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Correlating the Chemical Engineering Plant Cost Index with macro-economic indicators

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Abstract

The Chemical Engineering Plant Cost Index (CEPCI) is widely used for updating the capital costs of process engineering projects. Typically, forecasting it requires twenty or so parameters. As an alternative, we suggest a correlation for predicting the index as a function of readily available and forecast macro-economic indicators:

$$CEPCI(n) = 0.135 \cdot CEPCI(k_o) \cdot \exp\left\{A \cdot \sum_{k=k_o}^{n} i_k\right\} + B \cdot P_{oil} + C \quad ,$$

with k_o the first year of the period under consideration, i_k the interest rate on US bank prime loans in year k, and P_{oil} the US domestic oil price in year n. Best fit was obtained when choosing distinct sets of values of the constants A, B and C for each of the three periods 1958 to 1980; 1981 to 1999; and 2000 to 2011. These changes could have resulted from the impact of the oil shocks in the 1970's and very high interest rates in the 1980's, which perhaps heralded changes to the index formula in 1982 and 2002. The error was within 3% in any year from 1958 to 2011, and within 1% from 2004 to 2011 after readjusting the weighting of the price of oil. The correlation was applied to forecast the CEPCI under different scenarios modeled by the Energy Information Administration or predicted from oil futures contracts.

Keywords: Chemical Engineering Plant Cost Index, capital cost estimates, price of oil, interest rates, inflation

1. Introduction

1.1 The Chemical Engineering Plant Cost Index

Process engineers often require to forecast or update the capital cost of new plants as a function of historical data on plants that were previously built.

Cost indices are available for estimating the escalation of costs over the years, from a year *m* where the known or estimated cost is C_m and the index takes the value I_m, to a year *n* where it is C_n and the index takes value I_n. the projected cost in year *n* is then

$$C_n = (I_n / I_m) \times C_m \qquad \text{Eqn (1)}$$

Several indices are available to the process engineer; for example the Nelson-Farrar Refinery Cost Index published in the *Oil&Gas Journal* is widely used in the oil and gas industry; the Marshall and Swift equipment cost index, which was published monthly in *Chemical Engineering* until April 2012 and is now made available online (Marshall & Swift/Boeckh, LLC, 2013) is intended for the wider process and allied industries (chemicals, minerals, glass, power, refrigeration etc.); and the Process Engineering Plant Cost Index published by the UK monthly *Process Engineering* provides data not just for the UK but also for 16 other OECD countries.

However, it seems that the best known process plant cost index worldwide is the Chemical Engineering Plant Cost Index (CEPCI), which has appeared every month in the publication *Chemical Engineering* since 1963. Although it is primarily based on US cost data, the relative lack of local and specialised cost indices for the process industries amongst the countries in the world (according to The Institution of Chemical Engineers, 2000) might explain its widespread adoption. The dominance of the US dollar as an international currency has also favoured the use of an index based in the US. Often, the CEPCI is used alongside a location factor to transpose the estimate from one country to another.

The CEPCI is a composite index, made up from the weighted average of four sub-indices, and currently calculated from the following equation:

$$CEPCI = 0.50675\,E + 0.04575\,B + 0.1575\,ES + 0.290\,CL \qquad \text{Eqn. (2)}$$

where *E* is the Equipment index, *B* is the Buildings index, *ES* is the Engineering and Supervision index, and *CL* is the Construction Labour index (Vatavuk, 2002).

The Equipment index *E* itself is in fact a weighted average of seven components, including: Heat exchangers and tanks; process machinery; pipes, valves and fittings; process instruments; pumps and compressors; electrical equipment; structural supports and miscellaneous.

In turn, each sub-index is the weighted average of sub-indices, derived from monthly Producer Price Indices (PPIs, that are compiled by the US Department of Labor’s Bureau of Labor’s Statistics (BLS) from about 100,000 price quotations issued by about a quarter as many domestically producing companies. Sub-indices or components for which labour costs have a significant influence are discounted by multiplying their labour cost component by a productivity factor (calculated from an average yearly increase of 2.2% in productivity since 2002). Baselines are taken as values of 100 in 1957-1959 for the composite CEPCI and all four sub-indices (Vatavuk, 2002). Finally, although the CEPCI underwent overhauls in 1982 and 2002 which affected the selection of PPIs, the productivity factor and the weighting coefficients in equation (2), it remained unchanged in its basic form and adjustments were made to provide revised indices in years prior to the changes (Vatavuk, 2002).

1.2 Forecasting the Chemical Engineering Plant Cost Index

1.2.1. Micro-economic approach

The composite make-up of the CEPCI suggests that forecasting it requires a piecemeal approach to each of its four components as per Eqn. (2), given that each component is likely to respond differently to factors such as inflation on raw materials, productivity gains, labour costs, etc. In turn, each component could be disaggregated into the relevant sub-indices from which it is made. However, when taken too far, this disaggregation can become difficult. All 53 PPI inputs would require tracking and forecasting, not to mention the added inconvenience that at times some of the PPI components can be modified or even discontinued by the BLS.

These difficulties would suggest using a reduced number of sub-indices as proxies for the whole set. This 'micro-economic' approach was first advocated by Caldwell and Ortego (1975), who proposed a surrogate index that could track the CEPCI by using only five BLS indices: four wholesale price indices (metal tanks; general purpose machinery and equipment; electrical machinery and equipment; and processing materials and components for construction), and one chemical engineering labour index. Earl (1977) found that Caldwell and Ortego's index failed to keep up well with historical data after 1974, and advocated a more disaggregated approach. He kept the main sub-indices and their respective weightings in the CEPCI but substituted 24 variables for the 70 or so that the CEPCI was then using. Importantly, he selected the 24 proxy variables from those amongst the BLS's PPIs for which both historical records and forecasts were available. This basic approach appears to have been retained in modern practice: for example Hollmann and Dysert (2007) quoted that in their experience, no more than 20 or so relevant proxies are applicable to estimating cost escalation of a process plant.

1.2.2. Macro-economic approach

As an alternative to the disaggregation method, straightforward prediction of the CEPCI from more general economic indicators on the cost of materials and labour could also be attempted. Cran (1976) suggested two component indices as effective proxies for major construction engineering indices, including the CEPCI. The two indices that he proposed tracked the costs associated with steel and labour respectively, with the proxy index a weighted average of the two. He found that the resulting index was following the CEPCI pretty closely. However, these correlations may then become too simplistic to withstand major changes in technology, productivity, market or other macroeconomic factors. In the same year as Cran's paper, Styhr Petersen and Bundgaard-Nielsen (1976) observed that his two-component index could not account for productivity gains in assembling plant components, leading to an overestimate for the capital cost of plants in Western Germany between 1973 and 1975. In spite of its flaws, Cran's approach was followed by the PEI index, which was published by the journal *Process Economics International* for 36 countries, and formerly called the Engineering and Process Economics (EPE) index. Styhr Petersen and Bundgaard-Nielsen also suggested that to a lesser extent other multi-component indices would be affected in a similar manner, including the CEPCI.

Nevertheless, the idea that wider macro-economic data can be the sole input parameters is attractive because of the wide availability of data and forecasts for these. In fact, the wider economic activity is not just indicated by the cost of materials and labour as in Cran's model, but can be linked with more general indicators. This type of approach seems to have been initially advocated by Caldwell and Ortego (1975), as an alternative to their own micro-economic approach. They found that simple linear correlations held between the CEPCI and any of the following: the Gross National Product deflator; the Consumer Price Index; the Wholesale Price Index; and other price indices. In all cases the slope of the correlation was close to 1. However, they observed that the actual values of the CEPCI significantly swung cyclically above and below the values predicted by those simple linear correlations. Since then, literature on the topic of correlating the CEPCI with macro-economic indicators appears extremely scarce. A more recent example that we found regarded the Nelson-Farrar refinery cost index rather than the CEPCI, but it evidenced again the type of difficulty Caldwell and Ortego faced when trying this type of approach: Parker (2008) presented a graph where he plotted the fuel cost index against the construction cost index of the Nelson-Farrar refinery cost index from 1930 to 2007. While on a logarithmic scale the construction cost index seemed to be a broadly linear function of the fuel cost index with a slope of 1.00, there were wide swings away from this parity ratio, with vertical and horizontal segments indicating periods of rapid surges and drops of one factor apparently independently from the other. The two indices were correlated to some extent, but they were visibly subject to different influences too. As we shall see later, this may be explained by the fact that correlations are not immediately apparent unless at least two parameters are considered, and the right selection of these parameters is made, including careful appraisal of their degree of mutual correlation.

In fact, econometric methods have been developed since the 1970's outside the field of engineering that more generally model economic variables. A good introduction to these methods for the non-specialist can be found in (Koop, 2000). Of critical importance to these methods is a rigorous handling of time series, in particular with respect to the autocorrelation of the variables, which is the influence that the past values of a variable have on its current value. Another critical aspect of these methods lies in the avoidance of spurious correlations of trended variables (i.e. variables that tend to either increase or decrease monotonically with time), which will inexorably occur as the sample size of the series increases (if only as the ratio of the average rates of change with time of the series). In fact, Caldwell and Ortego's as well as Parker's seemingly good correlations (*op. cit.*) may have been affected by this flaw. Spurious correlation can often be resolved by differencing the variables, however testing for its presence (denoted by the existence of a 'unit root', i.e. the observed variable being correlated with its lagged value with a slope of 1) requires appropriate statistical testing which is not always conclusive if root values are close to 1. In the end, models may be obtained that predict the observed variable as a function of its past values as well as current and past values of the explaining variables, each variable and its lagged values being tested for statistical significance and retained if appropriate. From a practical viewpoint, building and testing these models require specialised software (e.g. Microfit® or Stata®). They may also require as many adjustable parameters as there are variables, including lagged values, thus potentially being as cumbersome as the models derived from the micro-economic approach.

Therefore, it is the aim of this paper is to present a simpler approach that can be readily used by engineers without the requirement for specialist tools; takes into account the influence of past values but with a very small set of adjustable parameters; and still allows effective modelling and prediction of the CEPCI.

2. Methodology

Values for the CEPCI from 1958 to 2010 were taken from Vatuvuk (2002) and *Chemical Engineering*, (2009) and (2012).

From consideration of the process of constructing a plant, we first determine the likely macro-economic factors that seem to impact directly on the capital cost of chemical plants: firstly, finance costs when paying for the project; secondly, market forces such as the balance of supply and demand of materials, equipment, and even labour during design and procurement, contracting and construction; and thirdly, labour productivity and costs during design, construction and commissioning. (We chose to neglect other factors such as taxation and subsidies as they are more site-specific, particular to a given state or region of the world.) The interdependence of these factors means that care is required in selecting macroeconomic indicators that will act as independent parameters in a model for the CEPCI.

2.1 Financial costs

Finance costs play a critical role in the construction of process plants. Prior to the decision on whether or not to invest in the plant and build it, they are typically factored in as “cost of capital” for the purpose of calculating a Net Present Value (NPV). In order for a project to be viable, the NPV must be as high as possible, highlighting the prime importance of financing costs to the industry.

The considerable extent to which financial costs have an impact on cost escalation has been known for a while. Often ‘real’ interest rates in which inflation has been discounted are used in NPV calculations when inflation is not explicitly applied to the data. However in this paper we are seeking to correlate an inflation indicator (the CEPCI) with interest rates, and therefore we wish to exploit this relationship, rather than nullify it through the use of a ‘real’ interest rate. For this reason, we only consider uncorrected interest rates.

The question is then, what is the observed relationship between inflation and interest rates in historical data? Back in 1981, Remer and Gastineau remarked that interest rates (taken as US AAA corporate bonds) and inflation (taken as the rate of increase of the EPE index) tended to cancel each other out for the purpose of calculating NPV on engineering projects, due to a certain degree of correlation between the two. We found that this still applied to some extent throughout the period from 1958 to 2011, for example we found a linear regression coefficient $R^2 = 0.19$ between the CEPCI inflation rate and the yearly averaged rate on prime loans, as shown in Figure 1.

This result is not surprising. It can be expected that any rise in the cost of financing will affect the CEPCI at several levels, from the costs to the company commissioning the plant to the cost of contractors and equipment, with everyone passing on their financing costs to their customers unless competition is significant and margins are wide enough to cushion any rise in interest rates. Conversely, market forces will also influence the cost of financing: depending on inflation figures, Central Banks like the Federal Reserve in the US will sell or buy back securities on the open market and in competition with private investors. While their mandated aim in doing so is to achieve an interest rate that they have set, ultimately the intended consequence is to keep the economy within a safe and fairly narrow window of inflation by controlling the availability of money.

When looking for a suitable indicator for finance costs, we considered both the rates on US AAA corporate bonds (long term) and the rates on US prime loans (short term), the data being collated by the Federal Reserve Bank of

St. Louis and found on their website (Federal Reserve Bank of St. Louis. 2012a) and b)). Both rates are expected to be representative of the range that would be available to industry. In this work, we tested both as parameters, and settled for the one that gave the best fit correlations.

2.2 Market forces and the price of oil

Alongside financing costs, market forces like the balance of supply and demand for raw materials, for plant components and for labour are expected to affect prices significantly. While we have just seen that finance costs are connected to some extent to market forces, we found that the yearly change in the price of oil seems to bear no apparent correlation with interest rates (for example, R^2 = 0.0004 with rates on prime loans from 1958 to 2011, as shown in Figure 2; and still R^2 = 0.014 when replacing the yearly change in the price of oil by the yearly % change in the price of oil). Therefore, we chose the price of the barrel of oil as our second indicator, as a major driving force for inflation that will gauge the state of the market fairly independently from interest rates. The historical data for US domestic crude oil prices was taken from (Illinois Oil and Gas Association, 2012), however other benchmarks could also be used (e.g. Brent or WTI). For the same type of reason that we chose to use raw interest rates rather than real interest rates, the yearly averages for the price of oil were taken without discounting inflation, i.e. we believe that the CEPCI being an escalation index it may as well be accounted for by inflation in the price of its contributing factors.

2.3 Productivity and the cost of labour

Finally, we also attempted to consider productivity and the cost of labour as a factor influencing the CEPCI. The relevant index that combine these two elements is the unit labour cost (in US $ labour cost per US $ output) published by BLS. However, we found some degree of linear correlation between the % change over a year of the unit labour cost and the interest rates (R^2 = 0.45 over the period 1958 to 2011 when considering prime loan rates, as shown in Figure 3). It might be that low interest rates encourage investments that increase productivity, and therefore push down the unit labour cost; conversely, high interest rates might discourage investments in productivity. Therefore, including interest rates might indirectly account for some at least of the effects of changes in productivity.

2.4 Parameters and method of the model

Starting with these datasets, we attempted to correlate the CEPCI linearly with either the yearly average of the price of US crude oil (in $US/bbl), $P_{oil}(n)$, or the yearly average of interest rates on prime loans (%), i_n. In order to distinguish between temporary effects and long term effects of the changes in the price of oil and in the interest rates, we also introduced integrated indices of these parameters. This approach was inspired by the following consideration: all along the supply chain that leads to the construction of a chemical plant, one would expect successive suppliers to pass on their operating and financing costs to their customers, who themselves are suppliers to other customers; so it is not unreasonable to expect that hikes in costs are more likely to be fully passed on than savings.

With oil, we simply assumed a certain percentage of the costs could translate into long term inflation. The resulting cumulative oil index $I_{oil}(n)$ in year n is the integral of the price of oil, P_{oil} from 1958 to year n, with a basis value of 100 ($US/bbl)·yr in 1958,

$$I_{oil}(n) = 100 + \sum_{k=1958}^{k=n} P_{oil}(k) \qquad \text{(Eqn. 3)},$$

For the cumulative interest rate index $I_{int}(n)$ in year n, we first considered compounding the yearly interest rates on prime loans from 1958 to year n, with a basis value of 100 %·yr in 1958. However, we found it difficult with this approach to take into account the proportion of escalation in costs that was represented by financial costs, and also maintain the proportion of financial costs to the CEPCI into a reasonably narrow range. We resolved these difficulties after we stepped back to a differential formulation of the problem,

$$\frac{\partial CEPCI(n)}{CEPCI(n)} = A \cdot i_n \qquad \text{(Eqn. 4)}$$

where $\partial CEPCI(n)$ is the variation of CEPCI attributable to interest rate i_n on year n when all other variables are held constant, and A is a proportionality constant between the relative increase in the CEPCI and the interest rates. On integrating,

$$CEPCI(n) = \Gamma \cdot CEPCI(1958) \cdot \exp\left\{ A \cdot \sum_{k=1959}^{n} i_k \right\} + F(X,n) \qquad \text{(Eqn. 5)},$$

in which Γ is a constant representing the proportion of CEPCI in 1958 that could have been attributed to current year and prior financing costs, and $F(X,n)$ is a function of all the variables other than the i_k's. The resulting cumulative index then takes the values

$$\begin{aligned} I_{\text{int}}(1958) &= \Gamma \cdot CEPCI(1958) \\ I_{\text{int}}(n)_{n \geq 1959} &= I_{\text{int}}(1958) \cdot \exp\left\{ A \cdot \sum_{k=1959}^{n} i_k \right\} \end{aligned} \qquad \text{(Eqn. 6)}$$

Having now selected our parameters $P_{oil}(n)$, $I_{oil}(n)$, i_n, and $I_{int}(n)$, we first attempted correlating the CEPCI with each of these separately, and if the fit was promising we tried to correlate the *difference* between the CEPCI and the fit given by the first parameter, by a second parameter.

3. Results

In the following we considered the rates on US prime loan rather than US AAA corporate bonds. Both gave similar results.

In table 1, we reported the extent of the linear correlations between the CEPCI and each of the four parameters that were introduced in the previous section. It can be seen that the best fits were achieved for the cumulative index for interest rates and the cumulative price of oil, with (R^2) values in the range 0.93-0.96. The price of oil was also quite a strong factor. Interest rates in themselves did not seem a determinant at all at R^2 = 0.0025, but the *cumulative* index for interest rates achieved the highest fit at R^2 = 0.958 (with A and Γ arbitrarily set at 0.2 and 1, respectively – these values constituted an initial guess, and it so happened that they produced a good enough correlation to warrant retaining the cumulated interest rate as a parameter before further optimising them).

However, the very high coefficient of correlation for the CEPCI with each of the two cumulated indices must be taken with caution: all three of these time series were in fact trended, in the sense that they all mostly increased with time, and hence they would necessarily present an apparent degree correlation with each other of a spurious nature (if only by the ratio of their respective average rates of change). A more meaningful indication of correlation between any two of them could be obtained by correlating their yearly rates of change, which tends to remove the effect of yearly trends (Koop, 2000). Thus, when correlating the % rate of change of the CEPCI with the rate of change of the cumulated interest rate index, we obtained the previously reported Figure 1, i.e. R^2 = 0.19. On the other hand, correlating the % rate of change of the CEPCI with the price of oil (i.e. the rate of change of the cumulated price of oil) gave a value R^2 = 0.05 (Figure 4), i.e. the cumulated price of oil was in fact barely worth considering on its own.

By contrast, the price of oil on the current year of the CEPCI seemed to have a much larger impact than its cumulated impact over the previous years. A plot of the CEPCI against the prices of oil (Figure 5) showed three distinct periods: From 1958 to 1980, the CEPCI seemed to increase with the price of oil in an approximately linear fashion; from 1981 to 2003, the CEPCI seemed to vary independently from the price of oil; and from 2004 to 2011, the CEPCI again seemed to increase with the price of oil in an approximately linear fashion but at less than half the rate that was observed during the first period.

Therefore, tentatively we retained the price of oil and the integrated interest rate index as parameters. We then attempted to optimize the linear fit for the function

$$f(\Gamma, A) = CEPCI(n) - I_{int}(n) \quad \text{(Eqn. 7)}$$

to match the price of oil, separately for each of the three periods that were identified in Figure 5 (allowing, if necessary, minor changes of boundaries). The result is shown in Figure 6. We found that the following correlation applied:

$$CEPCI(n) = 0.135 \cdot CEPCI(1958) \cdot \exp\left\{ A \cdot \sum_{k=1958}^{n} i_k \right\} + B \cdot P_{oil} + C$$

(Eqn. 8)

with the parameters *A*, *B* and *C* taking the following values over the following periods:

- From 1958 to 1978, *A* = 1.7; *B* = 1.616 (bbl/US \$); *C* = 79.5,
  with *A* dropping to 0.34 in 1979-1980.
- From 1981 to 1999, *A* = 0.34; *B* = 0.322 (bbl/US \$); *C* = 160.
- From 2000 to 2011, *A* = 0.54; *B* = 1.806 (bbl/US \$); *C* = 95.7.

The match between this model and the CEPCI can be seen in Figure 7. The deviation of the model with respect to CEPCI is shown in Figure 8. The error was within ±3% over the period 1958-2011 (or slightly over at 3.2% in 1965 and 1989), and it could be reduced to within ±1% over the period 2004-2011 after readjusting the weighting of the price of oil – this is discussed in the next section.

The same type of approach failed when trying to correlate the function $CEPCI(n) - \alpha \cdot I_{oil}(n)$ (with α an adjustable parameter) with any of the indices related to the interest rates.

4. Discussion

4.1 Respective influence of oil prices and interest rates

On Figures 5 and 6, the lack of influence of the price of oil on the CEPCI in the 1980's and 1990's may simply reflect the decrease in energy intensity within the process industries after the two oil shocks of the 1970s (the two successive rises of the oil prices during this period are very visible on Figure 5). By the early 1980s, the process industries had adapted and built resilience to high oil prices, but the subsequent drop in prices did not result in a drop in CEPCI. Instead, the CEPCI remained relatively flat for a few years even though the price of oil dropped significantly during the 1980s (Figure 1). When the prices began rising again, the CEPCI was seemingly unaffected up until 2004 when it reached the value of its previous peak again (yearly average US$ 37.7/bbl in 2004) and stayed above this value in the following 7 years. During this later period, the CEPCI increased almost linearly with the price of oil. From 2004 to 2011, the CEPCI varied linearly with the price of oil within 5%.

Perhaps surprisingly at first, the weighing of the price of oil in the correlation for the CEPCI from 2000 to 2011 is close to what it was in the period 1958-1980. At this point it is good to remember that P_{oil} was chosen as an indicator of the general health of the market regarding demand and supply, rather than just reflecting energy costs.

A comparison of Figure 2 with Figure 1 shows that the intermediate region between 1980 and 1999 has been flattened in Figure 2 once the high interest rates of that period have been discounted.

Changes in the value of the parameter *A* between the three periods, 1958-1978; 1979-1999; and 2000-2011 will be related to levels of investment in the manufacturing industry. The drop in value of *A* from 1.7 to 0.34 after 1978 might be explained in part as a consequence of exceptionally high interest rates in that period (mostly above 8% from 1979 till the late 1990s). These high rates would have discouraged new investments by companies concerned about reining in their financing costs. Consistent with this view, the average yearly rise in productivity was only 1.6% during the period 1979-1999, as compared with 2.5%.over the previous period (1958-1978) and 2.36% over the next period (2000-2011) (these figures were computed from BLS data taken from series PRS85006091 for the non-farm business sector, which is also the one used for evaluating labour costs in the CEPCI).

4.2 Further improvements to CEPCI and its estimates

We found that the accuracy of the correlation over a limited number of years could be excellent when using US prime loans. The following formula was found to predict the CEPCI within less than 1% from 2004 to 2011:

$$CEPCI(n) = 0.135 \cdot CEPCI(1958) \cdot \exp\left\{ A \cdot \sum_{k=1959}^{n} i_k \right\} + 1.64 \cdot P_{oil} + 107$$

$$2004 \le n \le 2011 \qquad \text{(Eqn. 9).}$$

where the values for *A* were specified when introducing Eqn. (8).

This is much better that the 5% or so accuracy that can be found from linear interpolation using the price of oil over the same period.

4.3 Accuracy of Eqn. (9) when applied to 2012 data

2012 data became available after this paper was submitted for publication. Encouragingly, Eqn. (9) still held when applying the 2012 values for US prime loan rates and US domestic oil prices to it (3.25% and US$ 86.46, respectively): The computed value was 589.6, compared with the actual value of 584.6, i.e. less than 1% error.

4.4 Forecasting the CEPCI in the next few years

For ease of use, Eqn. (9) is rewritten by substituting the value of

$0.135 \cdot CEPCI(1958) \cdot \exp\left\{A \cdot \sum_{k=1959}^{2012} i_k\right\} = 340.7$ into Eqn. (9), thus giving

$$CEPCI(n) = 340.7 \cdot \exp\left\{0.54 \cdot \sum_{k=2013}^{n} i_k\right\} + 1.64 \cdot P_{oil} + 107$$

$$2013 \le n \qquad \text{(Eqn. 10).}$$

Forecasting the CEPCI using Eqn. (10) requires a forecast of future interest rates and oil prices.

4.4.1 Forecasting interest rates

Forecast data on interest rates is available from some institution who developed suitable macro-economic models, e.g. the Financial Forecast Centre (at the time of writing, three year extended forecast can be bought from them for a fairly modest fee of about US$ 30; clients seem to include well known worldwide companies) (Financial Forecast Centre, 2013). However, one can attempt a guess from statements issued by the Federal Reserve.

US interest rates are strongly influenced by the target federal funds rate set by the Federal Open Market Committee (FOMC), which comprises the seven members of the Board of Governors of the Federal Reserve System and the 12 presidents of the Federal Reserve Banks. In its recent report to Congress, (Federal Open Market Committee, 2013), the FOMC stated that the majority of its members felt that the current economic climate required maintaining the base rate at 0.25% till 2015. In 2015, all but one member suggested a rise in interest rates would occur by the end of the year, the majority of them suggesting that the rates should be set between 0.5 and 1.25% by the end of 2015, the median being at 1%. The 'long term' value was expected to be set between 3.5% and 4.5% by all but one of the members, with a median value of 4%.

In practice, the effective rate may not quite match the target rate but should be quite close. In fact, the data for target rates can be painstakingly collated from press releases by the FOMC, and that for effective rates is available in tabulated form from e.g. (Federal Reserve Bank of St. Louis, 2012 c)). We performed a spot check on the period 2003-2008 and found that the yearly averages for the two agreed within 3% relative difference between 2003 and 2007, although 2008 produced an error of 9% as the financial crisis unfolded (Figure 9). In turn, the prime bank loan rate correlates very well with the effective federal funds rate with a slope of practically 1 and an offset of 3% point, as shown in Figure 10 for the period 2000 to 2012 (R^2 = 0.9993). In conclusion, it seems reasonable to forecast the prime loan rate by simply adding 3% point to the forecast target federal funds rate.

4.4.2 Forecasting oil prices

Oil companies will have their own forecast of oil process which will be necessary for planning their operations, but these are not publicly available. Forecast is also made by governmental and intergovernmental institutions using macroeconomic models, e.g. by the US Energy Information Administration under certain assumptions that include US and global GDP growth as well as monetary policies and a host of other factors. It has also been proposed to use Oil Futures Contracts as forecast for the price of oil (Chinn and Coibion, 2013), since their values represent a compromise between the estimates of those who buy them having factored in the risk that the prices will be higher, and those who sell them having factored in the exact opposite risk.

4.4.3 Forecasting the CEPCI

For the purpose of illustrating the application of Eqn. (9) to forecast and sensitivity analysis, we used the 2013 forecast produced by the US Energy Information Administration (EIA) for interest rates and oil prices, under a number of different scenarios:

- "**Reference**" (US real GDP growth is 2.5% p.a. and Brent spot prices rise from US$ 96.81 in 2013 to US$ 163 in 2040 (in 2011 US$))
- "**High growth**" (associated with lower interest rates; as in reference case, but US real GDP growth is 2.9% p.a.)
- "**Low growth**" (associated with higher interest rates; as in reference

case, but US real GDP growth is 1.9% p.a.)

- "**High oil price**" (as in reference case, but Brent spot prices rise to US$ 237 in 2040 (in 2011 US$), pushed by global growth and tight supply of oil)
- "**Low oil price**" (as in reference case, but Brent spot prices drop to US$ 75 in 2040 (in 2011 US$), depressed by slow global growth and oversupply of oil)

(US Energy Information Administration, 2013)

Noting that the EIA used the West Texas Intermediate (WTI) benchmark as its reference for crude oil price, we first correlated to it the Illinois Oil and Gas Association (IOGA) which we had used for Eqn. (9). Historical data for the WTI was taken from (BP, 2013), and it was found that the IOGA was obtained by multiplying the WTI by 0.9114 to a very good approximation (R^2 = 0.994 between 1976 and 2012). In addition, the oil prices were brought back to current year values using the price index from the same set of EIA data. We also noted that the EIA forecast for effective federal funds rates in the reference scenario was consistent with the FOMC's recent report to congress (FOMC, 2013) except for 2015 where it was higher. For the sake of using a consistent set of data for oil and rates, we chose to retain the EIA forecast rates, to which we added 3% point to estimate the prime loan rates as described in section 4.4.1. it is worth also mentioning that on inspecting the EIA forecast data, switching between the high and low oil price scenarios resulted in fairly minor changes to the interest rates up to 2020 when compared with the effect of GDP growth, consistent with our finding in section 2.2 that the two parameters were fairly independent from each other.

In addition to the EIA scenarios, we added a sixth scenario, "**Futures**", in which we combined the interest rates from the EIA reference case with the forecast given by the oil future markets (CME group, 2013). A plot of how the oil prices compare for the different scenarios is given in figure 11. Interestingly, the markets seem to "think" that the EIA's reference forecast is an overestimate, and is in closer agreement with the low oil price scenario.

Table 2 and Table 3 present the values of the prime loan rates and oil prices, respectively, under the different scenarios. Table 4 and Figure 12 present the forecast values of the CEPCI under these different scenarios as predicted by eqn. (10).

The results clearly indicate that the CEPCI forecast will be strongly influenced by the forecast for the price of oil, with values ranging from 605 in the low oil price scenario to 754 in the high oil price scenario, i.e. an increase of 25%. This amount of variation could impact on the economic viability of a project. However one could perhaps follow the trend indicated by the oil futures contracts as an indication of the most likely outcome according to the markets (indicated by the dashed line on Figure 12).

Figure 12 would seem to suggest that interest rates hardly matter when in fact they do: it is just that there is too little variance in interest rates between the scenarios that have been considered here to show any impact. If interest rates were kept at the very low levels where they currently are (3.25% for prime loan), this would remove 40 points from the CEPCI compared with the reference scenario in 2020, as can be found from Eqn. (10).

4.5 Limitations, enhancements and extensions to this approach

In spite of the apparent success of this approach in describing the changes in the CEPCI with a very small number of variables, there will remain omitted variables. Although the effect of some of these omitted variables on the index will be partly or wholly transmitted through co-linearity with the used variables, some influence may still remain unaccounted for. Another difficulty of the approach lies in accounting for ‘structural breaks’, i.e. abrupt changes in economic fundamentals such as oil shocks or deep recessions that may affect the values of the constants in the correlation.

It must also be noted that the actual rates available to the industry may be still different than those indicated here. Markets for the chemical industry are known to be cyclical and volatile, with alternating periods of tight supply and overcapacity – the resulting rates may reflect the associated risk by being even higher than the ones we used.

More generally, it is important to reflect on the inherent limitations in accuracy of an index like the CEPCI. In recent years, the CEPCI and other indices seem to have struggled to follow very volatile prices. The Association of Cost Engineers (ACostE) announced in 2008 that it would stop publishing updates to its Cost Engineers’ Index pending further review and consultation with members (ACostE, 2008). It stated that ”significant price increases (were) being reported anecdotally from various sources” of a magnitude such that the index “may no longer provide an appropriate guide to changes in the erected costs of process plants in the UK”. In the same year, Hollman and Dysert (2008) also emphasized that real costs were the result of “competitive bidding (usually with few bidders in a tight market)”, and will depart from estimates that are based on government-input measures like the BLS’s PPIs. Thus, they concluded, indices such as the CEPCI are missing out on market intelligence that becomes particularly critical to the pricing of large projects which only a limited number of players can deliver, and these indices cannot account for a situation where bidders are few and demand is rocketing up (as it already was in 2008 on the part of the Asian economies). These authors demonstrated the use of a ‘capex market adjustment factor’ to correct the CEPCI as a function of the state of the market, an approach that could easily be applied to the CEPCI estimates as obtained by the methods that have been proposed in this paper.

Ultimately, it is hoped that the method presented in this work should allow fairly straightforward and accurate forecasting of capital costs for industrial process plants. If the relationship that is presented here between the CEPCI, interest rates and the price of oil is upheld in the future, this model could help remove or manage uncertainty on the forecast of capital cost for new projects, since it clearly pegs the CEPCI to the wider economic outlook. One can model how the CEPCI varies depending on forecast oil prices and interest rates, thus informing investment decisions on building or not building a plant.

The implications concerning chemical plants for the manufacturing of alternative fuels are worthy of interest: while the price of oil sets a benchmark against which the production cost of an alternative fuel must compare favourably, it also impacts on the capital expenditure that is required for building the plant. The evaluation of this type of impact for the techno-economic assessment of such projects was in fact the starting point for this work.

Finally, it is interesting to note that the method proposed here could be extended to other cost indices.

5. Conclusions

From 1958 to 2011, an effective correlation was

$$CEPCI(n) = 0.135 \cdot CEPCI(k_o) \cdot \exp\left\{A \cdot \sum_{k=k_o}^{n} i_k\right\} + B \cdot P_{oil} + C \qquad \text{(Eqn. 8)}$$

with k_o the first year of the period under consideration, i_k the interest rate on US bank prime loans in year *k*, and P_{oil} the price of oil in year *n.* Best fit was obtained when choosing a distinct set of values of the constants *A*, *B* and *C* for each of the three periods 1958 to 1980; 1981 to 1999; and 2000 to 2011.

The error was within ±3% over the whole period (1958-2011). The error was reduced to within ±1% over the period 2004-2011 after readjusting the weighting of the price of oil, compared with ±5% from linear fitting as a sole function of oil prices. The same model also correctly predicted the 2012 value with the same accuracy. Forecasts were also presented for a range of scenarios, using available forecasts for interest rates and oil prices.

Future research could focus on developing this approach using actual interest rates as experienced by industry. It will also be interesting to track the robustness of the correlation when the circumstances change, for example rising interest rates, greater competitiveness of bidders from rising world economies, or further improvements in energy efficiency in the process industries as a whole.

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TABLE 1

Table 1: Initial attempt at correlating the CEPCI with the selected macro-economic indicators

First parameter	Interest rates	Cumulative interest rate	Price of oil	Cumulative price of oil
Linear regression coefficient (R^2)	0.0025	0.958	0.719	0.934

TABLE 2

Table 2: Prime loan rates (%) in the 2013 Energy Information Administration scenarios ("reference", "high growth", "low growth").

Year	**Reference**	**High growth**	**Low growth**
2013	3.11	3.3	3.06
2014	3.17	3.73	3.17
2015	4.81	6.48	4.83
2016	6.56	6.52	6.83
2017	6.89	6.29	7.44
2018	6.92	6.31	7.76
2019	6.96	6.37	8.2
2020	7.04	6.5	8.52

TABLE 3

Table 3: IOGA, non-deflated oil prices in the 2013 Energy Information Administration scenarios ("reference", "high price", "low price") and in the "futures" scenario. All values are in US $ / bbl.

Year	Reference	High price	Low price	Futures
2013	82.78	82.78	82.78	91.15
2014	84.45	109.03	72.69	87.63
2015	85.64	122.3	68.93	80.96
2016	90.06	135.1	67.06	77.01
2017	96.21	142.9	66.09	74.83
2018	100.4	148.9	67.46	73.45
2019	104.7	155.0	68.84	72.86
2020	108.8	161.0	70.27	72.10

TABLE 4

Table 4: CEPCI forecast for the different scenarios ("reference"; "high growth"; "low growth"; "high oil price", "low oil price"; and "Futures").

Year	Reference	High growth	Low growth	High oil price	Low oil price	Futures
2013	583.7	584.0	583.6	583.7	583.7	597.4
2014	586.77	588.1	586.6	627.0	567.4	591.9
2015	592.0	597.0	592.0	652.2	564.6	584.3
2016	606.0	610.5	606.4	679.8	568.2	584.6
2017	623.5	627.0	625.0	700.1	574.1	588.4
2018	638.1	640.4	641.3	717.6	584.0	593.8
2019	652.9	654.1	658.8	735.4	594.2	600.8
2020	668.0	668.1	677.1	753.6	604.8	607.8

CAPTIONS FOR FIGURES

Figure 1: Yearly % change in CEPCI plotted against yearly averaged prime loan interest rates, from 1958 to 2011.

Figure 2: Yearly change in price of oil plotted against yearly averaged prime loan interest rates, from 1958 to 2011.

Figure 3: Yearly % change in unit labour cost plotted against yearly averaged prime loan interest rates, from 1958 to 2011.

Figure 4: Yearly % change in CEPCI plotted against yearly averaged price of oil, from 1958 to 2011.

Figure 5: CEPCI plotted against the price of oil. Key: Δ 1958-1980; X 1981-1999; ♦ 2000-2011.

Figure 6: Optimized correlation between the CEPCI minus the cumulative interest rate, and the price of oil from 1958 to 2011 (with parameter value $\Gamma = 0.27$ optimized over the whole period, and *A* optimized for each of the three periods 1958-1978; 1979-1999; 2000-2011). Key: Δ 1958-1980; X 1981-1999; ♦ 2000-2011.

Figure 7: Comparison between the CEPCI (plain, thick line), and the CEPCI reconstructed from the optimized model (symbols). Key: Δ 1958-1980; + 1981-1999; ♦ 2000-2011.

Figure 8: % error between the result of applying the model and the CEPCI between 1958 and 2011.

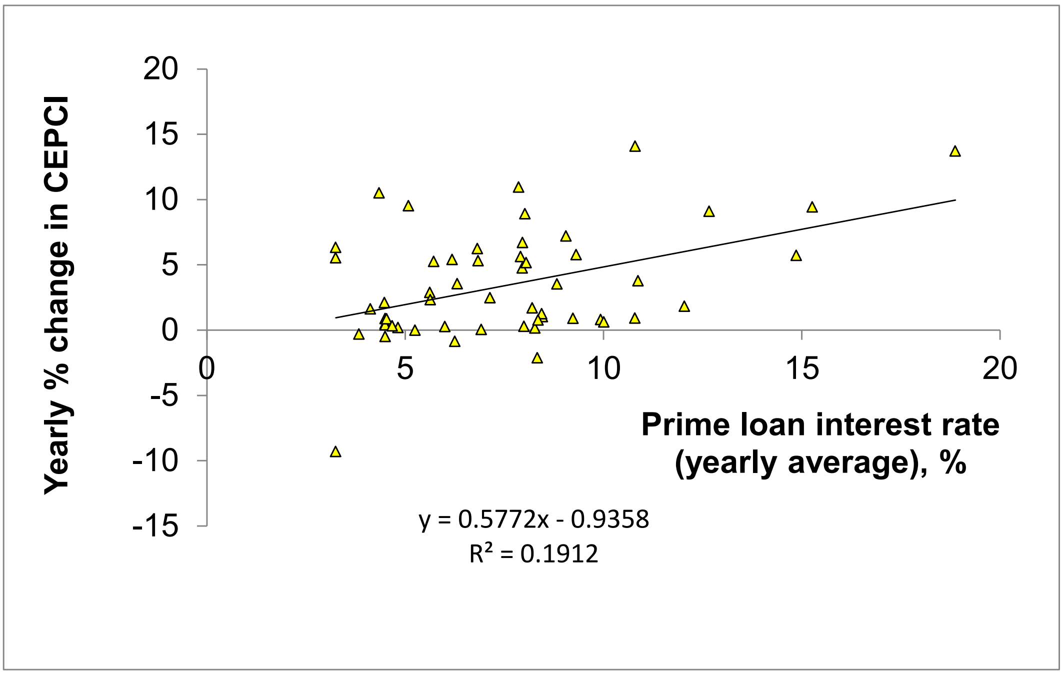
Figure 9: correlation between effective and target federal funds interest rates between 2003 and 2008

Figure 10: correlation between prime loan interest rates and effective federal funds rate between 2000 and 2012.

Figure 11: Forecast of oil prices in the different scenarios. Key: - - - Futures; O Reference; ♦ Low oil prices; ◊ High oil prices.

Figure 12: Forecast of CEPCI in the different scenarios. Key: - - - Futures; O Reference; + Low growth; x High growth; ♦ Low oil prices; ◊ High oil prices.

FIGURES



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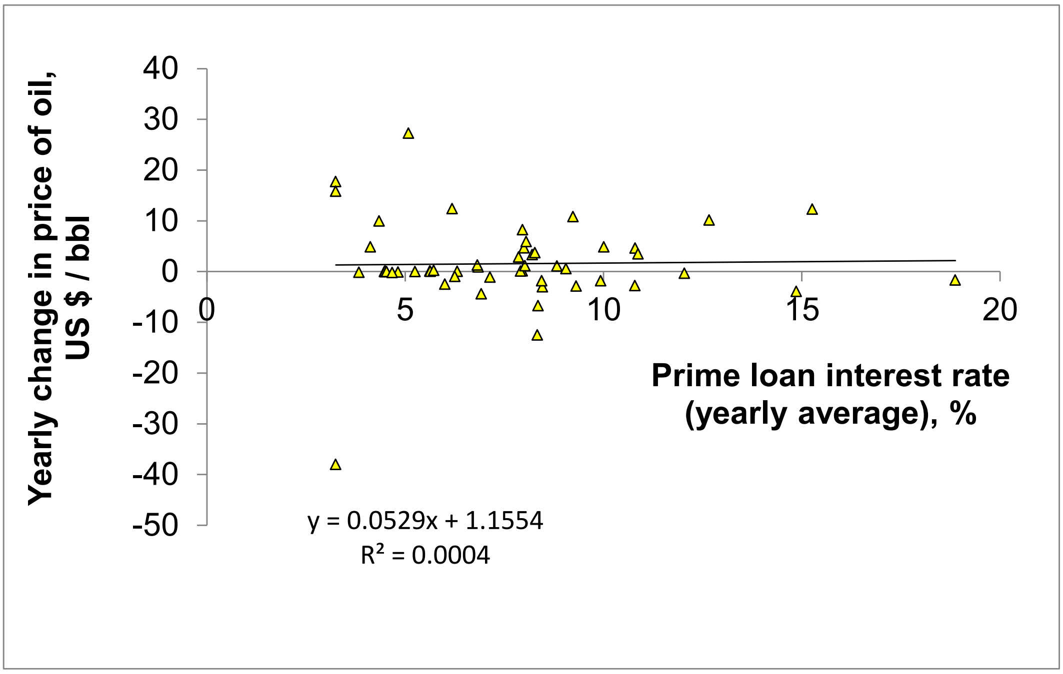

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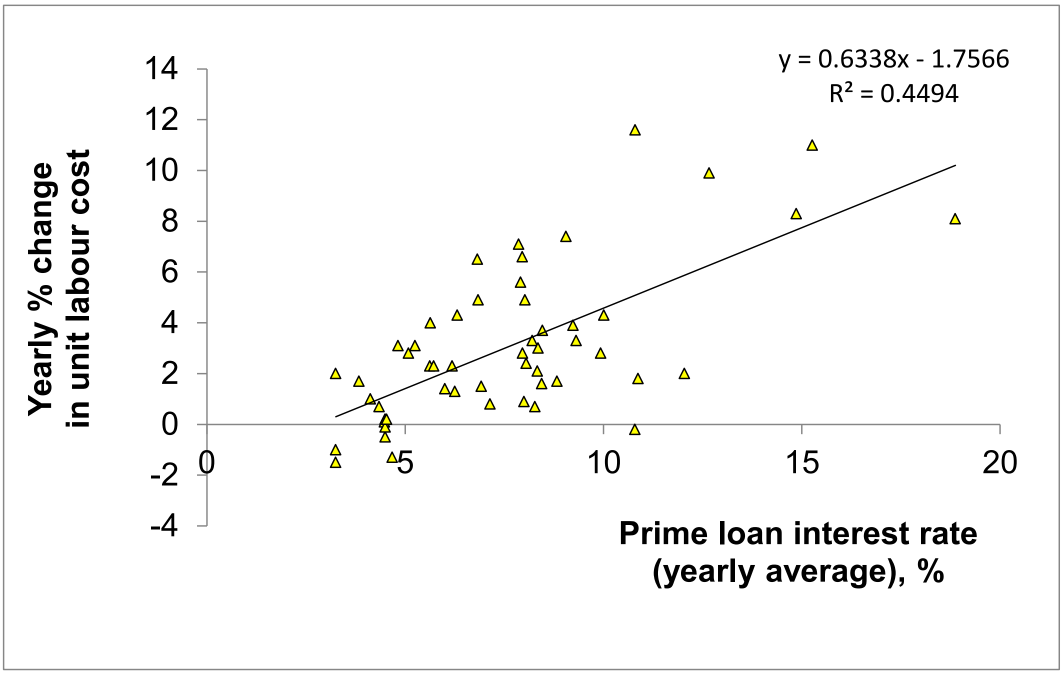

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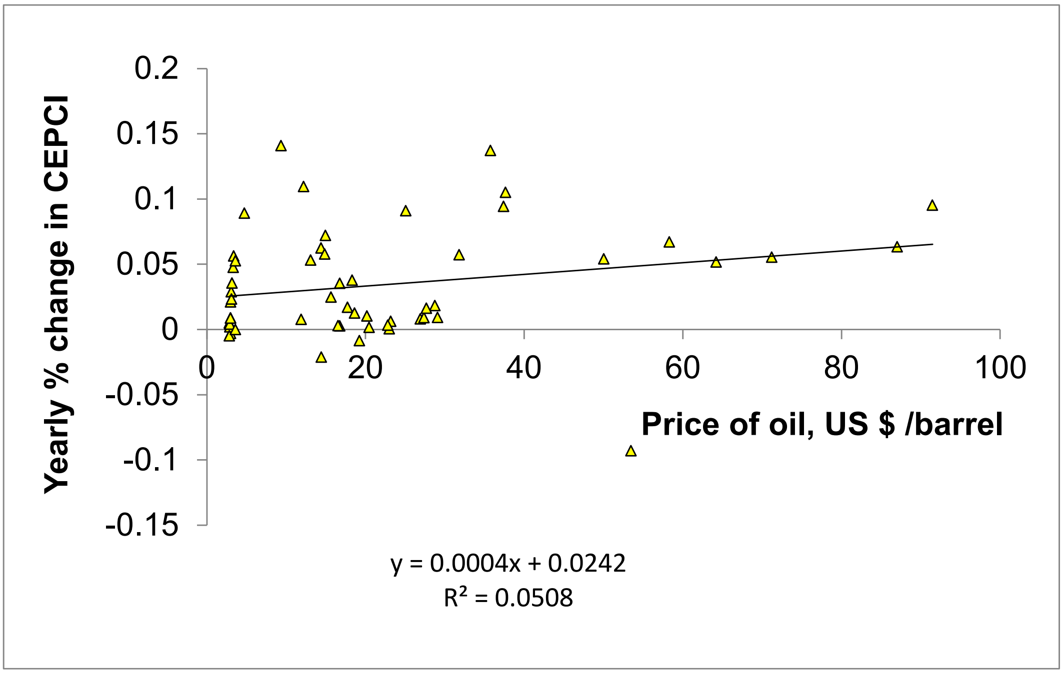

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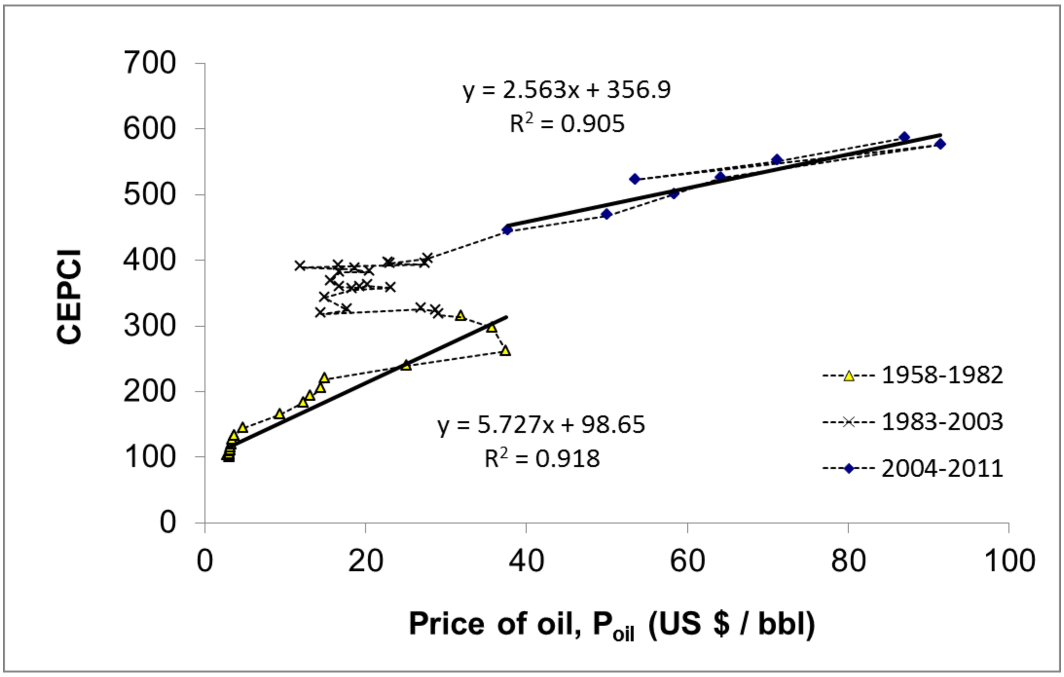

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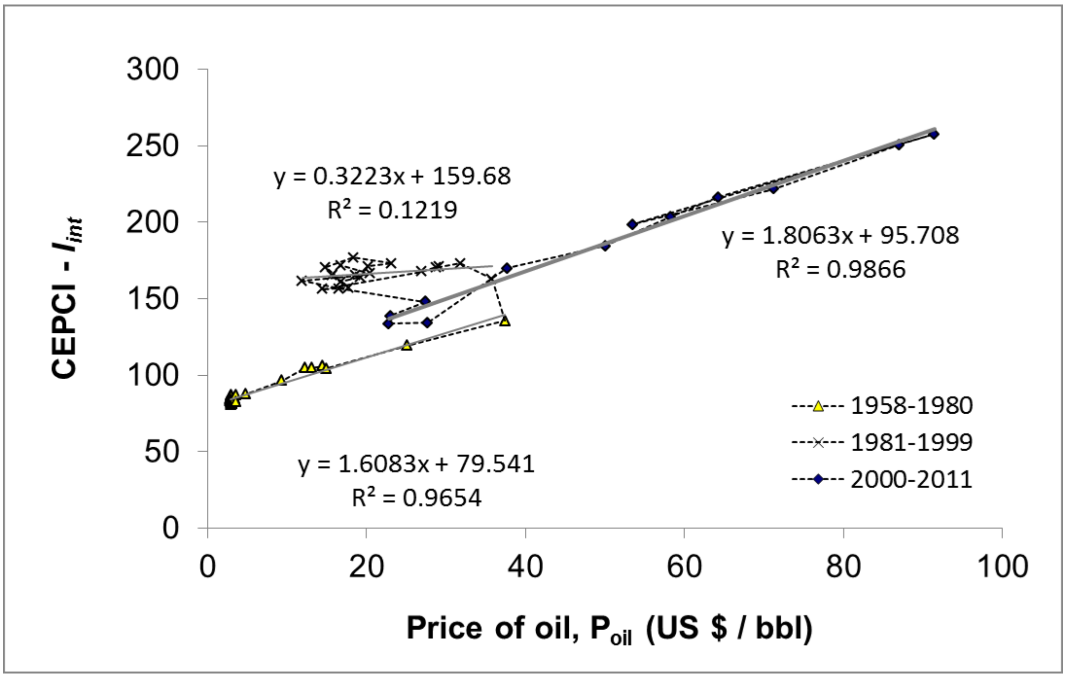

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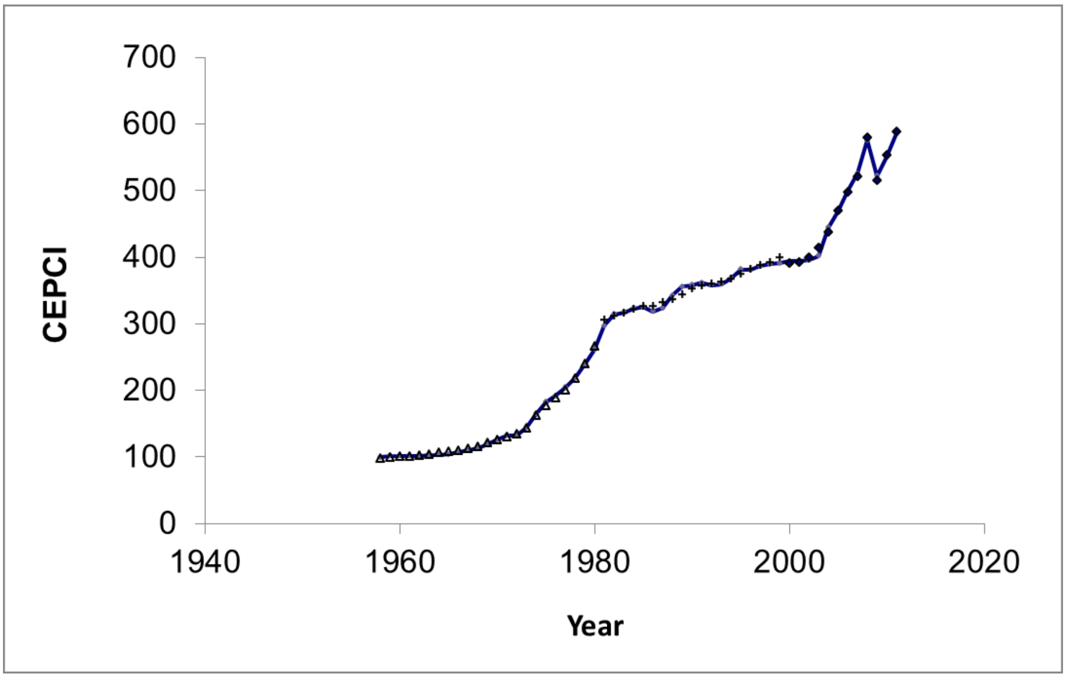

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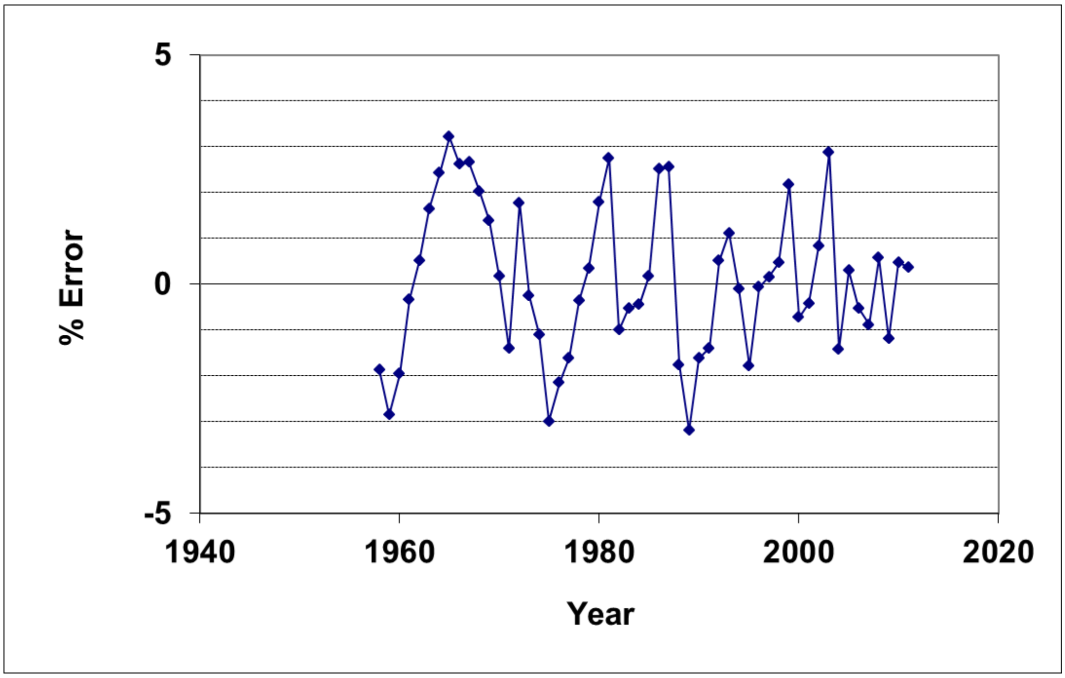

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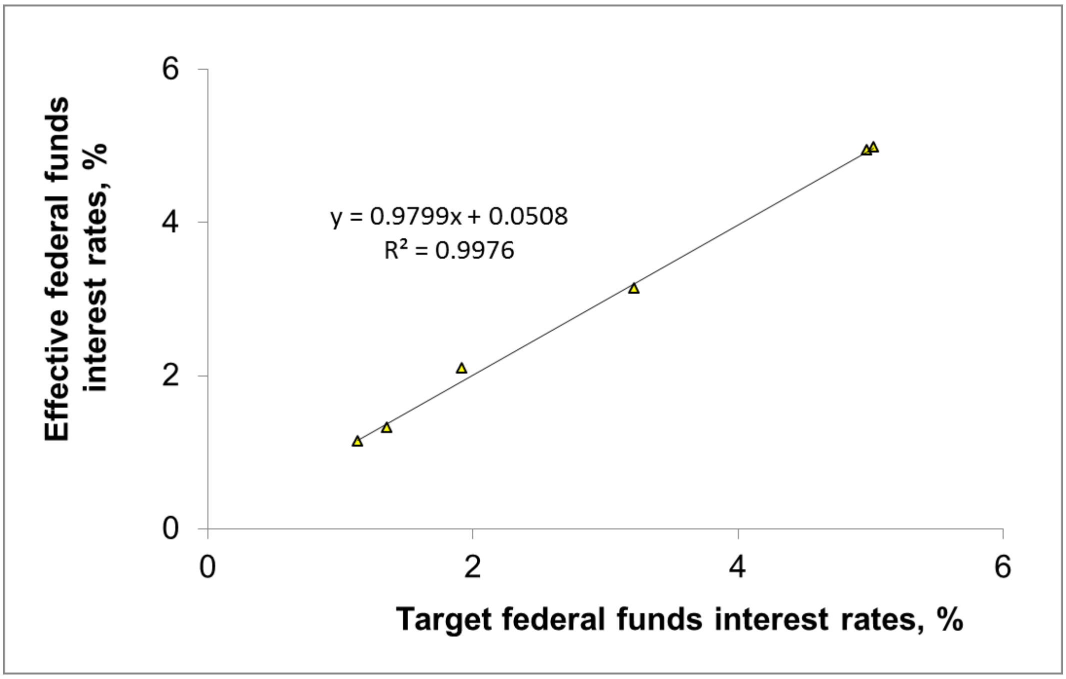

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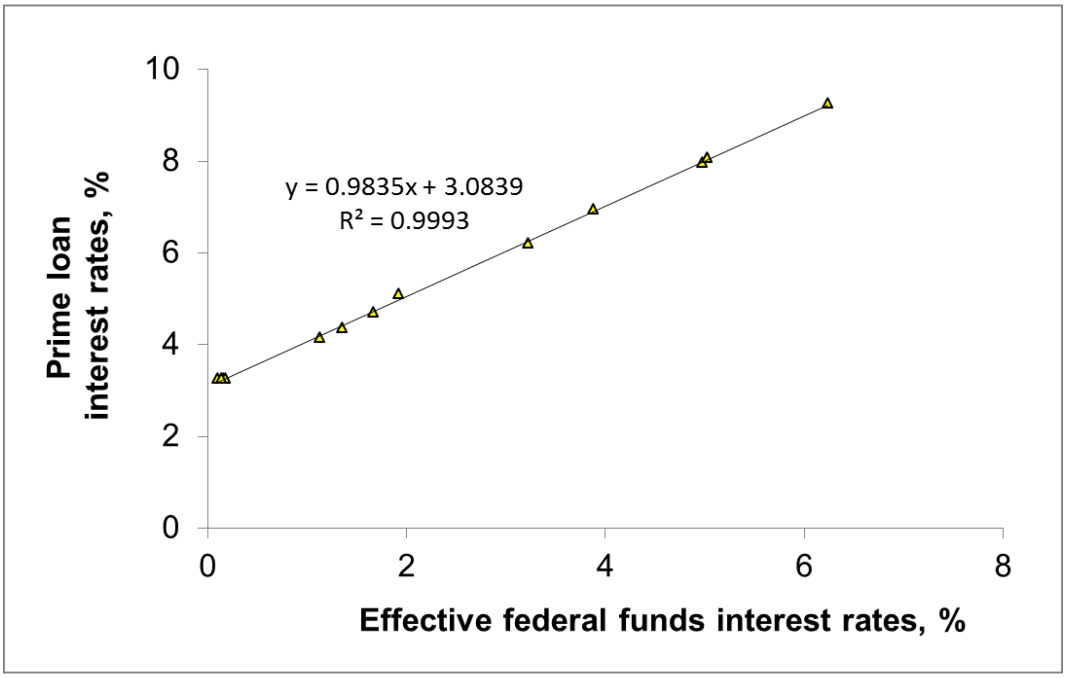

Figure 10

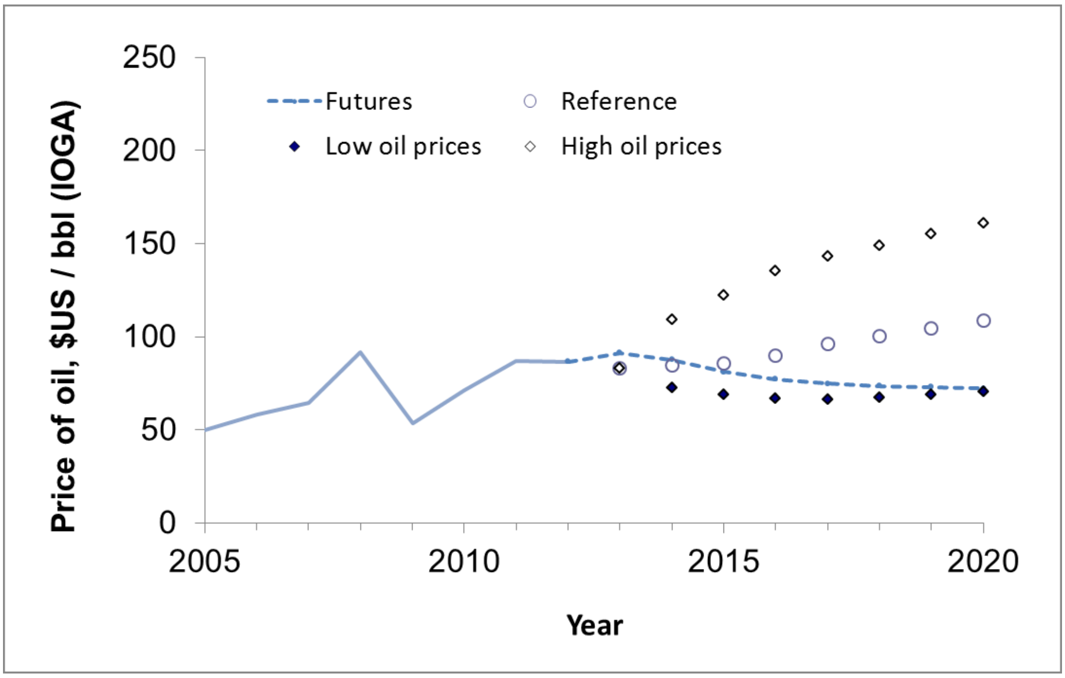

Figure 11

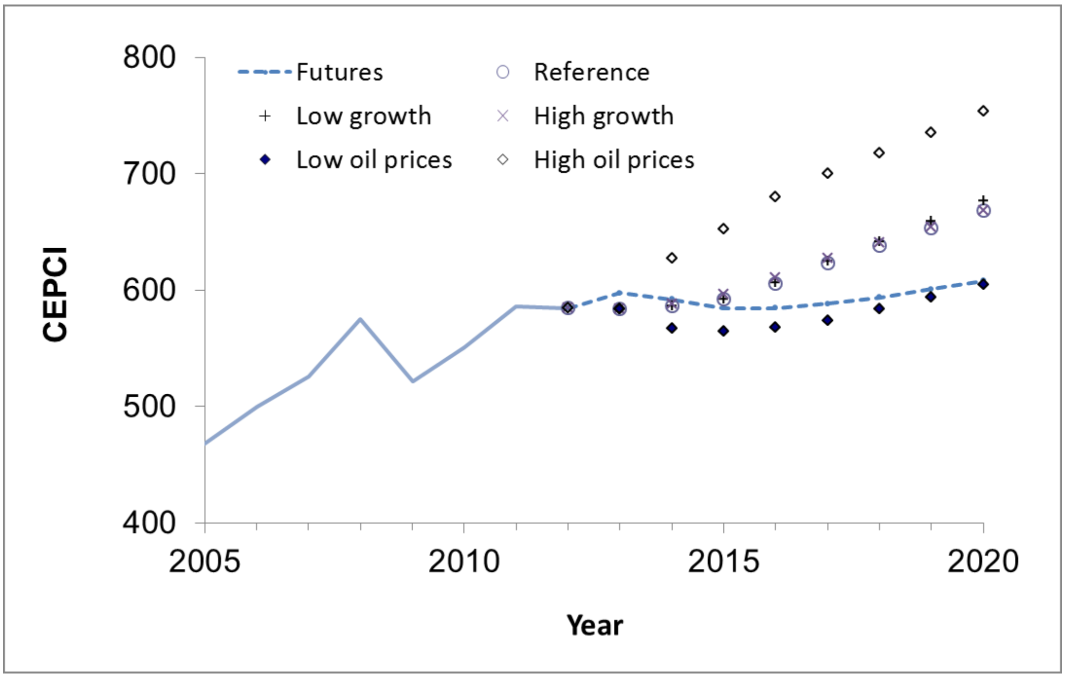

Figure 12