditions at both industrial and firm level results in the decline in the investment[2].

Of the uncertainties faced by modern industrial establishments, energy related uncertainty constitutes a prominent one and it was on display during the oil-shocks of the 1970s. As Hamilton (2008) and Kilian (2008) noted, energy price shocks get transmitted to investment through two channels. First, an increase in energy prices raises the marginal cost of production, which depends on the share of energy cost in the total cost of firms and second, higher energy prices force the consumers to cut down their spending and both these channels of energy shock transmission compels firms to cut down their investment. Therefore, in this paper, we investigate the specific effects of energy price uncertainty on the investment decisions of manufacturing firms in India.

1 See Carruth et al (2000) for a detailed review of studies on uncertainty and investment.

2 In contrast to this general conclusion, two early studies viz Hartman (1972) and Abel (1983) had found that uncertainty and investment are positively related.

Regarding the theoretical underpinning, the present paper pivots on the theory of partially irreversible investment under uncertainty (e.g. Arrow, 1968; Nickell, 1974; Dixit and Pindyck, 1994; Pindyck, 1991; Bernanke, 1983). This theory envisions most of the investments as irreversible or sunk costs since investment expenditure once incurred cannot be recovered in the face of unforeseen uncertainties. Therefore, such investments are treated, as Pindyck (1991) noted, as a financial call option which once exercised cannot be reversed. As a result, investors have an option to either invest or delay investment at a given point in time. Undoubtedly, future business uncertainty will be one of the many factors taken into consideration by a rational investor while choosing either of the two options. For, by the time the investor remains waiting; new information capable of dissipating looming uncertainty may arrive in the market and thereby enable the investor to take an informed decision. It means that the value of the 'option-to-delay' investment increases with the increase in uncertainty. In other words, increased uncertainty will reduce the current level of investment (Carruth et al., 2000). In short, theory of irreversible investment envisages uncertainty as a strong determinant of the investment expenditure. Therefore, the present paper examines empirically whether the experience of manufacturing investment in India bears testimony to the views of theories of irreversible investment.

The present study draws significance on the following grounds: First, no research related to India can be seen on this issue so far, and therefore, this study aims to check the robustness of the findings of previous studies conducted in other countries in the context of India. Second, in the backdrop of India's recent emphasis over boosting industrial investment, especially in the manufacturing sector as part of its 'Make In India' policy initiative to promote growth, the revelations of this kind of study will be important as investors in the present strategically sensitive and highly competitive business environment are wary of uncertainty and investment irreversibility (Pindyck, 1991)[3]. Third, Indian economy is critically dependent on global markets for its energy requirements. For instance, fuel products accounts for 40.44 percent of total imports in the year 2013-2014[4]. Twelfth 5 year plan has cautioned that India's reliance on import of energy products like crude oil is projected to rise to 78% of total use by 2016-17.

Fourth, volatile geopolitics prevailing today in the oil and gas rich countries in the middle-east region is also a matter of concern for India from the point of its energy security as it heavily depends on this region for its energy requirements. Economic Survey (2012-2013) has acknowledged this vulnerability of the Indian industrial sector to external shocks while pointing out that "industrial growth still remains vulnerable to several domestic factors and external shocks such as energy constraint." Thus, energy security at a reasonable price is a matter of great worry for Indian Industry as it is an important input in the modern industrial production. Therefore, an empirical study to characterize the nature of the relationship between manufacturing investment and energy market dynamics appears to be in order.

Accordingly, we use data from Indian manufacturing firms during 1992-2013 and estimated alternative panel data models using generalized method of moments (GMM) method developed by Arellano and Bond (1991). Empirical Results are consistent with irreversible investment literature on the supply side of the production, which shows that energy uncertainty has a negative effect on the capital accumulation in the manufacturing sector and this effect transpires in the form of firm's inability to adjust its actual capital stock to match up to its potential desired capital stock as proposed by the investment theories.

The remainder of this paper is organized as follows. Section 2 presents the review of literature regarding the effect of energy price uncertainty exclusively on investment of manufacturing firms. The econometric model employed in the empirical analysis is presented in Section 3 and Section 4 details econometric model and the nature and sources of data used in the study. Section 5 presents the empirical results and Section 6 concludes the paper.

## 2. REVIEW OF LITERATURE

Since theoretical and empirical studies on the relationship between uncertainty and investment are decades old, there are plenty of previous studies dealing with a variety of uncertainties both at the micro and macroeconomic levels[5]. Hence, for the sake of brevity, we review the studies exclusively on the relationship between uncertainty and industrial or manufacturing investment. Leahy and Whited (1996) tested empirically the relationship between investment and uncertainty by estimating a vector regression model using GMM. They used firm level panel data, such as investment, output, stock return, cash flow, etc. obtained from COMPUSTAT industrial file over the period 1981-87 concerning 722 manufacturing firms. The empirical results unequivocally showed a strong negative relationship between investment and uncertainty and thereby reinforced the belief that it is the investment irreversibility responsible for this negative relationship between investment and uncertainty.

Lee and Ni (2002) estimated vector auto regression (VAR) models with both macroeconomic variables such as money stock (M2), interest rate, consumer price ındex, oil price, etc., and industrial variables such as industrial output and price pertaining to 14 industries in the US. The study reported that even though both demand and supply of industries were affected by oil price rises, the effect in the form of supply reduction was more pronounced in the case of oil-intensive industries such as petroleum refinery and industrial chemicals, whereas, it affected many other industries in the form of reduction in the demand especially for automobile industry. Further, the output response was short-living which

3 Pindyck (1991) has even noted that irreversibility may have macroeconomic policy implications; if goal is to stimulate investment, stability and credibility could be much more important than tax incentives or interest rates. Put another way, if uncertainty over the economic environment is high, tax and related incentives may have to be very large to have any significant impact on investment.

4 Export Import Data Bank, Department of Commerce.

5 See Hamilton (2008) and Barsky and Kilian (2004) for studies on the macroeconomic impact of oil price uncertainty and relevant debates and insights in this respect.

occurred after 10 months of the shock in most of the industries. However, little correlation was found between severity of the oil price-triggered output decreases and industries' oil intensity and these findings were in consonance with the established views in the business press on this issue. Bloom et al. (2007) developed an econometric investment model to detect the effects of uncertainty and irreversibility on short-run dynamics of firm-level investment spending. They estimated the same model to study the investment behavior of a sample of 672 publicly traded United Kingdom manufacturing companies over the period 1972–1991. The GMM estimation results of the error correction model (ECM) indicated that greater the uncertainty, greater the caution exercised by firms in the investment and the response of investment to real sales growth is convex. Thus, the evidences were supportive of the theory of irreversible investment.

Rather in a first attempt, Edelstein and Kilian (2007) analyzed whether the response of nonresidential business fixed investment to energy price uncertainty is symmetric or asymmetric using the VAR model and ımpulse response function. The study included nonresidential business fixed investment in structures (including structures in manufacturing, mining, power etc.) and in equipments (including equipments in industry, transportation, mining etc.,) using a full sample ranging from 1970:II to 2006:IV. They found no compelling evidences in favor of asymmetric response of aggregate nonresidential business fixed investment in structures and equipments. Thus, their results were not consistent with theories of partial irreversible investment. A similar result was reported by Kilian (2008) based on a study into the energy price elasticity of non-residential investment expenditure on structures, equipment, etc., in US based on quarterly investment aggregates reported by the bureau of economic analysis for 1970.II-2006.IV

Elder and Serletis (2009) investigated the effects of oil price uncertainty in Canada by estimating a structural VAR with multivariate generalized autoregressive conditional heteroskedasticity (GARCH)-in-mean by using monthly data on output and oil prices from four sectors such as industrial production, mining and oil and gas extraction, goods producing industries and service industries. They found that oil price uncertainty exerts negative effect on the investment in all sectors except service industries which could be due to the fact that the service sector is not energy intensive compared to other sectors in an economy. Contrary to the commonly found evidence, system GMM model estimated by Mohn and Mismund (2009) using panel data on 155 oil and gas companies across globe during 1992-2005 reported overwhelming evidences in favor of a positive relationship between industry-specific measure of uncertainty - oil price volatility and investment in the long run even though the results were consistent with the theory of irreversible investment in the short run.

Fucunaga et al. (2010) attempted to carry out a comparative analysis of the impact of oil price changes on the industrial production and prices in USA and Japan and thereby decompose the components of oil price shock. VAR model estimated using monthly industrial and aggregate data covering the sample period of 1973:1-2008:12 indicated that the way oil price changes affects each industry depends on the inherent characteristics of industries such as the oil - intensity of production as well as the kind of underlying shock drives the oil price changes. Unexpected disruptions of oil supply act mainly as negative supply shocks for oil-intensive industries and act mainly as negative demand shocks for less oil-intensive industries. The results also shed light on the considerable difference in the transmission of energy shock between USA and Japan. For most industries in the U.S., the global demand shocks act mainly as positive demand shocks, and the oil-specific demand shocks act mainly as negative supply shocks. In Japan, the oil-specific demand shocks as well as the global demand shocks act mainly as positive demand shocks for many industries which indicate the shift in global demand in favor of fuel efficient automobiles made in Japan. Alghalith (2010) used time series data pertaining to the manufacturing sector in the U.S to estimate a nonlinear regression model and found that an increase in the input price riskiness reduces the optimal input and output due to risk aversion. Also, an increase in expected energy price reduces the optimal energy consumption and output. The correlation found between the oil price shocks and output price shocks has an adverse impact on the manufacturing output.

Lee et al. (2011) conducted a study on 3322 US manufacturing firms with data such as oil price, stock returns, sales, capital stock etc. collected from CRSP and COMPUSTAT databases over the period 1962-2007. The results obtained by estimating a standard investment model using the system GMM show that the oil price uncertainty results in the reduction of capital accumulation of firms both in the short run and long run. The study also noted that the oil price shock appears to be rather a transmitter of and thereby a proxy for uncertainty than acting as a crucial investment determinant implying that US economy is getting affected not because of the heavy dependence on crude oil but because of the fact that it acts as a precursor of the economic gloom ahead.

Elder and Serletis (2011) estimated a multivariate GARCH-in-Mean VAR using monthly measures of U.S. firm production related to industries in mining, manufacturing, and utilities during the period 1980:1-2009:12. The results revealed that oil price uncertainty has a considerable negative effect on industrial production, especially in 2008 and 2009 which observed extreme oil price volatility and the effect appears to be more pronounced in the manufacture of durable goods such as automobiles and other transportation equipments. Mohn and Osmundsen (2011) in connection with proposing an econometric modeling approach to test various predictions of modern investment theories, including various uncertainty indicators, used information on drilling activities, discoveries and exploration acreage regarding oil and gas exploration in Norway and estimated an ECM to examine the link between oil price volatility and investment in their exploration during the period 1966-2004. The results were in consonance with generally established view in the irreversible investment literature as to oil price uncertainty negatively affects the exploration activity. Similar results were reported by Kellogg (2010) from USA based on estimates of the responsiveness of oil well drilling firms in Texas to oil price volatility.

Ratti et al. (2011) estimated a dynamic model of investment to investigate the effect of variation in relative energy price on firm level investment in manufacturing and non-financial sectors in 15 European countries. The study used data on variables such as energy prices, investment, capital stock, sales, cash flow, etc. from 25 industries over the period of 1991-2006. Individual country regression results revealed that a rise in the relative price of energy has a statistically significant negative effect on firm level investment in 14 out of 15 countries. Panel regression results suggested that a 1% rise in energy price relative to other prices in a country reduces investment by firms in that country by 1.2% relative to investment by firms in other countries. Specifically, the study noted that for manufacturing firms the effect of a one percent rise in energy price is a reduction in investment by 1.9%. The negative effect of the higher relative price of energy on investment is significantly less marked the larger the firm. The study of Yoon and Ratti (2011) estimated a dynamic ECM of capital stock adjustment by GMM-IV method using data such as total assets, capital expenditures, sales etc on 2600 publicly traded US manufacturing firms during 1971-2006. Energy and oil price uncertainty is measured by the conditional variance obtained from a GARCH model. The study mainly found that energy price uncertainty affects the investment of firms by reducing the positive effect of sales growth on investment except for firms in petroleum and coal industries and energy intensity is a crucial factor in determining the negative effect. Even though the unfavorable effect of energy uncertainty is more pronounced as far as high growth firms are concerned, the findings generally suggested that stability in energy prices would be conducive to greater stability in firm-level investment.

Aye et al. (2014) investigated the nature of the dynamic relationship between oil price uncertainty and manufacturing investment in South Africa based on a structural VAR model estimated with monthly data covering the period 1974:2-2012:12. In addition to negative relationship between oil price uncertainty and manufacturing production, they also found that the responses of manufacturing production to positive and negative shocks are asymmetric.

Thus, it is evident that most of the previous studies found evidence in favor of the theories of partial irreversible investment. However, since most of these studies are conducted in the context of developed countries, there exists a case to conduct the present study in the context of one of the fastest growing economies of the world, India. For, apart from general factors such as energy intensity dictated by technological prowess relevant in the energy-related debate, India is a major economy today with almost complete dependence on the rest of the world for its energy security compared to other growing economies such as China.

## 3. ECONOMETRIC MODEL

We follow Bond et al. (2003) and Bloom et al. (2007) in the formulation of the econometric model. According to the modern investment theories, the actual capital stock chosen by a firm will be equal to the desired capital stock in a frictionless environment. However, in the presence of frictions like adjustment cost, the actual capital stock chosen by the firm tends to lag the desired capital stock. It suggests that there is a co-integrating long-run equilibrium relationship between actual and desired capital stocks. Therefore, we follow the representation theorem of Engel and Granger (1987) to specify an ECM of capital stock adjustment to model the short run adjustment of capital stock by firms. It provides a flexible framework to distinguish between the short run and long run effects of energy price changes on investment.

Chirinko et al. (1999) argued that structural models are strong in their theoretical formulation, but their performance in empirical studies is rather poor. In contrast, distributed lag models do not have a strong theoretical background, but do well in empirical studies. Therefore, based on the objective of the study, an applied econometrician has to choose a model from these two classes of models. Since the primary objective is to empirically examine the relationship between investment and uncertainty, we have chosen the distributed lag model in an error correction framework. This framework is extensively used in the extant literature (Bloom et al., 2007; Yoon and Ratti, 2011).

The co-integration between the actual and desired capital stock in the long run can be represented as:

$$LogK_{\mathrm{it}} = LogK_{it}^{*} + e_{it'} \quad (1)$$

Where, $K_{it}$ is actual capital stock for firm *i* at time *t*, $K_{it}^{*}$ is desired capital stock the firm would have chosen to in the absence of adjustment costs and $e_{\mathrm{it}}$ is the error term which is stationary.

The desired capital stock in the absence of frictions is specified as:

$$LogK_{it}^{*} = LogS_{it} + A_i^{*} + B_t^{*}, \quad (2)$$

Where, $S_{\mathrm{it}}$ is the sales of firm *i* at time *t*, and $A_i^{*}$ and $B_t^{*}$ are firm and time specific unobserved effects of variation in the components of and response to the user cost of capital across firms. If firm specific user cost of capital is stationary, equation (2) implies a long run equilibrium relationship between actual capital stock and sales consistent with the frictionless demand for capital.

Thus, equation (1) can be re-specified as given below:

$$LogK_{it} = LogS_{it} + A_i^{*} + B_t^{*} + e_{it} \quad (3)$$

Since the error term $e_{\mathrm{it}}$ in equation (3) need not be zero, the actual capital stock and desired capital stock need not be equal on average. To unearth the short-run dynamics between actual ($LogK_{it}$) and desired levels of capital stock ($LogK_{it}^{*}$), a basic ECM using equation (2) would have the following form:

$$\Delta LogK_{it} = \beta \Delta LogS_{it} + \theta(LogK_{it-1} - LogS_{it-1}) + A_i + B_t + v_{it}, \quad (4)$$

Where, $\Delta LogK_{it}$ and $\Delta LogS_{it}$ are the growth rate of capital stock and sales respectively, $A_i$ and $B_t$ are again unobserved firm and time specific effects on capital adjustment, $v_{\mathrm{it}}$ is the serially uncorrelated error term. If $Log(K_{it})$ and $Log(S_{it})$ are cointegrated, then the coefficient of the error correction term $LogK_{it-1}$-$LogS_{it-1}$, $\theta$ should be positive which implies that firms with capital stock below the desired level will eventually adjust upwards and vice versa.

Drawing on Bloom et al. (2007), we use the following approximation to represent growth rate of capital stock:

$$\Delta LogK_{it} \approx I_{it} / K_{it-1}\delta_i \quad (5)$$

Where, $I_{it}$ is the gross investment and $\delta_i$ is the depreciation rate, which could be firm specific.

We estimate the following basic investment model:

$$\frac{I_{it}}{K_{it-1}} = \beta_1 \frac{I_{it-1}}{K_{it-2}} + \beta_2 \Delta logS_{it} + \beta_3 \frac{S_{it-1}}{K_{it-1}} + A_i + B_t + v_{it} \quad (6)$$

Where, investment to lagged capital ratio ($\frac{I_{it}}{K_{it-1}}$) is the dependent variable and lag one of the same variable is also added as an explanatory variable to take care of possible autocorrelation in it. Growth rate in sales ($\Delta logS_{it}$) is the second explanatory variable and is expected to be positive. The error correction term $\frac{S_{it-1}}{K_{it-1}}$ is also expected to be positive.

### 3.1. Introduction of Uncertainty

Uncertainty in energy prices is captured using standard deviation and conditional variance by GARCH process. Standard deviation and univariate GARCH (1, 1) model is estimated from monthly data of growth rate in energy prices. The mean equation is specified as follows:

$$EP_t = \mu + \phi EP_{t-1} + u_t, u_t \sim N(0, h_t^2) \quad (7)$$

Where, $EP_t$ is the energy price at time $t$ and $u_t$ is the error term which is normally distributed with 0 mean and variance $h_t^2$ Variance equation is specified as follows:

$$h_t^2 = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta h_{t-1}^2 \quad (8)$$

Impact of energy price uncertainty on firm level investment is captured as follows:

$$\frac{I_{it}}{K_{it-1}} = \beta_1 \frac{I_{it-1}}{K_{it-2}} + \beta_2 \Delta logS_{it} + \beta_3 \frac{S_{it-1}}{K_{it-1}} + \beta_4 \left(\Delta logS_{it} * h_t\right) + A_i + B_t + v_{it} \quad (9)$$

Where, interaction between sales growth and energy price uncertainty ($\Delta logS_{it} * h_t$) is added to the basic investment model (i.e. equation (6)) to account for the impact of the energy price shock through the demand channel and $\beta_4$ is expected to be negative showing that energy uncertainty weakens the link between demand for the product and investment outlay of firms.

With the aim of reinforcing the results from above specification, we also estimate the following equation:

$$\frac{I_{it}}{K_{it-1}} = \beta_1 \frac{I_{it-1}}{K_{it-2}} + \beta_2 \Delta logS_{it} + \beta_3 \frac{S_{it-1}}{K_{it-1}} + \beta_4 \left(\Delta logS_{it} * SD_{it}\right) + A_i + B_t + v_{it} \quad (10)$$

Where, a different measure of energy price uncertainty viz. standard deviation of the monthly growth rate in energy price is interacted with sales growth to see the robustness of the relationship between investment and different measures of uncertainty.

Equations (9) and (10) test whether energy price uncertainty influences firm-level investment through demand shock. It is also possible that the energy price uncertainty can influence the investment through supply side by affecting the speed with which actual capital stock adjusts with the desired capital stock captured by the error correction term. Therefore, in equation (11) and (12) error correction term is interacted with energy price uncertainty viz. GARCH and standard deviation, respectively.

$$\frac{I_{it}}{K_{it-1}} = \beta_1 \frac{I_{it-1}}{K_{it-2}} + \beta_2 \Delta logS_{it} + \beta_3 \frac{S_{it-1}}{K_{it-1}} + \beta_4 \left(\frac{S_{it-1}}{K_{it-1}} * h_t\right) + A_i + B_t + v_{it} \quad (11)$$

$$\frac{I_{it}}{K_{it-1}} = \beta_1 \frac{I_{it-1}}{K_{it-2}} + \beta_2 \Delta logS_{it} + \beta_3 \frac{S_{it-1}}{K_{it-1}} + \beta_4 \left(\frac{S_{it-1}}{K_{it-1}} * SD_{it}\right) + A_i + B_t + v_{it} \quad (12)$$

In equations (11) and (12) the coefficients of interaction terms are expected to be negative, indicating that energy price uncertainty reduces the speed at which the actual capital stock catch up with the desired capital stock.

### 3.2. Introduction of Energy Intensity

The response of the firm's investment to energy uncertainty may also be influenced by the extent of energy input required in the production, i.e., energy intensity. Patterson (1996) classified the energy intensity measures used in the extant literature into four categories, i.e., thermodynamic, physical thermodynamic, economic thermodynamic and economic indicators. Using any thermodynamic based energy intensity measure, differences in the energy quality have to be adjusted in estimation. This makes its use difficult at the macro level. In the case of physical thermodynamic measure, output is measured in physical units. Its use is also limited as the output varies widely across sectors. Economic thermodynamic measure is similar to physical thermodynamic but measures the output in monetary units instead of physical units. However, it cannot separate the structural technical energy efficiency trends. Economic indicators measure both energy input and output in monetary terms. Since our objective is to capture the economic efficiency of the energy use, we use a pure economic indicator. Energy intensity is estimated as a ratio of expenditure on fuel and power to sales revenue. This solves the energy quality problem in any of the thermodynamic indicators (Turvey and Norbay (1965) and Berndt (1978)).

We estimate equations (13) and (14) interacting the energy intensity with energy uncertainty viz. GARCH and standard deviation, respectively.

$$\frac{I_{it}}{K_{it-1}} = \beta_1 \frac{I_{it-1}}{K_{it-2}} + \beta_2 \Delta logS_{it} + \beta_3 \frac{S_{it-1}}{K_{it-1}} + \beta_4 (EI_i * h_t) + A_i + B_t + v_{it} \quad (13)$$

$$\frac{I_{it}}{K_{it-1}} = \beta_1 \frac{I_{it-1}}{K_{it-2}} + \beta_2 \Delta logS_{it} + \beta_3 \frac{S_{it-1}}{K_{it-1}} + \beta_4 (EI_i * SD_{it}) + A_i + B_t + v_{it} \quad (14)$$

In equations (13) and (14) coefficients of the interaction of energy intensity and energy uncertainty are expected to be negative, indicating that higher the energy intensity along with uncertainty negatively affects the firm level investment.

Further, the simultaneous impact of energy intensity and energy price uncertainties operating through the sales channel is estimated in the equations (15) and (16).

$$\frac{\mathrm{I_{it}}}{K_{it-1}} = \beta_1 \frac{\mathrm{I_{it-1}}}{K_{it-2}} + \beta_2 \Delta logS_{it} + \beta_3 \frac{S_{it-1}}{K_{it-1}} + \beta_4 \left(\Delta logS_{it} * h_t\right) + \beta_5 (\Delta logS_{it} * EI_i * h_t) + A_i + B_t + v_{it} \quad (15)$$

$$\frac{\mathrm{I_{it}}}{K_{it-1}} = \beta_1 \frac{\mathrm{I_{it-1}}}{K_{it-2}} + \beta_2 \Delta logS_{it} + \beta_3 \frac{S_{it-1}}{K_{it-1}} + \beta_4 \left(\Delta logS_{it} * SD_{it}\right) + \beta_5 (\Delta logS_{it} * EI_i * SD_{it}) + A_i + B_t + v_{it} \quad (16)$$

In equations (15) and (16) growth rate of sales, energy intensity and uncertainty in the form of GARCH and standard deviation are interacted respectively to capture this effect. The interaction term is expected to be negative.

### 3.3. Econometric Issues

The proposed empirical model is a dynamic panel data model and there are several econometric issues associated with it. The lagged dependent variable, i.e., investment to lagged capital ratio is included as one of the independent variables to account for autocorrelation in the variable. Due to this, the lagged dependent variable may be correlated with the unobservable fixed effects, which may lead to dynamic panel data bias. Here are several ways proposed in the extant literature to overcome this problem. First, the fixed effect method may be employed to account for unobservable fixed effects. But the problem of a possible correlation between the idiosyncratic error term and lagged dependent variable will not be removed. Second, the variable may be transformed by first differencing or orthogonal deviation to overcome the problem. However, first differenced lagged dependent variable may still be correlated with the first differenced error term. Therefore, deeper lags of regressors may be used as instrumental variables for the transformed dependent variable because these variables are uncorrelated with the error term. However, in an unbalanced panel, the requirement of deeper lags results in the loss of degree of freedom. Therefore, it requires striking a tradeoff between the desire for the efficiency of the estimates and the sample size. In spite of this, the idiosyncratic error term of the first differenced data may not satisfy the homoscedasticity assumption required for the two- stage least squares estimators (2SLS).

The study has adopted the GMM with orthogonal deviation and has used the deeper lags of all the regressors as instrumental variables. The instrument adequacy test is conducted to confirm the validity of the exercise.

## 4. DATA

Data for the study is collected from two sources viz. Centre for Monitoring Indian Economy (CMIE) Prowess database and Reserve Bank of India (RBI) database on the Indian economy. Firm level financial data is taken from the CMIE Prowess database. It includes sales revenue, total assets in plant, machinery, computers and electrical assets, and expenditure on fuel and power. Total assets in plant, machinery, computers and electrical assets net of depreciation is taken as a proxy for the total capital stock of the firm *i* at time *t*, and year on year changes in total capital stock is taken as investment[6].

There are several measures of energy prices viz. specific energy prices, which are given in terms of price per standard unit and price indices representing all fuels. Following the precedence of Uri (1980), the study uses the wholesale price ındex[7] (WPI) on Fuel and Power. It captures the movement of the domestic price of the energy products in a most comprehensive way. WPI is widely used by government, banks, industry, and business circles in India.

Data is collected for all companies under the manufacturing sector amounting to a total of 10989 firms and for the period from 1990-1991 to 2013-2014. It includes all industry group classifications under the manufacturing sector. CMIE Prowess provides 97 industry group classifications[8]. WPI on fuel and power at 2004-2005 prices is taken from RBI database. All companies under manufacturing segment are considered in the estimation. However, due to missing or non-existing data for several companies and across years, final sample includes the period from 1992-1993 to 2013-2014, i.e., 22 years. We have created an unbalanced panel consisting of 3412 firms with 13238 observations.

Table 1 shows the summary statistics, i.e., mean and standard deviations of growth rate of sales, investments and energy intensity. The growth rate of sales is higher for bigger firms and last three deciles recorded negative average growth rate in sales. Standard deviation is higher for smaller firms compared with larger firms. The mean growth rate of investment also shows the same trend, whereas, standard deviation is more or less same across all deciles. Mean energy intensity is smaller for bigger firms compared to smaller ones, indicating that the former could afford energy efficient technology over the latter. It also means that smaller firms are more affected by the energy price uncertainty compared to bigger firms.

## 5. EMPIRICAL RESULTS

The error correction specification implies that logarithms of the sales and capital stock are $I(1)$ processes and sales to capital ratio to be an $I(0)$ process. It means that the logarithms of sales and capital are co-integrated. This restriction is tested using panel unit root test's statistics.

6 Investment is inferred from capital stock instead of capital expenditure to neutralize the influence of possible differences in the accounting practices regarding the treatment of capital expenditure. For e.g. an operating lease may be treated as capital expenditure or operating expenditure due to flexibility in the accounting rules.

7 Wholesale Price Index (WPI) is a broad based measure of inflation in India. More details about WPI is available at WPI Manual Office http://www.eaindustry.nic.in/WPI_manual.pdf.

8 Complete details about the industry group classification can be found in CMIE Prowess website: www.prowess.cmie.com.

Table 2 presents the Levin, Lin and Chu unit root test statistic with individual effects and individual linear trend. In the case of sales, investment and capital stock, the null hypothesis of unit root is not rejected. However, the null hypothesis of unit root is rejected in the case of the growth rate of sales, investment, sales to capital ratio, investment to lagged capital ratio variables. This result suggests that capital stock and sales are co-integrated, and ECM can be applied in this context.

The empirical results of GMM estimation of the basic firm level investment equation (6) is reported in the column (1) in Table 3. Results reveal that there is a positive relationship between investment in the current period and investment in the previous period as indicated by the positive and statistically significant coefficient, $\beta_1$. Positive and statistically significant $\beta_2$ shows that investment is influenced by the growth rate of sales. The coefficient of the error correction term, $\beta_3$, has got a correct positive sign implying that firms adjusts their actual level of investment temporally so as to maintain the desired level of capital stock in the long run.

As a next step in the analysis equations (9) and (10) are estimated by incorporating energy uncertainty in the basic investment model. To control for energy uncertainty, we have considered two measures of uncertainty: viz, conditional variance of monthly energy price return, $h_t$, approximated as GARCH (1, 1) process and standard deviation of the monthly energy price return ($SD_{it}$). To test the impact of energy price uncertainty on investment though demand side, we have interacted them with growth rate of sales $\Delta logS_{it}$. The results given in the column (2) and (3) in Table 3 show that estimates of variables in the basic investment model remain almost intact despite the introduction of the uncertainty variables. However, even though estimates of both energy uncertainty measures are statistically significant, their sign is contrary to the expectation. This result seems to suggest that the effect of energy price uncertainty on investment in this context cannot be characterized as an indirect link through the demand side. Lee et al. (2011) has reported similar results.

Therefore, to probe further whether investment is getting affected through the supply side of production, equations (11) and (12) are estimated in which energy uncertainty measures are interacted with error correction variable, $\frac{S_{it-1}}{K_{it-1}}$ to gauge the speed of adjustment between actual and desired capital stock. A negative coefficient would imply that energy uncertainty delays firm's efforts to match its actual capital stock with the desired volume of capital in the short run. The results are reported in the columns (4) and (5) in Table 3. The results show that respective estimates are correctly signed and highly statistically significant, implying that energy uncertainty in the form of oil price volatility adversely affects the investment of firms as firms are unable to adjust their actual investment to the desired level in the absence of frictions and thereby the error correction process in the short run becomes slower. In other words, firms become more cautious with respect to investment decisions in the face of higher oil price uncertainty. These findings are consistent with results of previous literature such as Bloom et al. (2007) and Yoon and Ratti (2011) on the theories of partial irreversible investment.

### 5.1. Energy Intensity, Energy Uncertainty and Investment

Given the preliminary evidences consistent with the propositions of the theories of partial investment under uncertainty, we investigate further whether firm's investment response to uncertainty varies according to the energy intensity in the production. The role of energy intensity as a crucial factor capable of influencing the investment in the face of energy related uncertainties are already established in the literature (Fukanaga et al., 2010 and Yoon and Ratti, 2011). Hence we have estimated the equations through (13) to (16) which incorporates multiple influences of oil price uncertainty and energy intensity on firm's investment and as per the principles of theories irreversible investment, we expect that dampening effect of the energy price uncertainty on investment will be reflected in the form of a negative coefficient associated with the interactive variables, ($EI_i{*}h_t$) and ($EI_i{*}SD_{it}$).

The results are reported in column (1) in Table 4. Here also the coefficients of the variables used in the basic firm level investment model are having expected sign and statistically significant. For instance, estimates of the growth rate of sales reveals that a spurt in the demand for the product encourages firms to scale up investment and thereby production to address burgeoning demand. Likewise, the coefficient of error correction process once again reiterates the investment dynamics between short run and long run at the level of firms. In column 1, the result of interest is the coefficient associated with the interaction of energy intensity with $h_t$, - the measure of energy uncertainty. Even though the estimate is statistically insignificant, it is correctly signed indicating that volatility of energy price and consequent business uncertainty has a negative effect on the use of energy resources.

**Table 1: Summary statistics of growth rate of sales, investment and energy intensity**

| Size group | Mean±standard deviation | | |
|---|---|---|---|
| | Growth rate of sales | Growth rate of investment | Energy intensity |
| Decile 1 | 0.184±0.523 | 0.189±0.570 | 0.085±0.940 |
| Decile 2 | 0.163±0.509 | 0.161±0.595 | 0.112±1.872 |
| Decile 3 | 0.135±0.532 | 0.128±0.565 | 0.119±2.957 |
| Decile 4 | 0.114±0.608 | 0.102±0.568 | 0.244±4.455 |
| Decile 5 | 0.092±0.705 | 0.065±0.523 | 0.444±8.450 |
| Decile 6 | 0.051±0.784 | 0.041±0.586 | 0.489±8.642 |
| Decile 7 | 0.007±0.880 | 0.001±0.521 | 0.420±6.307 |
| Decile 8 | −0.014±0.921 | −0.027±0.562 | 0.286±2.026 |
| Decile 9 | −0.126±1.016 | −0.070±0.546 | 0.438±4.388 |
| Decile 10 | −0.138±1.138 | −0.050±0.639 | 0.300±2.352 |

**Table 2: Unit root test result**

| Series | Statistic | Probability |
|---|---|---|
| Investment | 4127.6 | 1 |
| Sales | 5417.8 | 1 |
| Capital stock | 1424.4 | 1 |
| Sales growth | −485.3 | 0 |
| Sales to capital ratio | −881.4 | 0 |
| Investment to lagged capital ratio | −573.4 | 0 |

Levin, Lin and Chu unit root test statistic with individual effects and individual linear trend

**Table 3: GMM estimates of dynamic investment model for panel data: Firm level investment and energy price uncertainty**

| Dependent variable: $\frac{I_{it}}{K_{it-1}}$ | Equation (6) (1) | Equation (9) (2) | Equation (10) (3) | Equation (11) (4) | Equation (12) (5) |
|---|---|---|---|---|---|
| $\frac{I_{it}}{K_{it-2}}$ | 0.0341*** (8.47) | 0.0338*** (8.24) | 0.0334*** (8.37) | 0.0332*** (7.97) | 0.0352*** (8.33) |
| $\Delta logS_{it}$ | 0.9618*** (29.94) | 0.7707*** (7.55) | 0.7959*** (21.32) | 0.9439*** (29.51) | 0.9536*** (26.97) |
| $\frac{S_{it-1}}{K_{it-1}}$ | 0.7085*** (27.63) | 0.7095*** (27.11) | 0.7101*** (26.27) | 0.7477*** (25.47) | 0.7349*** (22.51) |
| $\Delta LogS_{it}*h_t$ | | 2.0101** (2.17) | | | |
| $\Delta LogS_{it}*SD_t$ | | | 5.6196*** (3.96) | | |
| $\left(\frac{S_{it-1}}{K_{it-1}}*h_t\right)$ | | | | −0.5542*** (−4.59) | |
| $\left(\frac{S_{it-1}}{K_{it-1}}*SD_t\right)$ | | | | | −0.7462*** (−5.45) |
| Probability of (J-statistic) | 0.3671 | 0.3894 | 0.4267 | 0.3919 | 0.3691 |

Figures in the parentheses are t-statistics. ***, ** and * indicate statistical significance at 1%, 5% and 10% levels respectively. J-statistic is used as a test of over-identifying moment conditions. Lag 2 of the dependent variable used as an instrument

**Table 4: GMM estimates of dynamic investment model for panel data: Firm level investment, energy price uncertainty and energy ıntensity**

| Dependent variable: $\frac{I_{it}}{K_{it-1}}$ | Equation (13) (1) | Equation (14) (2) | Equation (15) (3) | Equation (16) (4) |
|---|---|---|---|---|
| $\frac{I_{(it)1}}{K_{it-2}}$ | 0.0287*** (5.02) | 0.0278*** (4.86) | 0.0276*** (4.87) | 0.0287*** (5.14) |
| $\Delta logS_{it}$ | 0.9278*** (24.76) | 0.9282*** (24.61) | 0.7242*** (6.56) | 0.7476*** (17.25) |
| $\frac{S_{it-1}}{K_{it-1}}$ | 0.7091*** (26.65) | 0.7153*** (25.67) | 0.7356*** (26.91) | 0.7196*** (26.12) |
| $(EI_i* h_t)$ | −0.9449 (−1.15) | | | |
| $(EI_i* SD_{it})$ | | −5.1362* (−1.86) | | |
| $(\Delta logS_{it}*h_t)$ | | | 2.1363** (2.08) | |
| $(\Delta logS_{it}*SD_{it})$ | | | | 4.4998** (2.95) |
| $(\Delta logS_{it}*EI_i* h_t)$ | | | −0.8572* (−1.92) | |
| $(\Delta logS_{it} *EI* SD_{it})$ | | | | −0.5778 (−0.44) |
| Prob (J-statistic) | 0.4085 | 0.4061 | 0.4064 | 0.4555 |

Figures in the parentheses are t-statistics. ***, ** and * indicate statistical significance at 1%, 5% and 10% levels respectively. J-statistic is used as a test of over-identifying moment conditions. Lag 2 of the dependent variable used as an instrument

In other words, it implies that firms are constrained in the of use of energy resources, at least in terms of intensity of energy use, which indirectly shows that energy uncertainty may have an adverse technological impact and thereby cost implications for the firm. Empirical results reported in column (2) of Table 4 incorporating standard deviation of energy price return as a measure of uncertainty provides satisfactory results which are consistent with the just outlined interpretation (Table 4).

To test further how the effect of energy price uncertainty transpires through energy intensity and growth rate of sales together, we have estimated the equation (15) and (16) in which we have incorporated additional variables, ($\Delta logS_{it}*EI_i*h_t$) and ($\Delta logS_{it}*EI* SD_{it}$), to the basic investment model. The results are reported in columns (3) and (4) in Table 4. These results consistent with the estimates of the basic investment model reported in column 1 of the Table 3 and corroborates the subsequent view expressed there as to energy uncertainty does not appear to have weakened the link between sales growth and investment. That is why estimates attached to variables, ($\Delta logS_{it}*h_t$) and ($\Delta logS_{it}*SD_{it}$), are positive and statistically significant. However, when energy uncertainty measures were interacted with energy intensity and sales growth, ($\Delta logS_{it}*EI_i*h_t$) and ($\Delta logS_{it}*EI* SD_{it}$) the results are having correct sign even though the estimate attached to latter variable is statistically insignificant. The negative sign of the coefficients attached with triple interactive variables compared to the inconsistent positive sign of the estimates of double interactive terms is worth highlighting here. This change essentially supports our earlier view that the negative effect of energy price uncertainty is getting channeled to the firm's investment overtly through the supply side of the production rather than covertly through demand side. That is why positive sign of the double interaction terms changed to the negative sign when we incorporated the variable energy intensity (representing the supply side of the business) into it making the triple interactive variables.

## 6. CONCLUSION

Theory of irreversible investment under uncertainty treats most of the investment expenditures as sunk costs and therefore irreversible once incurred. Whatever researches carried out so far to test this theory at the firm level are mainly based on the developed industrial countries such as the USA. Therefore, the present study attempts to empirically test this theory in Indian context using data from manufacturing firms. Towards that we have estimated a dynamic panel data model extensively used in the literature using the GMM method to take care of the potential endogeneity of explanatory variables. Results reveal evidences in favor of the theory of irreversible investment on the supply side of production as to uncertainty affects the speed of adjustment of error correction process between actual and desired capital stock. Thus, the slackening of the error correction process can be attributed to the cautious approach of investors in the face of uncertainty extensively propagated by the theories of partial irreversible investment.

This study, therefore, calls upon the policy makers to take into consideration the economic and environmental implications of finding that Indian firms are vulnerable to oil price uncertainty. The negative impact of energy uncertainty on investment is also a matter of great concern for India at present from the point of view of employment opportunities for its burgeoning younger population. Therefore, a sustainable approach to tap available energy resources in general and renewable energy sources in particular in India is to be seriously mulled over given the expected rise in the use of energy resources in the future.

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