The Economics of Construction Price Inflation in the UK: Measurement, Output and Productivity

by

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Declaration

I, Marco Ka Wai Yu, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

To my parents

Abstract

This thesis evaluates the UK construction price and cost indices and their use in measuring inflation, construction output and productivity. It proposes theoretically grounded and econometrically sound models for construction demand and supply.

This study reviews the compilation methods of the published tender price indices (TPIs) in the UK and finds that they have distinct advantages. However, some components (M&E trades), some procurement methods (design and build), and some sub-sectors (private commercial and housing) are disproportionally under-represented or absent from the sampling of projects that underpins the TPIs. The TPIs are found to be very likely biased upwards. The review of the construction cost indices in the UK, measures of the input prices facing contractors, finds that the measure of labour cost is based on increasingly unrepresentative national wage agreements, and appears to be biased upwards.

The construction new orders series published by ONS are reviewed as a possible measure of demand and predictor of quantity of construction output, and are shown to be unfit for either purpose.

Grounded on a simple demand-and-supply theoretical model, the method proposed by Haynes and Stone (1985) is applied to estimate a system of demand-and-supply equations for new construction work in the UK, which is tested against and supported by the results of the data-driven vector autoregressive model.

Findings from *EU-KLEMS* show that the rate of productivity growth of the construction sector is lower than that of the whole economy. Applying Baumol's two sector unbalanced growth model, econometric studies are undertaken for the UK and other European countries. Results confirm the proposition that the relative rate of growth of labour productivity of the construction sector determines the long-run relative price movement of its outputs. The positive productivity growth in UK construction industry explains the differential between its (higher) input price growth and (lower) output price growth.

Keywords: Tender price index, construction cost index, construction output deflator, construction output price index, index compilation methodology, construction statistics, construction new orders, construction output, construction price index model, construction productivity, construction demand and supply model

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List of Abbreviations

ADF	Augmented Dickey-Fuller
ARIMA	Autoregressive Integrated Moving Average
ARMA	Autoregressive Moving Average
BCI	Building Cost Index
BCIS	Building Cost Information Service
BERR	Department for Business, Enterprise and Regulatory Reform
BIS	Department for Business Innovation & Skills
BQ	Bill(s) of Quantities
CCI	Construction Cost Index
COPI	BIS Output Price Index for New Construction: all new construction
CPI	Consumer Price Index
DL	Davis Langdon (now part of Aecom)
DTI	Department of Trade and Industry
GDP	Gross Domestic Product
ICE	Institution of Civil Engineers
IDBR	Inter Departmental Business Register
M&E	Mechanical and Electrical
ONS	Office for National Statistics
OLS	Ordinary Least Squares
PFI	Private Finance Initiative
PPI	Producer Price Index
RICS	Royal Institution of Chartered Surveyors
R&M	Repair and Maintenance
RPI	Retail Price Index
TPI	Tender Price Index
UK	United Kingdom
VAR	Vector Autoregression
VEC	Vector Error Correction

Chapter 1 Introduction

1.1 Background

The construction industry has a special role to play in the economy. The diverse outputs of the construction industry not only satisfy the daily wants and needs of individuals, but also contribute to the accumulation of the majority of the tangible long-lasting assets of an economy in the forms of houses, office buildings, schools, hospitals, roads, bridges and so on. These assets, on the one hand, are a reflection of the wealth of a society, and on the other hand, contribute to the production of goods and services and thus affect the competitiveness of an economy and the living standards of its people.

The inflation of the output of the construction industry decides the relative price of acquiring these man-made capital goods, and thus affects the trade-off between short term consumption and long term investment. Being the most volatile part of the national expenditures, understanding the price of construction output is essential to policymakers for the purpose of stabilising the economy by managing the public sector demand for construction output. ICE (2008a) has identified a £8 billion gap in infrastructure funding from the government by 2015 because the government has been using the consumer price index (CPI) forecast to allow for inflation in infrastructure expenditures whereas ICE expects the inflation of infrastructure to be a lot higher than the forecast increase in CPI[1].

Modern construction contracts usually place the risk of inflation with contractors and the profit margins are low in the construction industry, typically less than 5%[2].

[1] ICE forecast a construction price inflation of 5.7% per annum between 2005 and 2015, circa 3.7% above the 2% per annum CPI inflation forecast.

[2] For example, Akintoye and Skitmore (1991b) have found that profitability as a percentage of turnover was 3.23% in their sample of 80 UK general contractors.

Therefore, accurate short term construction price forecasting plays a very vital role in the success of a contractor.

PFI projects involve long term forecasting of the refurbishment and maintenance construction 'prices' over typically a 30 year period (typically with provisions for adjusting prices every five or so years), and require some appropriate price deflators to adjust the inflations of building life-cycle and maintenance cost.

Apart from the above important short and long term needs of understanding and forecasting of construction price indices (chapter 2), other applications of construction price indices include a) converting the nominal construction output in current prices to real output at constant prices (chapter 4), b) capturing relative price change and inflation in the construction industry for assessments and forecasting of market conditions (chapter 5), c) updating historical cost data for cost planning and estimating (chapter 3), and d) international, intersectoral or intertemporal comparisons of the level and growth of price, real output and productivity (chapter 6).

1.2 Purpose and Objectives of the Research

Several construction output price forecasting models have been developed and most of them are time-series atheoretical models (Taylor and Bowen 1987, Fellows 1991, Goh and Teo 1993 and Wang and Mei 1998). Some models have a theoretical basis. However, there is scope for improving both the underlying theoretical basis and technical specification of these models. (For example: the models in Akintoye 1991, Akintoye and Skitmore 1993 & 1994, Akintoye *et al* 1998, Ng *et al* 2004). It also appears that none of the index modelling literature has reviewed the compilation methods of the indices they modelled. The authors seem to presume that all indices accurately measure the general inflation of relevant output or input of the construction industry. Chapter 2 provides a literature review of international construction price and cost modelling.

Given the lack of understanding of the measurement basis of the construction price indices in the existing literature, this research aims at filling the accuracy presumption gap by critically reviewing the compilation method of selected construction tender price indices and construction cost indices in the UK in chapter 3 before attempting to incorporate them in applied quantitative economic modelling in chapter 5.

The review of the construction statistics also covers the new orders series. At the time of concluding a construction contract of new work (as opposed to repair and maintenance), the tender price and the volume of work, saving the relatively small amount to be amended by variations, are agreed between the contractor and the client. This contracted volume of work (which should be measured by the construction new orders at constant price series) will be translated to actual output over time (measured by the construction output constant price series). Therefore construction new orders is more appealing than output as a concept to capture the quantity of construction demand and in principle more consistent with the tender price indices. The objective of chapter 4 is to explore whether the actual orders series is fit to perform these functions.

Low productivity growth is reported in many construction industries of developed countries. In the long run the price levels of any goods and services are believed to be predominantly driven by the supply side factors. The higher user costs of buildings and other structures in the form of higher building price commissioned or higher rent will increase the cost of outputs for which the cost of built assets is a major cost of production, such as power generation and transportation. Consequently low construction productivity growth in the UK increases the cost and reduces the competitiveness of some UK produced internationally traded goods and service industries relative to international competitors. BIS (2013d) sets out aspirations for the UK construction industry to 2025 and two of the aspirations are reducing the cost of construction by 33% and reducing the trade gap in construction products and materials by 50%.

The existing literature is weak in capturing the long term driving force of relative productivity growth in its models. Therefore this thesis will try to fill this gap of linking productivity growth and the output price of the construction industry in chapter 6.

To recapitulate, the main goal of this thesis is to enhance understanding of construction price inflation in the UK, which is further elaborated into specific objectives as follows:

- Critically evaluate the main construction price and cost indices and construction new orders series in the UK with a view to understanding what has been measured and their accuracy;
- Propose and estimate theoretically grounded and econometrically sound models to understand and explain short and long term driving forces of the movements of relative construction price and relative construction output.

1.3 Hypotheses and Key Ideas

(a) This study notes that the main tender price indices (TPIs) published for the UK construction industry are transaction based indices capturing mainly the price movements of the traditional trades, and that the main building cost indices (BCI) are list-based weighted input price indices;

(b) The construction new orders series and the construction new work output price index published by the then Department of Trade and Industry were not compatible with other construction statistics. ONS has taken over the responsibility of publishing construction statistics recently and has published these statistics compiled by their new method since 2010. Since these statistics are relevant to the understanding and modelling of construction price inflation, the new ONS construction statistics are scrutinised to see if the errors have been corrected.

(c) It is hypothesised that the TPIs are driven by demand side factors in the short run. This means that in the short run the observed relationship between price and output is primarily constrained by the law of supply (i.e. the slope of the short run supply curve). In graphical terms, the demand curve is shifting along the short run supply curve and the observations about price and output are mainly on one supply curve. Therefore most existing literature finds a positive correlation between construction output and price, but very little of that literature attempts to identify both supply and demand relationships.

(d) It is hypothesised that the TPIs are driven by supply side factors in the long run. In the long run, the more productive one industry is, the more abundant are its good and services. Competition holds prices down to just cover full economic costs. Therefore, in the long run, the relative price of a product is inversely related to the physical productivity of its industry.

(e) The so-called building cost indices (BCIs) are actually price indices for the inputs (labour, plant and materials) used in construction. Comparison of BCI with TPI indices over the long run therefore indicates change in the sum of changes in productivity and in construction profit margins. In long run the (unmeasured) actual unit cost index must change at approximately the rate of change of the TPI[3].

(f) This study proposes that the trend rate of change of economy wide inflation (as measured by GDP deflator or Retail Price Index) is lower than that of construction output price inflation (measured by Tender Price Index or implied construction deflator), which in turn is lower than that of construction input price inflation (measured by Building Cost Index) in the long run. This hypothesis rests on the observation that the productivity growth of the economy as a whole is higher than that of the construction industry but that the construction industry has positive productivity growth in the long run.

1.4 Research Methodology and Methods

The key consideration in choosing the research methodology and methods (approach) is to provide logical linkage between the research questions and the data, and priority should be given to the approach maximising the chance of meeting the research objectives (Fellows and Liu 2008: pp 20-21).

Robson (2011) states that the primary purposes of literature review are to identify main gaps in knowledge and locate areas of controversy and assist in identifying appropriate research methodologies. Therefore, a literature review of research on

[3] i.e. Actual unit construction cost index (unknown) = BCI ÷ physical productivity index

international, not just British, construction price and cost index modelling is carried out to identify gaps and weakness of the existing research and the common methodologies adopted.

The literature review shows that the existing literature presumes the published data to be accurate and reliable without interrogating the method of data collection and compilation. While Fleming and Tysoe (1991) provide a brief review of the indexation methods of construction cost and price in the UK, there is a need for an in-depth review of the indexation method of the most widely used construction price and cost indices in order to understand their limitations and reliability. This approach of critical review of the data also extends to choosing the measure of the volume of construction output.

The literature review also reveals some weakness in the applied economic study of construction price inflation. When developing construction price inflation models, this thesis takes both theory-driven "bottom up" and data-driven "top-down" approaches as described in Ruddock (2008a). It makes use of the theory-driven specification suggested by Haynes and Stone (1985) and data-driven vector autoregressive model pioneered by Sims (1980) to distinguish demand shocks from supply shock in construction price index modelling with a view to identifying separately the demand and supply functions.

The theory driven approach is also adopted in the empirical (econometric) study of the impact of divergence in productivities on different price indices. The thesis derives the hypothesis of the impact of productivity disparities on price indices from a two sector growth model and the concept of Baumol's disease (Baumol 1967), and verifies it by studying their long run relationship for construction and other sectors in a time series regression model

Albeit that the review of data compilation methods raises questions over and doubts about the published construction price and orders data, the aforesaid quantitative analyses inevitably have to rely on best available of the published data which are either national statistics or statistics deriving from the national statistics. While care needs to be taken to interpret the results, there is no ready-available alternative or accepted way to adjust the data to attain the consistency and length of coverage of the data needed for the quantitative research.

1.5 Structure of the Thesis

This thesis consists of seven chapters and this chapter is a general introduction setting out the background, objectives, hypotheses and the methodology. The contents of the remaining chapters are outlined below.

Chapter two is a literature review of international construction price and cost index modelling with particular attention to the econometric techniques and use of economic theory. It reveals the research space for an in-depth review of the data in chapters three and four and also informs the quantitative applied economic research in chapters five and six.

Chapter three contains a critical appraisal of the construction cost and price indices in the UK. Through examining the compilation methods, it finds out what "price" and "cost" measure and do not measure in those indices, and suggests ways to improve them.

Chapter four scrutinises the construction new orders series and the BIS Output Price Index for New Construction before and after the implementation of the new method by ONS in the UK. It reveals that the new orders series is inferior to the new output series as a measure of construction output. On the other hand the errors in the output price index appear to be corrected.

Chapter five, relying on a method proposed by Haynes and Stone (1985), proposes and estimates a simple demand and supply model for the UK new building work industry, a major subset of the construction industry, and compares and contrasts the results with those from a VAR model. This chapter benefits from chapters three and four in terms of choosing the relatively more accurate measures of construction price and output. However, this chapter relies on best of the published statistics that are still subject to the limitations highlighted in chapter three.

Chapter six develops and applies the classic two sector unbalanced growth model in Baumol (1967) to cross-section and time series analyses of the UK and some other European countries, enabling a study of the relationship between relative construction output price and relative labour productivity. The EU KLEMS dataset is used in this chapter. While the team of researchers behind EU KLEMS have endeavoured to make the dataset as accurate and reliable as possible, it should be borne in mind the limitations that follow from the fact that the underlying statistics are collected by different statistical agencies using their own methods to measure their countries which are heterogeneous in many aspects.

Chapter seven concludes the thesis. It summaries the major findings, judges the key hypotheses to be largely verified, discusses the limitations of the results, and suggests avenues of future research.

Chapter 2 Construction Price Index Modelling: Literature Review

> "It is easy to lie with statistics, but it is easier to lie without them."
> —Charles Frederick Mosteller

2.1 Introduction

Compared with other goods and services produced in the economy, the output in the construction sector is relatively lumpy and entails large and long lasting financial impact for both producers and consumers. The importance of market intelligence is manifested in formulating informed decisions for producers (such as the tender sum submitted in a lump sum bid by a contractor) and consumers (such as the budget allowed to construct a hospital by the government). The decision process at the buying side and the estimating process at the producing side have naturally attracted great attention from researchers.

Construction statistics summarise what has happened in the construction sector in the recent past and require model building, interpretation and extrapolation if they are to be used for guiding decisions on future actions. There is no shortfall in efforts from the academy, government and the industry to produce models of a forecasting nature to interpret the statistics and extrapolate them to guide decisions. This chapter attempts to survey the body of academic, government and industry literature.

The price and quantity of construction output are the twin headline statistics that attract most attention. Construction output includes a disparate group of products such as the construction, refurbishment and maintenance of houses, offices, hospitals, factories, roads, bridges, tunnels, and so on. Therefore, there is no single representative unit of quantity of this wide range of products. Instead, statistical agencies, for instance ONS in the UK, measure the quantity of each category of construction output over time by deflating the value in monetary terms by approximate price deflators. The aggregate volume is a sum of the deflated monetary values of all categories of construction outputs.

This chapter reviews the existing international literature of construction price index modelling and traces the trend of their evolution. Emphasis is placed on evaluating their statistical techniques as well as their command of the economic concepts of demand and supply. This chapter also reviews the international price indices in the construction sector in both senses of ‘price’: output price indices, such as a tender price index, and input price indices, such as a building cost index. Generally construction output price indices reflect the movement in price levels that main contractors charge their clients, whereas construction cost indices reflect the movement in price levels that main contractors and subcontractors pay for their material, plant and labour inputs. Clear distinctions will be made when they are discussed in more detail below.

The modelling literature is categorised by its main methodologies. The next section (2.2) reviews the earlier construction price or cost index models that have made use of the techniques of time series analysis. It is followed by a discussion of the joint approach that has arisen out of an urge for paradigm shift, in section 2.3. Reduced form multivariate regression researches are evaluated in section 2.4. Then section 2.5 reviews the attempts to build structural demand and supply construction price or cost models, and the single and multiple equation models applying the error correction mechanism in the long run co-integrating relationship are reviewed in section 2.6. The research making use of Artificial Neural Networks is reviewed in section 2.7. Then section 2.8 of this chapter reviews the models built by the industry. The final section concludes the chapter by identifying some shortfalls in the existing research in the field and suggests the possible ways for improvement.

2.2 Time Series Analysis

Many earlier construction price models are univariate time series models such as Koppula (1981), Taylor and Bowen (1987), Fellows (1991), Goh and Tao (1993). The most common method adopted for modelling is the Box-Jenkins approach (Box and

Jenkins 1970) perhaps because it provides a more structured way of choosing the specification of the model and estimating the parameters. Despite these advantages, it still leaves room for subjective judgement in terms of interpreting the partial correlograms.

The general univariate time series model is called ARIMA (p, d, q), where p is the number of lagged values of the variable (autoregressive component), d is the number of times the variable is differenced, and q is the number of lagged values of the error term (moving average component). The general equation of ARIMA (p, d, q) for *Y* is as follows:

$$Y_t = \sum_{i=1}^{p} \beta_{t-i} Y_{t-i} + e_t + \sum_{i=1}^{q} \alpha_{t-i} e_{t-i}$$

where β and α are unknown parameters and e are independent and identically distributed normal errors with zero mean. ARIMA stands for autoregressive integrated moving average.

The table below summaries the results of the major literature in time series analysis applied to construction price index modelling. P_t denotes the price index at time t. d is a difference operator, so that $dP_t = P_t - P_{t-1}$. ln is natural logarithm operator, so $dlnP_t$ is an approximation of the growth rate of the price index P over the time t.

	Time Series Model	**Data**	**Index**	**Period / Frequency**	**Country**
Koppula (1981)	CCI Model: ARIMA (0, 0, 1) $lnP_t = e_t - 0.248\ e_{t-24}$ BCI Model: ARIMA (0, 0, 2) $lnP_t = e_t + 0.102\ e_{t-1} - 0.854\ e_{t-12}$	Construction Cost Index and Building Cost Index (BCI) compiled by Engineering News Record	Cost Index	Jan 1962 to Dec 1978 Monthly	US

Taylor & Bowen (1987)	ARIMA (2, 0, 1) $P_t = 1.2864P_{t-1} - 0.3115P_{t-2} + 0.76506e_{t-1} + e_t$	Although it is called Bureau for Economic Research Index of Building Cost, the authors noted it was a misnomer and the index (P) was a tender price index based on returns obtained from quantity surveying firms.	Price Index	1971Q1 to 1985Q2 Quarterly	South Africa
Fellows (1988 and 1991)	ARIMA (2, 1, 0): BCIS $dP_t = 1.161 + 1.33dP_{t-1} - 0.4734 dP_{t-2} + e_t$ ARIMA (1, 1, 0): PSA $dP_t = 0.673 + 0.8891dP_{t-1} + e_t$ ARIMA (3, 1, 0): DBE $dP_t = 1.254 + 1.4425dP_{t-1} - 0.7963dP_{t-2} + 0.2063 dP_{t-3} + e_t$	BCIS All-in tender price index PSA tender price index Davis, Belfield and Everest tender price index	Price Index	1974Q1 to 1981Q4 1975Q1 to 1981 Q4 1970Q1 to 1981Q4 Quarterly	UK
Goh & Teo (1993)	ARIMA (1, 1, 0) $dP_t = -0.38399dP_{t-1} + e_t$	Public industrial buildings' tender price index in Singapore compiled by the authors.	Price Index	1980 to 1991 Annual	Singapore

Wang & Mei (1998)	ARIMA (1 , 1, 0) $dP_t = 0.1916 + 0.4234dP_{t-1} + e_t$	Executive Yuan of the Republic of China: 'Indices of Construction Costs in the Taiwan Area'	Cost Index	Jan 1991 to Dec 1995 Monthly	Taiwan
Goh & Teo (2000)	ARIMA (1, 1, 0) $dP_t = -0.3864dP_{t-1} + e_t$	Public industrial buildings' tender price index in Singapore compiled by the authors.	Price Index	1980 Q1 to 1991Q3 Quarterly	Singapore
Goh (2005)	ARIMA (1, 1, 0) $dP_t = -0.082519dP_{t-1} + e_t$	Building and Construction Authority (BCA) Tender Price Index	Price Index	1993Q1 to 2002Q3 Quarterly	Singapore
Touran & Lopez (2006)	ARIMA (1, 1, 0) $dlnP_t = dlnP_{t-1} + e_t$	Engineering News Record (ENR): building cost index (BCI)	Cost Index	Jan 2000 to Dec 2004 Monthly	US
Ashuri & Lu (2010)	Seasonal ARIMA (1, 0, 0) (0, 1, 1) for in-sample $(P_t - P_{t-12}) = 0.845(P_{t-1} - P_{t-13}) + 0.207e_{t-12} + e_t$ Holt-Winters Exponential Smoothing for out of sample Level smoothing weight = 0.887 Trend smoothing weight = 0.028	Engineering News Record (ENR): construction cost index (CCI)	Cost Index	Jan 1975 to Dec 2008 Monthly	US

	Seasonal smoothing weight = 0.999				
Hwang (2011)	ARIMA (5,2,5) $R_t = P_t - P_{t-12}$ $dR_t = -2.33\ dR_{t-1} + 0.33dR_{t-2} + 0.36\ dR_{t-3} - 0.18dR_{t-4} - 0.53dR_{t-5} + e_t + 0.27\ e_{t-1} - 0.46\ e_{t-2} - 0.49e_{t-3} + 0.21e_{t-4} + 0.97e_{t-5}$	Engineering News Record (ENR): construction cost index (CCI)	Cost Index	Jan 1960 to Dec 2006 Monthly	US

Table 2.1: Results reported in the Major Literature in Time Series Analysis applied to Construction Price Index Modelling

The principal concept of the time series analysis is that the dependent variable (price or cost index at time 't' is driven by a random stochastic variable. The core of the model, ARIMA, is to find out whether this variable is serially correlated, so that by knowing the historical values, there is a higher chance to get the future values right.

Koppula (1981) and Taylor and Bowen (1987) were early attempts to build ARIMA models on construction price and cost indices. Koppula (1981) modelled the construction cost and building cost indices published by Engineering News Record in the US, which captured the labour wage and material price movements to contractors. Taylor and Bowen (1987), however, modelled the tender price index in South Africa which reflected movements in price that contractors charged their clients. These authors do not appear to appreciate that the variables they were studying were non-stationary. Non-stationarity means that either the mean or the variance of the variable under study, in these cases the construction cost index and tender price index, are not constant over time. Figure 1 of Koppula (1981: pp. 737) and figure 5 of Taylor and Bowen (1987: pp. 32) showed that the indices display upward trends which suggest that at least the means of these indices are not constant over time. The autocorrelation function (ACF) reported in figure 7 of Taylor and Bowen (1987), which dies out gradually over circa 20 quarters, also indicates the tender price index is non-stationary.

The presumption of the Box-Jenkins technique is that the time series variable is stationary, because the sample ACF and partial autocorrelation function (PACF) used in the Box-Jenkins technique as approximation to the true data-generating process of the time series variable assumes the variable to be stationary. The t-statistics used in significance test of the estimated coefficients and the Ljung-Box Q-statistics used in testing any autocorrelation in the residual of the chosen ARIMA model also assume that the time series variable is stationary.

Fellows (1991) reports the major result of the author's PhD thesis submitted in 1988. Fellows is aware of the issue of stationarity and he finds that the three construction price indices in the UK become stationary after first differencing (difference stationary). The probabilistic or stochastic properties such as mean and variance of the price indices become invariant over time after first differencing. The price indices are said to contain unit root. This is opposed to trend stationary time series, which become stationary after removing a time trend.

The preferred models in Fellows (1991) were all autoregressive but without the moving average component of the standard ARIMA model. Goh and Teo (1993 and 2000), Goh (2005), and Wang and Mei (1998) obtained similar results in their studies of modelling construction price index in Singapore and construction cost index in Taiwan respectively. These studies find that 1) the indices become stationary after first differencing; 2) the model is improved by adding the lagged first difference; and 3) the lagged error terms are dropped from the model.

Strictly speaking, Touran and Lopez (2006) do not adopt Box-Jenkins technique in modelling. However, their preferred model of the cost index is an ARIMA (1, 1, 0). Their Figure 2 (Touran and Lopex 2006: pp. 856) shows strong correlation between the value of the cost index (in level) and the lagged value of the cost index, and this is held to justify that the growth rate of the cost index is autoregressive. A more appropriate justification should be a graph showing strong correlation between the growth rate of the cost index and the lagged growth rate, because strong correlation of the value of a variable is neither a necessary nor a sufficient condition for strong correlation of the growth rate of such variable.

Ashuri and Lu (2010) used moving average (SMA), Holt Exponential Smoothing (Holt ES), Holt-Winters Exponential Smoothing (Holt-Winters ES), ARIMA, and seasonal ARIMA to model the monthly ENR construction cost index. Using the entire data series between January 1975 and December 2008, Ashuri and Lu (2010) find that the accuracy of the above methods ranked by the three error measures, namely mean absolute percentage error, mean square error, and mean absolute error, is in the following ascending order: SMA, Holt ES, Holt-Winters ES, ARIMA, and seasonal ARIMA. In other words, they find that seasonal ARIMA is the best fit of the data, and they call this "in-sample" forecasting.

The preferred ARIMA model in Ashuri and Lu (2010) is also ARIMA (1, 1, 0). Since they use monthly data and observe summer peaks every year, they model the seasonality by taking the difference of the data with the data of the same month in the previous year. The preferred seasonal ARIMA model is ARIMA (1, 0, 0) (0, 1, 1), which has smaller error measures than the ARIMA (1, 1, 0).

Ashuri and Lu also carry out out-of-sample forecast. They use the five above-mentioned techniques and a subset of the historical data to produce rolling forecast of the data that is not used in developing the model. For example, they use the ENR construction cost index between January 1975 and December 1986 to forecast the construction cost index in December 1987 in the first group. They repeat this by using historical data between January 1975 and December 1987 to forecast the index in December 1988 in the second group. Therefore, the 22nd group forecast of December 2008 is by using the date between January 1975 and December 2007. They calculate the forecast errors of these 22 forecasts and the out-of-sample forecasting accuracy of the five techniques in ascending order is as follows: SMA, ARIMA, seasonal ARIMA, Holt ES, and Holt-Winters ES. The Holt-Winters Exponential Smoothing technique, what has taken into account of trends and seasonal changes, is found to outperform other methods in out-of-sample forecasting accuracy.

Hwang (2011) concludes that an ARIMA (5, 2, 5) model of the monthly ENR construction cost index is more accurate than the alternative models in his study. Similar to Ashuri and Lu, Hwang tries to remove seasonality by "lag-12 differencing", which is the difference between the monthly index and that in the previous 12 month ($P_t - P_{t-12}$). However, the ENR construction cost index remains non-stationary after "lag-12 differencing", so Hwang applies another lag-1 differencing to the data [$(P_t - P_{t-12}) - (P_{t-1} - P_{t-13})$]. Therefore, his study in fact models the difference of the annual difference in the construction cost index.

2.3 Joint Methodology Approach

When Bowen and Edwards (1985) discussed the proposed paradigm shift in quantitative cost modelling and price forecasting for construction projects in the early 1980s, the paradigm adopted by quantity surveyors consisted of the initial rate per square metre estimates, followed by elemental cost plans, and concluding with pricing of the bills of quantities. The proposal was to shift this "historic-deterministic" paradigm to a probabilistic one which explicitly considered variability, supplemented with an expert system that captured and applied the experts' 'rules of thumb'. However, Fortune and Lees (1996), Fortune and Hinks (1998) and Fortune and Cox (2005) find that the traditional cost and price forecasting models of the old paradigm remain pervasively used in quantity surveying practices based in the UK, with limited applications of the probabilistic type of models in practice.

In a series of papers, Dawood and Bates (Dawood and Bates 1998, Dawood 2000, Dawood and Bates 2000, Dawood 2001 and Dawood and Bates 2002) apply this concept of integrating probabilistic modelling with experts' judgement to construction cost index forecasting and call it a joint methodology approach. Dawood and Bates (1998, 2000 and 2002) apply this joint methodology of combined scientific analysis of historical data and subjective judgement to heavy civil engineering industry cost index forecast. The index under examination is a historical monthly cost index from the water industry, covering a period from January 1985 to December 1989. However, the authors do not provide the source of the index, so it leaves the followings questions about the index to be answered:

a) Has the index been seasonally adjusted?
b) Since even the earliest paper was published in 1998, why do the authors not use more recent data?
c) Is the index discontinued?
d) Which country is the index compiled for?

Dawood (2000 and 2001) applies the same methodology to analyse the cost values of activities (cost of laying sub-base per square metre for major road) published by the Greek Ministry of Economy for the period between the first quarter of 1993 and the fourth quarter of 1996. Similar questions of a) to c) about the index under examination are not answered by the papers.

The concept of the so-called joint methodology approach is nothing new. In fact all of the time series analysis and econometric models involve subjective judgment. In Box-Jenkins approach, researchers need to judge the appropriate numbers of autoregressive and moving average terms by reading the PACF. In multivariate linear regression, researchers need to decide the specification of the model and the variables included in the model. In neural network, even adopting the most common sigmoid function, researchers need to decide the numbers of hidden units and hidden layers to balance between the flexibility for good modelling and the problem of over-fitting. These are judgements within a single model described in Bunn and Wright (1991).

The way that Dawood and Bates illustrate the joint methodology concept is uncommon and unclear, and the results that they present in graphic forms are unsatisfactory. They choose the Classical Time Series Decomposition method as the objective part of their joint methodology, which is a very old method that can be traced back to Poynting (1884), and was further developed by Persons (1916 and 1919) and Macauley (1930). Later works such as Yule (1927), Crum (1923), Greenstein (1935), Slutsky (1937) and Frisch (1933 and 1937) have discredited this approach. In their forecasting textbook, Makridakis *et al* (1998: pp. 126) suggest that "we prefer to use decomposition as a tool for understanding a time series rather than as a forecasting method in its own right". The ARIMA method discussed in the previous section was developed in the late 1960s and has been widely used in forecasting since. Nowadays, the application of the concept of Classical Decomposition can mainly be found in seasonal adjustments, but even in seasonal adjustments an ARIMA augmented technique has become widely adopted amongst statistical agencies. For example, ONS use X-12-ARIMA for seasonal adjustments of many time series they publish.

The Dawood and Bates' illustration of 'joint methodology' is unclear because the subjective judgement comes in the form of adjusting the cyclicality component in the Classical Decomposition. Dawood and Bates (1998 and 2000) state that the cyclicality component reflects the expert judgments on market factors such as government variations and changes, inflation changes, interest rate changes, and legislation. However, the papers are silent on how the judgements on such market factors are used to forecast the cyclicality in the Classical Decomposition, which was the crucial step of combining the subjective judgement with objective probabilistic model. With the hindsight of actual data, one can improve the 'forecast' of the data without too much difficulty.

However, the results improved by the subjective judgements remain unsatisfactory. Figure 6 of Dawood and Bates (1998) and figure 11 of Dawood and Bates (2000) show that the forecasts of the water industry cost indices, after subjective interventions, are biased downward. Figure 4 of Dawood (2000 and 2001) show that the adjusted forecasts of Greek construction cost indices are biased downward in the last 5 quarters and the whole profile of the adjusted forecast appears to lag the actual series by a few quarters. These unsatisfactory results undermine the 'subjective judgement' of using Classical Decomposition as the model at the first place, or judgement across several models (Bunn and Wright 1991).

2.4 Reduced Form Model

The discussion so far has concentrated on the techniques of time series analysis developed by statisticians specialised in analysing time series data. Modern econometrics has been established as a discipline to apply statistical methods to economic data to confirm, reject and / or quantify economic theories from the mid-1960s (Gilbert and Qin 2005). Economic theories usually assert relationships between two or more variables such as price and output. Least squares-based linear regression models are widely used to find the correlation between economic data, and naturally they are applied to construction price or cost index modelling. The table below summarises the results of the literature on using single equation regression to model construction price or cost indices.

	Preferred Model	**Data**	**Index**	**Period / Frequency**	**Country**
McCaffer *et al* (1983)	$\frac{TPI_t}{BCI_t} = a + b \times O_{t-4}$ a and b are estimates of the regression coefficients	TPI = tender price index BCI = building cost index O = output index of construction work BCIS, Building Cost Information Services. Directorate of Quantity Surveying Services. Property Services Agency of the Department of the Environment.	Price Index	1971Q1 to 1979Q4 Quarterly	UK
Herbsman (1983)	CCI = f (BVF, ICI)[4]	CCI = Composite Cost Index compiled by the Florida Department of Transportation BVF stands for bid volume factor, which is defined as the total amount of work in an area.	Price Index	1968 to 1981 Yearly	US

[4] Herbsman (1983) does not provide the fully estimated model.

		ICI stands for input cost indices, which is weighted sum of material prices, wages and equipment cost.			
Runeson (1988)	$MCR_t = 0.9568 + 0.81x10^{-5}BA_{t-1} + 0.12x10^{-4}BA_{t-2} + 0.12x10^{-4}BA_{t-3} + 0.81x10^{-5}BA_{t-4} – 0.2084x10^{-3}CF_t – 0.2797x10^{-1}UR_t$	MCR = Market Conditions Ratio, a ratio of tender price to market neutral estimate taking into account input price change compiled by New South Wales Public Works Department BA = Building Approvals in New South Wales (intention to build) CF = Fixed Capital Formation in Buildings (the current output) UR = Rate of Unemployment (measured of spare capacity)	Price Index	1972Q1 to 1982Q4 137 projects Quarterly	Australia
Chau (1998)	$\ln\left({LMI_t}/{TPI_t}\right) = 0.8553 + 0.009124t$ where t is time in quarters.	LMI = Labour and Material Index compiled by Architectural Services Department of the Hong Kong Government TPI = tender price index, an average of the tender price indices for private sector compiled by Levett and Bailey Chartered Quantity Surveyors and Davis Langdon and Seah Hong Kong Ltd.	Price Index	1970Q1 to 1995Q4 Quarterly	Hong Kong
Ng *et al* (2000)	$Z = -1.079 + 0.264BCI_{t-2} – 0.007BLR_{t-2} +$	TPI = tender price index compiled by Levett & Bailey Chartered Surveyors	Price Index	1981Q1 to 1998Q4	Hong Kong

	$0.528CPI_{t-2}$ – $0.012GDP_{t-2}$ – $0.024GDPC_{t-3}$ + $0.025IGDPD_{t-2}$ – $0.080M3_{t-2}$ – $0.034UR_{t-2}$	Z = discriminant score BCI = Building Cost Index BLR = Best Lending Rate CPI = Composite Consumer Price Index GDP = Gross Domestic Product GDPC = Gross value of investment in buildings, construction, plant, machinery, developers' margin and transfer costs of land and buildings. IGDPD = Implicit Gross Domestic Product Deflator M3 = Money Supply Definition 3 UR = Rate of Unemployment			
Wilmot & Cheng (2003)	$LHCI = f(PI_1, PI_2, PI_3, PI_4, PI_5)$ $PI_j = f(I_l, I_e, I_m, Q, D, BV, BVV, P, S, T, L1, L2, L3, L_4, L_5, L_6, L_7, L_8)$[5]	LHCI = Louisiana Highway Construction Index, compiled by the Louisiana Department of Transportation and Development PI_1 = Embankment material rate in excavation & embankment PI_2 = Class AA	Price Index	1984 to 1997 Yearly 2,827 highway and bridge contracts	US

[5] The complete model for each of the 5 pay items (PI_j, where j = 1, 2, 3, 4 and 5) is reported in table 2 of Wilmot and Cheng (2003).

		concrete rate in concrete pavement PI_3 = Asphaltic concrete rate in asphaltic pavement PI_4 = Deformed reinforced steel rate in reinforcing steel concrete PI_5 = Class AA concrete rate in structural concrete I_l = BEA labour cost index I_e = DRI equipment cost index I_m = DRI material cost index Q = pay item quantity D = contract duration BV = number of contracts in the year BVV = bid volume variance in the year P = number of plan changes in the year S = dummy for new practice T = dummy for the 4th quarter of fiscal year L1, L2, L3, L_4, L_5, L_6, L_7, L_8 = district dummies			
Ng *et al* (2004)	Combined Regression Analysis (RA) and ARIMA	TPI = tender price index compiled by Levett & Bailey Chartered Surveyors	Price Index	1980Q1 to 1998 Q4	Hong Kong

	One Period Forecast F = 0.512RA + 0.488 ARIMA Two Period Forecast F = 0.647RA + 0.353ARIMA Regression Analysis (RA) $TPI_t = 66.6274 + 1.6115BLR_{t-3} + 0.4746BCI_{t-1} - 0.3117CPI_t - 2.7375UR_t + 0.0932M3_t - 0.00215HSIVA_{t-1}$ ARIMA (0,1,2) $TPI_t - TPI_{t-1} = e_t + 0.7312e_{t-1} + 0.47e_{t-2}$	BCI = Building Cost Index BLR = Best Lending Rate CPI = Composite Consumer Index M3 = Money Supply Definition 3 UR = Rate of Unemployment HSIAV = Hang Seng Index 100 Days Moving Average		Quarterly	
Li et at (2006)	$TPI = 176\ (Demand/Capacity)^{1.94}$	TPI = tender price index compiled by Sheffield Hallam University Demand = quarterly workload Capacity = local experts' views on technology, labour forces and materials	Price Index	1990Q1 to 2001Q4 Quarterly	Guernsey
Hwang (2009)	Linear Regression CCI = 828.19 + 14.63t	CCI = Construction cost index reported by Engineering News Record	Cost Index	Jan 1967 to Feb 1991	US

	t is time in months Dynamic Regression $CCI_t = 11.18 + 1.32CCI_{t-1} - 0.32CCI_{t-2}$ $CCI_t = 16.08 + 0.99CCI_{t-1}$			Monthly	
Olatunji (2010)	Linear regression Y = 28187.037 + 38.479 X1 – 1064.135 X2 – 432.467 X3 + 350.809 X4 – 114.134 X5 + 14.643 X6 – 89.543 X7	Y = GFA construction cost / m^2 X1 = inflation rates X2 = lending rates X3 = GDP growth X4 = foreign exchange X5 = crude oil export X6 = cement prices X7 = cement demand deficit index	Price Index	2000Q1 to 2008Q4	Nigeria

Table 2.2: Results reported in the Major Literature on using Single Equation Regression to Model Construction Price or Cost Indices

McCaffer *et al* (1983) is a seminal work in construction price and cost index modelling. The research objective is to analyse and explain the disparity between the input and output price of building contractors. The input price is measured by building cost index (BCI) which is a weighted sum of labour wages, material prices and plant cost, and the output price is measured by tender price index (TPI) which is a weighted sum of the rates in bills of quantities. McCaffer *et al* (1983) hypothesise that the disparity is primarily driven by market conditions which are best measured by either the construction output or orders index. Hence, their regression model, as below, relates a TPI to BCI ratio to construction output index in four subsectors, namely public housing, other public work, private commercial and private industrial, as well as all work. They find that the best explanatory variable in the simple regression models is all construction output in 2 to 4 quarters earlier than the price index ratio.

$$\frac{TPI_t}{BCI_t} = a + b \times O_{t-4}$$

It is worthy of note that McCaffer *et al* (1983) have used a data set covering 9 years (36 quarters) and they find that the best statistical result applies to their data spanning 6 to 6.5 years. It seems that they do not appear to realise that their model portrays a short run supply curve of the building construction industry, which is supported by the fact that the estimated coefficients (b) of the regression models as reported in their table 5 (McCaffer *et al* 1983: pp. 24) are all positive. These results suggest that demand side shocks dominate the fluctuations in quarterly data used by McCaffer *et al* (1983). This is contrasted with Chau (1998), who has found a downward trend of the TPI to BCI ratio in his Hong Kong data over 16 years. Chau (1998) proposes that this long run downward trend reflects the productivity growth in the building construction industry in Hong Kong.

Herbsman (1983) reports the Highway Construction Cost Forecasting (HCCF) Model developed for the Florida Department of Transportation. The HCCF Model forecasts the composite cost index (CCI) compiled by the Florida Department of Transportation. The CCI is in fact an output price index of the highway construction industry because it is a weighted sum of the rates of six major elements namely common excavation, Portland cement, concrete surfaces, bituminous concrete surfaces, structural reinforcing steel, structural steel, and structural concrete in the contracts accepted by the Florida Department of Transportation. Herbsman (1983) finds a positively correlated relationship between the CCI and the total amount of highway work in the area which is incorporated into the HCCF Model. In addition, the HCCF Model also includes the input cost index as an explanatory variable, which is a weighted sum of labour wages, material prices and equipment cost.

McCaffer *et al* (1983) and Herbsman (1983) confine the explanatory variables of their price index models to measures of the industry's output. Runeson (1988) extends his price index model to incorporate the capacity of the industry and the capacity utilisation. The dependent variable is a market conditions ratio (MCR), a ratio of tender price to a market neutral estimate compiled by New South Wales Public Works Department. Runeson (1988) finds that the MCR is positively correlated with lagged building intentions variables (as measured by the numbers of building approvals for dwellings in New South Wales), negatively correlated with the simultaneous industry output variable (measured by the value of fixed capital formation on dwellings and other buildings), and negatively correlated with a capacity utilisation variable (measured by the unemployment rate). Since Runeson (1988) did not describe the statistics of the variables in his final model, their statistical characteristics cannot be judged. However, the assumption of stationarity of the numbers of dwelling approvals and the value of fixed capital formation are cause for concern.

Li *et al* (2006) try to link the growth rate of the tender price index in Guernsey to a ratio of demand to capacity and argue that the model would cater for the changes driven from both demand pull and cost push. However, it is difficult to generalise their model to any other applications because their capacity measures are based on views of local experts, and Li *et al* (2006) do not explain how the experts' views are formed or obtained. The description of the demand measures in their model is also brief, stating only that the "s-curve method was applied" to "workload data". Therefore, it is not possible to replicate the demand measures nor apply it to other countries.

Ng *et al* (2000) apply multivariate discriminant analysis (MDA) to predict the directional changes of a tender price index of new building work in Hong Kong. Directional changes of the tender price index are subsumed into three categories: 1) upward movement, 2) constant, and 3) downward. Economic indicators included in the discriminant function are quarterly changes of the following 8 variables: building cost index; best lending rate; composite consumer price index; gross domestic product; gross value of investment in buildings and construction; implicit gross domestic product deflator; money supply definition 3; and the rate of unemployment.

Ng *et al* (2000) test the predictive power of their discriminant function by the 8 holdout quarter data and find that in 7 out of the 8 cases (87.5%) the predictions are correct. When they apply the discriminant function to 'predict' all directional changes of tender price index in the 72 quarters in their data, the model correctly predicts 43 out of 72 cases (59.7%). The authors consider the model is satisfactory because they believe random guessing would only get one third of the cases correct (33.33%).

However, under closer scrutiny the study is questionable on many fronts. Firstly, the definition of the "constant movement" category of tender price movement is changing over time. The authors define constant movement as when the value of the tender price index is the same as the previous quarter. For example, the tender price index values in the second and third quarters of 1991 are both 1075, so "constant movement" occurs in the third quarter of 1991. The tender price index published by Rider Levett Bucknall (formerly Levett and Bailey Chartered Quantity Surveyors) is rounded to the integer, which are whole number approximations to a range of values. For instance 1075 (second quarter 1991 value) is an approximation of a range of values from more than 1074.4999 to less than 1075.5000. Therefore, if the index value is rounded to 1 decimal place instead, the values may not be "constant" anymore. More importantly, given the general upward trend of the tender price index, the likelihood of "constant movement" would decrease over time. For example, the index value at the fourth quarter of 1968 is 100. If it is increased or decreased by less than **0.5%** (99.50 to 100.49), the next quarter index would remain at 100. However, the index value is 1605 in the second quarter of 2009, and it needs to be increased or decreased by less than **0.031%** (1604.50 to 1605.49) to remain at 1605 in the next quarter.

Secondly, the economic indicators are chosen because the Pearson correlation analyses indicate strong correlations between them and the tender price index. However, level values of such indicators, instead of the first differences, are used in the Pearson analyses. Given these economic indicators generally display upward trend, the correlations are very likely spurious.

Thirdly, the justification of the discriminant model by the holdout out sample is debatable. As reported in their table 2 (Ng *et al* 2000: pp. 847) the authors use the “holdout out” sample to select the best lag periods for the economic indicators in the model. Therefore, the ‘holdout sample’ is not really held out from the model construction.

Fourthly, the prediction power of the model can be regarded as poor. Given the clear long term upward trend of the tender price index, the fair benchmark predictions of the direction change would be always upward, which would be correct in 65% of the cases, better than the 59.7% by the model.

By using a very similar data set, Ng *et al* (2004) develop a building tender price index (TPI) forecasting model by combining the multivariate regression model with univariate ARIMA model. The authors find that the best time series model is ARIMA (0, 1, 2) which means the change of TPI is related to the moving average of the past two errors. However the multivariate regression model is questionable. Since the model is built on the levels rather than the growth rates of the TPI and other economic indicators, and many of them, including TPI, display strong upward trend, it is very probable that the relationship is spurious. However, the authors do not seem to be aware of this problem because no unit root test nor co-integration test is carried out.

Since the explanatory variables in the regression model include contemporaneous variables, namely composite consumer price index, money supply and unemployment rate, the forecast of the TPI would at least require the forecasts of those contemporaneous variables as inputs. The authors forecast the explanatory variables by simply extrapolating the historic variable at historical constant growth rate. However, the authors do not explain the reason for not using more commonly used forecasting methods such as ARIMA to forecast those variables, nor, more importantly, why those variables are more suitable to such simple extrapolation than the TPI.

The integrated model of Ng *et al* (2004) is in fact a hybrid combining the level forecast of the regression model and the growth rate forecast from the ARIMA model, and such hybridity is not common. The established econometric method to capture the short run dynamics and the long run relationship between variables is Error Correction Mechanism (ECM), which combines the co-integrating relationship of non-stationary level variables and stationary growth rate variables (Engle and Granger 1987). The next section will explain ECM in more details.

Hwang (2009) attempts to develop a dynamic regression model of the construction cost index (CCI) published by Engineering News Record. The research begins by regressing the CCI on the contemporaneous prime interest rate, numbers of housing starts and consumer price index. The author decides to drop the prime interest rate and numbers of housing starts from the model because the adjusted coefficient of variation remains very close to unity after dropping these two variables. The paper then focuses on the lagged CCI variables and lagged consumer price index in estimating the dynamic regression model. By using backward stepwise method, the author finds his preferred models: i) an autoregressive model with 2 lagged CCI's (by one month and two months) and ii) an autoregressive model with 1 lagged CCI (by one month).

Hwang (2009) does not appear to notice that the CCI and consumer price index are non-stationary, and thus the regression analysis he performed is spurious. The sum of the coefficients of the lagged CCI's in the author's preferred models is very close to unity, which could be read as a strong indication that the CCI variable has a unit root.

The aim of Wilmot and Cheng (2003), similar to Herbsman (1983), is to build a highway construction cost forecast model. The index that Wilmot and Cheng (2003) study is the Louisiana Highway Construction Index (LHCI) which is a weighted sum of the average prices of 5 representative 'pay' items in the contracts let by the Louisianan Department of Transportation and Development. Therefore, the LHCI is an output price index of the same type as the tender price index compiled by Building Cost Information Service (BCIS)[6].

[6] Please see chapter 3 for a detailed description of the compilation method the tender price index.

The five representative 'pay' items are i) embankment material rate in excavation and embankment, ii) class AA concrete rate in concrete pavement, iii) asphaltic concrete rate in asphaltic pavement, iv) deformed reinforces steel rate in reinforcing steel concrete, and v) class AA concrete rate in structural concrete. The authors go on to build forecasting models on each representative pay item. The explanatory variables include labour cost index, equipment cost index, material cost index, quantities of the pay item in the contracts, numbers of contracts, contract duration, bid volume variance in the year, number of plan changes, and dummies to capture location, change in specification, and the end of fiscal year effect. The pay item rates are, as expected, positively correlated with the input cost indices and numbers of contracts (a measure of total output), and negatively correlated with the quantities of the items in contracts. Location is also statistically significant in the model. However, the forecast of LHCI requires the forecasts of the explanatory variables as inputs. The authors obtain those forecasts from the Bureau of Economic Analysis of the Department of Commerce of the US government, and Data Resources Incorporated, a commercial supplier of industrial data.

Olatunji (2010) studies the impact of oil price on construction cost per meter square in Nigeria. The pairwise correlation analysis shows interesting results of strong positive correlation between construction cost per meter square and the following variables: petrol price, average crude oil price and cement price, as well as strong negative correlation between construction cost per meter square and these variables: lending rates and inflation rate. However, the preferred model as reported in *table 2.2* does not include petrol price and average crude oil price for the reason that these two variables are seriously multicollinear with cement prices. The author considers multicollinearity is a more severe problem than missing variables. One would expect GDP growth and crude oil export will have positive impact on construction cost, but the coefficients of GDP growth and crude oil export in the preferred model are both negative. Olatunji does not provide any explanations of these counter-intuitive results. Missing variables in oil or petrol price may be part of the explanations.

In terms of the regression analysis results, Olatunji justifies it with the high adjusted coefficient of variation (adjusted R^2) of 94% without realising that many of the variables in the model are probably non-stationary. No unit root test is carried out, but many variables display clear trends in figures 1 to 4 in Olatunji (2010). Therefore the result is likely spurious.

In the reduced form models reviewed in this section, the output variables are found positively correlated with the output price variables of the construction industry. This implies that demand shocks dominate in the short run and the observations of the price and quantity data are mainly on a relatively stable short run upward sloping supply curve. Cheng and Wilmot (2009) find that after Hurricanes Katrina and Rita, typical demand shocks, the construction price and output measures have both gone up dramatically in the hurricane-impacted areas.

2.5 Structural Demand-Supply Model

In the development of econometrics, the Cowles Commission structural approach established primarily in 1940s, a dynamic simultaneous-equations model based on Walrasian general equilibrium system, is very influential. Christ (1994) describes the intention of the research programme of the Cowles Commission as combining "economic theory, statistical methods, and observed data to construct and estimate a system of simultaneous equations that could describe the workings of the economy." The interaction of demand and supply curves is a simple system of simultaneous equations. Estimations of such equations predated the Cowles Commission, such as Wright (1915) and Working (1927), but the Cowles Commission's research in the identification of structural equations brought the issue of identification to the forefront of econometric research.

In construction price index modelling, Akintoye and Skitmore have undertaken the challenging task of identifying structural demand and supply equations of the UK construction sector in Akintoye and Skitmore (1990, 1991a and 1993) and Akintoye (1991). Akintoye and Skitmore (1994) conclude that, compared with the forecasts made by Building Cost Information Service and Davis Langdon LLP (formerly Davis, Langdon & Everest), their reduced form equation produced more accurate tender price index forecasts up to 3 quarters ahead.

Before reporting and commenting upon their results, it is appropriate to acknowledge that Akintoye's thesis and the series of his papers co-authored with Skitmore are the most thorough and systematic published academic study of UK construction price index modelling. They intend to construct their price index forecasting model on the foundation of demand and supply curves, and have also rigorously examined the available data.

The results reported in their various papers were slightly different and the following is based on Akintoye and Skitmore (1993) which has used quarterly data between the 1st quarter of 1974 and the 4th quarter of 1987. Their first result is the so-called structural form of equation of construction price:

$$\begin{aligned} \ln TPI_{t} = \; & -3.614 + 0.807 \ln BCI_{t} + 0.009 \ln STR_{t-4} - 0.296 \ln PRO_{t-2} \\ & - 0.258 \ln FRM_{t-5} + 0.003\, RIR_{t-3} + 0.542 \ln MAN_{t-7} \\ & - 0.136 \ln EMP_{t-2} + 0.606 \ln GNP_{t} + 0.061\, OIL_{t-1} \end{aligned}$$

where,

TPI: BCIS quarterly tender price index deflated by retail price index
BCI: BCIS building cost index deflated by retail price index
STR: number of strikes or stoppages
PRO: labour productivity
FRM: number of construction firms
RIR: real interest rate
MAN: profit margin in manufacturing sector
EMP: level of unemployment
GNP: Gross National Product deflated by retail price index
Oil: Oil crisis dummy for 1978Q2 to 1980Q2

Their supply equation is as follows:

$$\begin{aligned} \ln QS_{t} = \; & 1.049 + 0.970 \ln TPI_{t} + 0.628 \ln PRO_{t-4} - 0.695 \ln BCI_{t-2} \\ & - 0.019 \ln STR_{t-3} + 0.239 \ln FRM_{t-8} - 0.093\, OIL_{t-1} \end{aligned}$$

where,

QS: quarterly construction output at current prices in the UK deflated by retail price index

Their demand equation is as follows:

$$\ln QD_{t} = -14.051 - 0.766 \ln TPI_{t-3} + 1.632 \ln GNP_{t} - 0.011\, RIR_{t-1} - 0.249 \ln EMP_{t-4} + 1.764 \ln MAN_{t-4}$$

where,

QD: quarterly construction new orders at current prices in the UK deflated by retail price index

Their so-called equilibrium equation is as follows:

$$\ln QS_{t} = 3.281 + 0.197 \ln QD_{t} + 0.158 \ln QD_{t-1} + 0.106 \ln QD_{t-2} + 0.055 \ln QD_{t-3} + 0.02 \ln QD_{t-4} + 0.016 \ln QD_{t-5} + 0.058 \ln QD_{t-6}$$

The first ‘structural’ equation is a misnomer because any changes in the coefficients of the structural demand and supply equations will change the coefficients of that equation[7]. It is a reduced form equation[8] generated by solving the demand and supply equations.

Asano, Yu, Bhattacharyya, and Tsubaki (2008) attempt to replicate the ‘structural’ equation by using the data provided in Akintoye and Skitmore (1993). Asano *et al* (2008) obtain a comparable result but the values of some coefficients differ and some variables become less statistically significant. The difference was due to the fact that

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[7] Christ (1994: pp. 36) explains that Haavelmo (1944) “used the name structure to denote such a system of structural equations when numerical values are specified for all its parameters, including the parameters of the joint distribution of the disturbances as well as the coefficients of the equations.”

[8] In a system of simultaneous equations, reduced form equations are obtained by solving the equations, so that each endogenous variable is expressed as a function of exogenous variable(s).

Akintoye and Skitmore had used in the calculation a data set different from the one published in their paper.

Akintoye and Skitmore are aware of the issue of spurious regression and express the hope that deflating the nominal variables namely TPI and GNP by retail price index would resolve the problem. It is surprising that they do not test the stationarity of their variables. By using the data in Akintoye and Skitmore (1993), it can be found that the augmented Dickey-Fuller test statistics for the deflated TPI and GNP are -1.986[9] and -0.939[10] which fail to reject the non-stationary hypotheses even at 10% level. In other words, both TPI and GNP are non-stationary, so no valid inference can be made from the OLS regression statistics of the 'structural' equation.

In the estimation of the supply and demand equations, Akintoye (1991) and Akintoye and Skitmore (1991a) argue that the best proxy of the quantity of construction demand is the value of construction new orders (deflated by RPI)[11] and the best proxy of the quantity of construction supply is the value of construction output (deflated by RPI), both published by the then Department of Environment[12]. In their words, Akintoye and Skitmore (1991a: pp. 110) make the following distinction between the construction new orders and construction output:

> "At first sight, construction output is synonymous with construction new orders. A moment's reflection, however, suggests that the two terms are quite different. The volume of new orders relating to contracts obtained by or awarded to contractors for new construction is regularly published and is

[9] t-statistics for 5% and 10% critical values are -2.914 and -2.595

[10] t-statistics for 5% and 10% critical values are -2.912 and -2.594

[11] Having reviewed some literature such as Herbsman (1983), Killingsworth (1990), Runeson (1988) and Tan (1989), Akintoye (1991: pp. 116) concluded that "a measure of construction demand (that) has received some acceptability is the value of construction new orders obtained by contractors." Akintoye (1991: pp. 117) further explains that "This definition (of the value of the construction new orders published by the then Department of the Environment) appears to meet the description of effective demand as they are backed up with the willingness and ability of client to pay by entering into contract with contractors at a market price." Equally, however, construction orders value represent the willingness of contractors to supply (in a specified future) at the market price.

[12] Akintoye (1991: pp. 147) states that "Consequently, construction output may be considered a reasonable proxy for construction supply.", and "This definition of (the value of) construction output (by the then Department of the Environment) is considered relevant to our description of construction supply."

> tantamount to effective construction demand. Construction output, on the other hand, relates to the total work done by contractors which is a reflection of construction supply."

Both the value of new orders and the value of construction output are transaction values. They are quantities demanded by the purchasers and simultaneously quantities supplied by the suppliers at and multiplied by the prevailing price, because only the interaction points of demand and supply curves from transaction statistics can be directly observed. The value of the new orders and the value of construction output both reflect the quantities of construction work demanded by clients and also the quantities of construction work supplied by contractors at the prevailing prices. The difference between them is that new orders reflect contracted amounts that will be delivered in the future, and that outputs reflect the actual amounts completed in the previous period. Using two different measures of the transaction values and linking them by a distributed lag model (in their equilibrium equation) would introduce unnecessary noise to the model, without achieving the aim of identifying the demand and supply curves.

Since the directly observed quantities and prices over time are the interaction points of demand and supply curves, they trace the demand curve[13] only if the demand curve is static over time while the supply curve is shifting over time, so that all the interaction points are on the same demand curve. However, this is not a general case or at least a strong reason is needed to accept it as a prior. Therefore, the grounds provided by Akintoye and Skitmore cannot substantiate that what they estimated is a demand equation. Likewise, the foundation of the so-called supply equation rests on flimsy theoretical foundation.

The key to identify the demand and supply curves, in less technical terms, is to identify at least one exogenous factor that would only shift the demand curve and at least one exogenous factor that would only shift the supply curve. Demand (supply)

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[13] Demand curve is defined as a schedule relating the quantity of an economic good demanded and its price for given tastes, real income and prices of other economic goods.

curve is usually defined as a relationship between quantity demanded (supplied) of an economic good and its price, given other things stay the same. The aforesaid exogenous factors are amongst these "other things". However, Akintoye and Skitmore did not approach the topic from this perspective.

On a more technical note, Akintoye and Skitmore in their discussion show no awareness of the issue of simultaneity bias in the estimations of simultaneous equations that was one of the major concerns of the Cowles Commission. Ignoring simultaneity bias means that all of their estimates of the coefficients of their demand and supply equations are probably biased estimates of the true values.

2.6 Error Correction Model (ECM) and Vector Error Correction (VEC) Model

Moving away from the demand and supply framework, Dorward, Akintoye and Hardcastle attempt to build a causal relationship model between construction workload and construction price in Dorward *et al* (1998) based on the error correction model (ECM) jointly developed by Engle and Granger (1987)[14]. Quarterly UK data for the period between the 1st quarter of 1980 and the 2nd quarter of 1995 is used for the analysis. Their error correction mechanism equation is as follows:

$$\Delta Q_t = 0.26519 + 0.00.0952\ \Delta TPI_t - 0.26923\ (Q_{t-1} - 27.1447 - 0.88261\ TPI_{\ t-1})$$

Q_t: quarterly construction new orders at constant prices in the UK at time t

$\Delta Q_t = Q_t - Q_{t-1}$

TPI_t: BCIS quarterly tender price index at time t

$\Delta TPI_t = TPI_t - TPI_{t-1}$

[14] Engle and Granger won the Nobel Prize in economics in 2003, and the study of non-stationarity and co-integration in the analysis of economic time series – the core concepts behind error correction mechanism – are credited as their major contributions.

The major idea behind error correction mechanism is co-integration. Non-stationary variables tend to display extensive movement over time. However, some pairs of non-stationary variables do not drift too far apart because it is believed that there are forces that bring the variables into an equilibrium in the long run. For example, prices of a tradable good in different countries may be non-stationary, but they are believed not to drift too far apart amongst them. Otherwise, someone could profit from arbitrage. In other words, arbitrage is the force keeping the prices of the same tradable good in different countries not too far apart. Such pairs of variables are said to be co-integrated.

Error correction model is linking the long run equilibrium of the economic variables with the short run fluctuations. Dorward *et al* (1998) find that construction output measured by construction new orders moves in tandem with tender price index over time. They find that the residuals from regressing Q_t on TPI_t are stationary. The long run relationship resembles a supply curve.

$$Q_{t-1} = 27.1447 + 0.88261\ TPI_{t-1}$$

The short run fluctuations are modelled by the first difference of the variables (dQ_t and $dTPI_t$) which are stationary. The resulting error correction mechanism brings the short run dynamics of the variables together with the long run equilibrium.

It is noteworthy that construction orders is found positively correlated with tender price index in a supply curve-like equation, which contradicts Akintoye's previous assertion that construction orders is the proxy for construction demand. This supports the explanation that construction orders is a measure of transaction value which reflects both the quantity demanded and the quantity supplied.

It is not always clear whether the tender price index data is deflated. The TPI used in Akintoye (1990) and Akintoye and Skitmore (1991a and 1993) are deflated by Retail Price Index to provide a measure of the relative price of construction output to other economic goods available in the UK economy. However, Dorward *et al* (1998) is silent on deflating the TPI. If the TPI is not deflated, under the classical dichotomy between real and nominal economic variables which economists generally accept at least in the long run equilibrium, the real output in construction should not be affected by the movement of its nominal price (TPI).

Wong and Ng (2010) estimate a vector error correction (VEC) model for the tender price index in Hong Kong between the first quarter of 1983 and the first quarter of 2006. VEC model is a further development of ECM, by incorporating the relationship of co-integrating non-stationary variables into vector autoregression model. Table 4 in Wong and Ng (2010) reports their preferred VEC model, and is summarised as follows:

$$\begin{aligned}\Delta tpi_t = {} & 0.0034 - 0.0737(long\ run\ relationship) + 0.39\Delta tpi_{t-1} + 0.05\Delta tpi_{t-2} \\ & + 0.04\Delta tpi_{t-3} - 0.06\Delta tpi_{t-4} + 0.32\Delta bci_{t-1} - 0.11\Delta bci_{t-2} \\ & + 0.21\Delta bci_{t-3} + 0.12\Delta bci_{t-4} - 0.10\Delta gdp_{t-1} - 0.08\Delta gdp_{t-2} \\ & - 0.12\Delta gdp_{t-3} - 0.14\Delta gdp_{t-4} - 0.04\Delta gdpc_{t-1} + 0.04\Delta gdpc_{t-2} \\ & + 0.17\Delta gdpc_{t-3} + 0.03\Delta gdpc_{t-4}\end{aligned}$$

where tpi_t is log of quarterly tender price index of building industry in Hong Kong at time t; bci_t is log of quarterly building cost index at time t; gdp_t is log of quarterly gross domestic product at time t; $gdpc_t$ is log of the quarterly construction component in gross domestic product at time t; Δ is the first difference operator such that $\Delta tpi_t = tpi_t - tpi_{t-1}$

The *long run relationship* in their preferred model is as follows:

$$long\ run\ relationship = tpi_{t-1} + 1.81\ bci_{t-1} + 1.88\ gdp_{t-1} - 0.03 gdpc_{t-1}$$

In other words, they find the long run co-integrating equation as follows

$$tpi_{t-1} = -1.81\ bci_{t-1} - 1.88\ gdp_{t-1} + 0.03 gdpc_{t-1} + e_{t-1}$$

where e_{t-1} is a white noise random variable with a constant variance and zero mean.

The negative coefficient of *bci* means in the long run the higher the building cost index, the *lower* the tender price index of building work. It is counter-intuitive but the authors do not point out this perverse sign nor provide any explanation.

The *gdpc* variable is a measure of construction output, so the long run relationship once again resembles a supply curve.

Ashuri, Shahandashti and Lu identify eight leading indicators of the construction cost index published by Engineering News Record, namely consumer price index, crude oil price, producer price index, GDP, employment levels in construction, number of building permits, number of housing starts and money supply in Ashuri (2012). They apply Johansen's integration tests to these eight variables and find money supply and crude oil price are co-integrated with the construction cost index. The data is monthly and covers the period between January 1975 and December 2010.

Shahandasti and Ashuir (2013) examine the same set of data and estimate five VEC models. They have gone into some length in reporting statistics of superior forecasting accuracy of the VEC models compared with the alternatives proposed in Ashuri and Lu (2010) but they have only reported the specification of their second best VEC model in autoregressive distributed lag format:

$$\begin{aligned} CCI_t = 13.09 + 1.23CCI_{t-1} - 0.20CCI_{t-2} - 0.09CCI_{t-3} + 0.01CCI_{t-4} \\ - 0.07CCI_{t-5} + 0.12CCI_{t-6} - 0.73COP_{t-1} + 2.76COP_{t-2} \\ - 1.03COP_{t-3} - 1.02COP_{t-4} + 1.51COP_{t-5} - 1.29COP_{t-6} \end{aligned}$$

where CCI_t is the monthly construction cost index at time t published by Engineering News Record; COP_t is the monthly crude oil price at time t published by the US Energy Information Administration.

The model can be re-arranged to the usual VEC specification as follows:

$$\Delta CCI_t = 13.09 - 0.0006CCI_{t-1} + 0.1943COP_{t-1} + 0.23\Delta CCI_{t-1} + 0.03\Delta CCI_{t-2} - 0.06\Delta CCI_{t-3} - 0.05\Delta CCI_{t-4} - 0.12\Delta CCI_{t-5} - 0.93COP_{t-1} + 1.83COP_{t-2} + 0.80COP_{t-3} - 0.22COP_{t-4} - 1.29\Delta COP_{t-5}$$

Therefore the long run relationship is as follows:

$$CCI_{t-1} = constant + 32.38COP_{t-1} + e_{t-1}$$

where e_{t-1} is a white noise random variable with a constant variance and zero mean.

The construction cost index is positively correlated with the crude oil price in the long run, but no measure of construction output has entered the long run relationship.

Jian, Xu and Liu (2013) apply the VEC model to quarterly Australian data between the third quarter of 1996 and the first quarter of 2011. They also estimate the impact of the global financial crisis in 2008 and 2009 on the producer price index of the construction industry published by the Australian Bureau of Statistics. Their result shows that the financial crisis reduced by circa 9% the construction producer price index and the long run relationship of their VEC model is as follows:

$$CP = -83.31 + 1.86\, NI + 10.73POP - 0.12\, UR - 1.59IR$$

where *CP* is the construction producer price index in Australia; *NI* is the Australian national income; *POP* is the size Australian population; *IR* is the interest rate.

Similar to Shahandasti and Ashuir (2013), the long run co-integrating relationship is a reduced form of supply and demand that no measure of construction output is present.

2.7 Artificial Neural Networks

In her review of the quantitative analysis techniques applied in construction economic and management research, Goh (2008) finds that there is an increasing trend of using artificial intelligence techniques such as artificial neural networks (ANN), genetic algorithms (GAs) and fuzzy logics. Li (1995) considers that the ability to cope with complex relations and handle incomplete data are the advantages of ANN applied in construction cost estimation. On the other hand, the massive amount of data required and the difficulty in explaining the result in the absence of a theory behind it are considered as disadvantages.

At first glance, the vocabularies used in ANN such as “input, hidden and output layers”, “training”, “nodes”, “feedforward and back-propagation” cover ANN with a veil of mystery and make it look very different from the more conventional regression based analysis. In a nutshell, both ANN and conventional regression analysis fit the data with a function form. Regression analysis usually assumes the relationship between the variables under study is linear and econometricians make use of economic theory to guide their selection of the variables and specification of the equation. ANN is a data driven process and usually a very flexible functional form – sigmoid function – is used to relate the variables under study. Therefore, flexibility is the key advantage of ANN which allows more complex patterns to be recognised. By the same token, however, the flexibility would model the “noise” or random error specific in the data sample[15]. Therefore, the pattern recognised is *ad hoc* and not general to the population of the data. Balancing between the advantage and disadvantage brought by the flexibility in ANN requires subjective judgement of the researchers.

In construction cost index modelling, Williams (1994) applies back-propagation neural networks to model the ENR construction cost index for the US published between July 1967 and December 1991. The input variables include one month percentage change of the construction cost index, six month percentage change of the construction cost index, prime lending rate, one month change of the prime lending rate, six month change of the prime lending rate, number of housing starts for the month, one month percentage change of the number of housing starts, six month percentage change of the number of housing starts, and the month of the year. The output is the forecast of the ENR construction cost index. Comparing the sum of

[15] This problem is called over-fitting.

squares of errors (SSE)[16], the predictions made by ANN are found to be less accurate than predictions made by exponential smoothing and simple linear regressions. This seems to be due to over-fitting. The random errors of the data in the sample are mistakenly recognised as the pattern. Williams attributes the poor predictions to the reason that factors affecting prices are very complex and that data collected in a different economic climate is of little use to predict price.

Wilmot and Mei (2005) repeat the analysis of the Louisiana Highway Construction Index (LHCI) in Wilmot and Cheng (2003) which has been reviewed in the Reduced Form Model section of this chapter. While Wilmot and Cheng (2003) apply regression analysis, Wilmot and Mei (2005) make use of ANN on the same data. Wilmot and Mei (2005) conclude that ANN reproduces past LHCI better than regression analysis. This is unsurprising because of the more flexible functional form in ANN. However, Wilmot and Mei (2005), unlike Williams (1994), do not hold out any samples for making out-of-sample forecast, which is a better test for forecasting accuracy.

2.8 Construction Price Models Developed by the Industry

The construction price index models that have been reviewed so far are produced by academic researchers. However, construction price index forecasting also takes place in private commercial organisations in the UK such as EC Harris LLP and Davis Langdon LLP, in government departments such as Department for Business Innovation & Skills, and in professional bodies such as RICS.

Although no explicit equation is provided in their publications, it is apparent that the tender price index forecast published by EC Harris is based on the prospects for the (volume of) UK construction output. In their quarterly reviews of the UK construction market such as EC Harris (2009), they always produce a graph showing the national

[16] The SSE for the exponential smoothing model is 2.45. The SSE for the regression model is 2.65. The SSE for the ANN model is 5.32

tender price index tracking closely the series of construction output at constant prices, and their tender price forecast also tracks closely with the construction output forecast made by Experian Business Strategies and the Construction Products Association. No theoretical justification of the relationship is provided in EC Harris' publications. However, a standard Keynesian Phillips curve model with the following assumptions would yield a similar conclusion that real output and the price level move in tandem in the short run, because:

a) The monetary authority controls the growth in money supply with a view to controlling the long run inflation rate at a constant rate.
b) Shocks to the aggregate demand dominate in the short run and supply shocks are secondary in order of importance.
c) The growth rate of *potential* output is largely constant and crudely at about the same value as the long run inflation rate, say at 2%.

Davis Langdon, another leading construction cost consultancy in the UK, publishes its tender price index forecast in a trade journal, *Building* magazine, such as Fordham (2009 and 2010) Fordham and Baldauf-Cunnington (2009). Although there is no direct description of how the forecast is made nor any equation provided, there are some common threads running through the many quarterly market forecasts published in *Building*.

Leading indicators for construction output such as construction new orders and CIPS/Markit Purchasing Managers' Index for construction are analysed. Forecasts of construction output made by Experian Business Strategies and the Construction Product Association are compared with the trends suggested by the aforesaid indicators. Together with their own first-hand experience in the construction market, Davis Langdon forms a view on the outlook for construction output and thus the market competitiveness in terms of overhead and profit percentages charged by contractors. In addition, they also review the labour wage agreements and negotiations in the construction industry to form a view on the trend in labour cost.

Construction material costs, such as steel and oil prices, and exchange rates[17] are usually reviewed to guide the forecast.

Building Cost Information Service (BCIS), part of the Royal Institution of Chartered Surveyors, has been providing construction cost information to the industry since 1962 and also compiles its own well-respected tender price indices. Peter Rumble, the managing technical editor at the BCIS, explains the major factors that BCIS consider when they make their 5-year tender price index forecasts in Rumble (2006).

Rumble (2006) considers new orders, housing starts and wage agreements good leading indicators up to a 24 months horizon. Since BCIS forecasts the tender price index for 5 years, it needs a longer term perspective. Rumble lists out the key drivers, namely input costs, construction demand and capacity, and he argues that tender prices are more reactive to demand pull than cost push. This in fact is consistent with EC Harris's model.

Rumble (2006) points out that money supply, interest rates, earnings, GDP and government policies will impact on the tender price via the aforementioned direct factors. Three long-term relationships are also analysed for the 5-year forecasts:

1) inflation and tender prices: the historical data in the last 50 years tends to suggest that the annual growth rate of tender price index precedes inflation rate measured by RPI.
2) GDP and construction output: the historical data in the last 50 years appears to suggest that the annual GDP growth rate and construction output growth rate track each other (without clear lead or lag relationship) and the latter is more volatile.
3) Construction output and tender prices: the long-term relationship was not mentioned in Rumble (2006). However, the 5-year forecast published by BCIS

[17] Fordham (2009) argues that circa 25% of building materials are imported, predominately from Eurozone, in recent years, so the change in the sterling exchange rate would have a significant impact on material costs.

shows a close relationship between annual growth rate of tender price index and construction output at constant prices. This is in congruence with EC Harris's model.

In their five year forecasts such as BCIS (2008, 2009, 2010a, 2011, 2012 and 2013), BCIS follows the same logic described in Rumble (2006). Inflation measured by RPI, GDP growth, interest rates, material prices, labour wages, gross mark-up, construction output, construction orders, and housing starts are analysed to produce tender price forecast. External forecasts such as the independent forecasts for RPI inflation, GDP growth and the base rate published by HM Treasury[18], as well as construction output forecasts made by Experian Business Strategies and the Construction Products Association are also referenced and compared. Without providing detailed equations, BCIS forecasts (2008, 2009, 2010a, 2011, 2012 and 2013) all mention that there is a BCIS econometric model on construction output. Up to 2011, BCIS reports the BCIS econometric model is based on the Joseph Rowntree Foundation Housing and Construction Model. Since 2012, BCIS comments that BCIS econometric model is prepared by Oxford Economics, an economic forecasting consultancy.

The construction statistics and economics unit at the Department for Business Innovation & Skills (BIS) publishes its renowned tender price index in its quarterly publication called BIS Construction Price and Cost Indices[19]. BIS provide 8-quarter forecasts of its Public Sector Non-housing Building tender price index (Pubsec TPI). The latest two quarters' Pubsec TPIs are provisional and are subject to revisions when more samples are available. Unfortunately, although the compilation of the Pubsec TPI is very similar to the BCIS All-in TPI and the Davis Langdon TPI (see chapter 3),

[18] For example, HM Treasury (2010) *Forecast for the UK Economy: a Comparison of Independent Forecasts*, January, No. 273, London: HM Treasury.

[19] It is now only available in an online format provided by BCIS. BIS was formed on 5 June 2009, and before that the publication was called Quarterly Price and Cost Indices for Construction Works when it was published by the then Department for Business, Enterprise and Regulatory Reform (BERR) from June 2007, which was preceded by a similar publication by the then Department of Trade and Industry (DTI) from 2000 and the then Property Services Agency at the Department of Environment from 1981.

there is no known literature describing how BIS or its predecessors produce their forecasts.

OGC[20] commissioned Deloitte to develop an economic model of the UK construction sector to illustrate the impact of additional public work, especially the work for the London 2012 Olympics, on the demand and capacity in construction sector in 2006. Deloitte chose price inflation measured by BCIS Output Price Index as the key indicator of the capacity relative to demand. Although they believe the effects of capacity / demand ratio are multi-dimensional and can be reflected in price, quality and time, their model concentrates on the inflation of construction output price because of the availability of historical data and the ease of measurement.

Deloitte / Experian have contributed to compile the Public Sector Client Construction Demand Database which centralises the data in construction work planned to be commissioned by various government departments. The information, together with other exogenous variables that will be explained later, is fed into the Public Sector Construction Demand Econometric Model. The major focus of the Econometric model is scenario testing. The users of the model can alter the values of construction output, oil price, labour migration inflows and labour productivity and obtain the corresponding construction output price inflation.

The key assumptions and predictions of the model are as follows:

1) There is no manual labour capacity constraint because of unrestrictive use of migrant labour;
2) However, there are skills shortages in project management, design (such as M&E and civil engineering), bidding capacity and client side leadership capacity;

[20] Following the recommendations made in the Kelly Report (OGC 2003), a senior stakeholder group for the construction market in the public sector – Public Sector Construction Clients' Forum – has been established since December 2005 to understand how the public sector can help and improve the capacity of the construction sector to match the demand. The construction demand / capacity study was the result of the first of the seven working groups reporting to the Public Sector Construction Clients' Forum.

3) Construction output price inflation is forecasted to be at 3% between 2006 and 2015 given that the CPI is at 2%;
4) The inflation impact of the London 2012 Olympics (for each £2.5 billion[21] spending) will be an extra 0.12% on output price inflation and 0.2% on TPI inflation in London between 2006 and 2010;
5) Energy and steel prices are considered as important cost push factors.

The structure of the econometric model is best described by the following flowchart taken from Deloitte's report (OGC 2006: pp. 75).

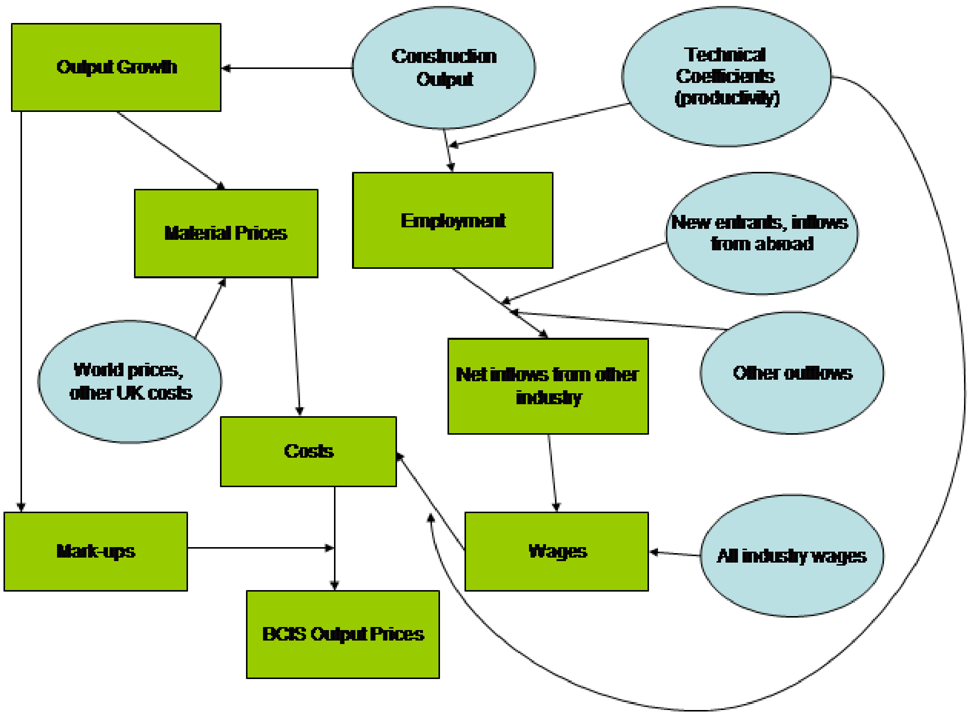

Figure 2.1: Structure of the Econometric Model of OGC 2006

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[21] The then Culture Secretary Tessa Jowell announced to the House of Common in 2007 about the £5.3 billion for venue and infrastructure, including £1.7 billion for the Lower Lea Valley regeneration. In addition Jowell also budgeted £2.2 billion for contingency, £0.6 billion for security and policy, £0.8 billion for VAT and £0.4 billion elite sport and Paralympics funding. The London Olympic budget amounted to £9.3 billion.

The variables in ovals are exogenous to the model while the variables in rectangular boxes are endogenous to the model. The key outputs of the model are the construction output price indices at sector levels (such as private commercial and public non-residential). Annual data between 1986 and 2005 is used to build the model. For instance, the equation for construction output price index in private commercial sector is as follows:

$\ln(PCOMUK/CCOMUK)_t = -0.02852 + 0.81384 \times \ln(PCOMUK/CCOMUK)_t - 0.33338 \times d\ln(OTOTUK)_t + 0.3333 \times d\ln(OCOMUK)_t$

where

PCOMUK = price of output in the UK (private commercial)
CCOMUK = cost of output in the UK (private commercial)
OTOTUK = total construction output in the UK
OCOMUK = construction output in the UK (private commercial)
$d\ln(OTOTUK)_t = \ln(OTOTUK)_t - d\ln(OTOTUK)_{t-1}$
$d\ln(OCOMUK)_t = \ln(OCOMUK)_t - \ln(OCOMUK)_{t-1}$

The cost of output is an endogenous variable in the model, which depends on the material prices, unit labour costs and plant costs. Therefore there are equations linking the cost of output to material prices, unit labour costs and plant costs. Likewise, since material prices and unit labour costs are endogenous to the model, they are linked with other variables such as net flows of construction workers, wages of workers in the UK, oil prices and import price levels. Ultimately all endogenous variables are linked to the exogenous variables and historical values of the endogenous variables.

This is by far the most rigorous construction price model published with clear economic logic behind it. For example improvement in labour productivity will reduce unit labour cost and that will eventually reduce the output price. On the demand side, higher output will push up the mark-up and will result in higher output price.

However, the model depends on a lot of exogenous variables, most notably the forecast of the construction output. Moreover, unlike other main construction price forecasts, it is built on annual data rather than quarterly data. Under closer scrutiny, there are a lot of ad hoc fittings in the estimated equations and the output price index used appears to be the one published by BIS rather than BCIS. The former appears to understate the inflation in the construction industry.

2.9 Conclusion

This chapter has reviewed many construction price and cost index models produced by academic researchers and the industry in different parts of the world. The methodologies employed range from relatively simple ARIMA to complex multi equation regression models. Common shortfalls of the existing literature are as follows:

1) There is a common lack of understanding of how the indices are being compiled and of the issue of data revision (chapter 3 and 4);
2) Some researchers have insufficient statistical knowledge. The most common problem is spurious regression i.e. non-stationarity issues (chapter 5);
3) Some researchers do not appear to fully understand the concept of demand and how to relate it to the published statistics (chapter 5);
4) Most literature relies on the demand side factors to model the movement of the price indices. Demand side factors dominate the timeframe of a few years. However, in the existing literature it is not fully appreciated that the long term relative price is decided by supply side factors namely (relative) productivity growth (chapter 6).

Most of the next three chapters address issues 1, 2 and 3 by focusing exclusively on the UK, which is the country with the longest and most relatively reliable data. However, chapter six returns in part to international scope to address issue 4.

Chapter 3 Construction Cost and Price Indices in the UK: what do they measure? - a review of literature and sources and methods

> "Index numbers have their limitations and none more so than construction indices. But their proliferation in the single sector of the economy covered by construction may be taken as an indication of the extent of the needs which they have been developed to serve." Fleming and Tysoe (1991: pp. vii)

> "The major message that I will be trying to convey is that we often misinterpret the available data because of inadequate attention to how they are produced…" Griliches (1994: pp. 2)

3.1 Overview

The most basic assumption in economics is that demand and supply and total revenues (costs) can be broken-down into a quantity and a price (cost). But where a natural unit of quantity is lacking, both measurement of price (directly) and measurement of volume (indirectly via the concept of value of output at constant prices) depend on the development of an accurate price index. The importance of accurate measurement and pertinent modelling of the general level of construction prices cannot be over emphasised. Uses range from macroeconomic statistics such as real value of investment to micro-level budgeting like construction project price forecasts. Numerous research studies posit that the measured productivity growth rates of the construction sector are distorted and that an inaccurate general construction price index is a main villain of the piece.

The academic research published in this arena has primarily focused on models to forecast or predict changes in the general construction price level, whereas this chapter scrutinises the compilation methods and hence fitness-for-purpose of the general construction price and cost indices in Britain. It finds that the price indices measure the price movement of more traditional building trades but almost completely ignore the mechanical and electrical services. The existing price indices also do not gauge the tender price movements of new building work that is not procured through the conventional lump sum BQs route, such as many projects in private housing and PFI markets. These omissions make out a case for allowing resources to the project of developing alternative methodologies: a) a revised version of the present method, and b) a hedonic price index.

On the other hand, the source for labour costs in the construction cost indices mainly reflects the movement of the wage rates in the national labour agreements, which appears to overstate the movement of the actual wages in the construction sector. The chapter ends by recommending a close examination of various labour earnings indices with a view to controlling the impact of composition and skill levels of the labour force on average wages as well as a more frequent revision of the base weightings for the indices.

3.2 Introduction

What determines the living standard of a society is the quantity of goods and services produced by the society. The importance of measuring this quantity is obvious for the understanding of economic progress. However, the statistical agencies of governments measure the monetary (nominal) value of the goods and services produced by their countries (usually called GDP at current prices). This value is a set of (not-directly known) quantities multiplied by a set of (not-directly known) prices. The conversion of the monetary value of output to the real output of the economy requires a price index because the changes in monetary value of the goods and services produced are the combination of two movements: monetary price level movements and quantity movements. Therefore the measure of the real outputs is as accurate as the price indices are in measuring price changes. Hence also the importance of the construction price and cost indices[22] in construction productivity research in which the focus is on understanding the relationships between the changes in real inputs and outputs of the construction industry over time.

The *prior* reasons for questioning the quality and accuracy of the existing British construction price and cost indices are fourfold. First, Allen (1985 and 1989), Dyer *et al* (2012), Goodrum *et al* (2002), Gordon (1968), Ive *et al* (2004) and Pieper (1989 and 1990) consider the biases in the published construction price and cost indices in, variously, the UK, USA, France and Germany, as one of the main probable causes of inaccurate measures of productivity growth rates in the construction sector.

Second, the existing compilation method of British building price indices was developed in the late 1960s and that for construction cost indices in the 1970s, and since then there have been profound changes in construction technologies, changes in procurement routes and the associated contract documents, as well as the growing significance of the mechanical and electrical services. For example, building projects procured via design and build route, which has been gaining in popularity, are completely ignored in the existing building price indices.

Third, the advances in general economic theory of indexing have not been incorporated in compiling British construction price indices since the late 1960s. Recent improvements such as hedonic price indices haven been adopted by the UK, US and German statistical agencies, to name but a few, to compile other price indices.

Fourth, most research on construction price and cost indices is about forecasting and modelling using time series or other techniques, in which past values of price indices, or other variables, are used to forecast future values of the indices and thus construction price and cost inflation (Akintoye and Skitmore 1994, Akintoye *et al* 1998, Fellows 1991, Hwang 2009 and 2011, McCaffer *et al* 1983 and Ng *et al* 2004). Such models presume that the published indices do accurately measure construction

[22] Construction price refers to the output price charged by the main contractors and construction cost refers to the input price paid by contractors.

inflation. To fill this 'presumption' gap, this chapter aims to scrutinise the compilation method of construction price and cost indices with a view to indicating what are actually being measured and identifying opportunities for improvements.

Year	All work (£ million)	New Work		Repair & Maintenance
		Building	Infrastructure	
1983	26,623	52%	11%	38%
1984	28,990	51%	10%	39%
1985	30,957	51%	9%	39%
1986	33,427	52%	9%	39%
1987	39,143	53%	8%	38%
1988	46,811	55%	9%	36%
1989	54,391	56%	9%	35%
1990	57,673	54%	10%	36%
1991	53,378	49%	14%	37%
1992	49,602	46%	15%	39%
1993	48,431	45%	15%	40%
1994	51,647	47%	13%	40%
1995	55,013	46%	13%	40%
1996	57,749	45%	14%	40%
1997	60,990	47%	13%	40%
1998	64,829	49%	12%	39%
1999	68,582	52%	11%	37%
2000	72,714	52%	11%	37%
2001	77,958	51%	11%	38%
2002	87,218	52%	12%	37%
2003	97,259	53%	10%	37%
2004	106,657	57%	8%	36%
2005	111,494	57%	7%	36%
2006	118,320	58%	7%	35%
2007	127,062	59%	7%	34%
2008	128,641	56%	8%	37%
2009	111,079	51%	10%	39%
2010	117,385	52%	12%	36%
2011	121,737	51%	13%	36%
2012	115,583	49%	12%	39%
	Geometric Mean	**52%**	**10%**	**38%**

Table 3.1: Construction Output of Great Britain at Current Prices, 1983 to 2012 (Source: ONS Statistical Bulletin: Output in the Construction Industry, various issues).

The construction sector is complex and its projects are heterogeneous, including housing, offices, schools, hospitals, roads, bridges, tunnels, dams and so on. Therefore, a number of price and cost indices measuring the inflation in each subsector of the construction industry may be required. As exhibited in *table 3.1*, very roughly fifty percent of the output of the construction sector is believed to comprise projects of the kind covered by the Tender Price Indices and the remaining fifty percent not covered, comes mainly from repair and maintenance (40%) and 10% new infrastructure work[23]. Buildings account for more than 80% of the new work output, and infrastructure for the remainder. In comparison with new infrastructure and all repair and maintenance work, the output of the new building sub-sector is less diverse and easier to be gauged and as a result the price indices of new building work are relatively well developed. Moreover, new building work in Britain, as will be shown, has traditionally been the field of application of Bills of Quantities (BQs), in which the aggregate values of successful tenders are broken down into unit prices for specified quantities of elements in the finished building. The British method of compilation of tender price indices is based upon this fact. BQs of course only exist for new construction and some major refurbishment projects, and not for repair and maintenance projects. Moreover, it is noteworthy that the samples collected for compiling the British Tender Price Indices (TPI) do not even represent the subsectors within the new building work proportionally. This issue is returned in the section 3.5 of this chapter. This chapter only focuses on one country, i.e. on the Tender Price Indices (TPI) of the new building sector in Britain[24] and Construction Cost Indices (CCI) in the UK.

TPI are attempts to measure the change over time of the contract prices between clients and contractors for constructing new buildings. In addition TPI are

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[23] The 'repair and maintenance' work actually includes, especially for housing, much improvement and alteration work. The actual share of 'work to existing structures' is unknown, but significantly higher than 38% as reported in *table 3.1* because improvement and alteration of housing is reported as 'repair and maintenance', although much alteration and improvement of other buildings and infrastructure is reported as 'new work'.

[24] Cannon (1994) and Briscoe (2006) call for attention to the quality and usefulness of the general construction statistics in the UK. Regarding construction price and cost statistics, Fleming and Tysoe (1991) provide a comprehensive collection of British construction cost and price indices and Fleming (1966) is a valuable review of various indices of construction factor costs and market prices over the period between 1845 and 1964.

components of the deflators used (output price indices) to derive the building industry real new output (output at constant prices). CCI are attempts to measure the change over time of the input prices (such as labour wages, construction material prices, and plant hire prices) to the contractors. To recapitulate, the four important uses of the TPI and CCI are as follows:

- Deflation of building sector components of the nominal national product to produce estimates of real output from the sector;
- Capturing relative price change and inflation in the construction industry for assessments and forecasting of market conditions;
- Updating historical cost data for cost planning and estimating;
- International, intersectoral or intertemporal comparisons of the level and growth of price, real output and productivity.

The UK Department of Business, Innovation and Skills (BIS) (2013) reported that the main uses of the construction price and cost indices by the 75 user respondents to their consultation included market forecasting and information as well as contractual issues (pre-construction estimates, contract pricing, and contract and programme management). In terms of usage of the three main types of indices (the third type is output price indices derived from TPI), 69 of the 75 respondents use the tender price indices, 38 respondents use output price indices, and 30 respondents use construction cost indices. Most of the users of these price and cost indices consider the cessation of the indices would cause major or significant disruption to their work. Overall, the users are satisfied with the indices while most respondents would like improvement in the speed of publishing updated indices.

Figure 3.1 presents the trends of the BCIS All-in Tender Price Index and the BCIS General Building Cost Index. This example clearly shows that they deviate in terms of levels, growth rates and volatilities, and therefore CCI would not be a good proxy for the TPI. If similar relationships hold elsewhere, this undermines the validity of using CCI as the deflator of the construction output as is done in some countries.

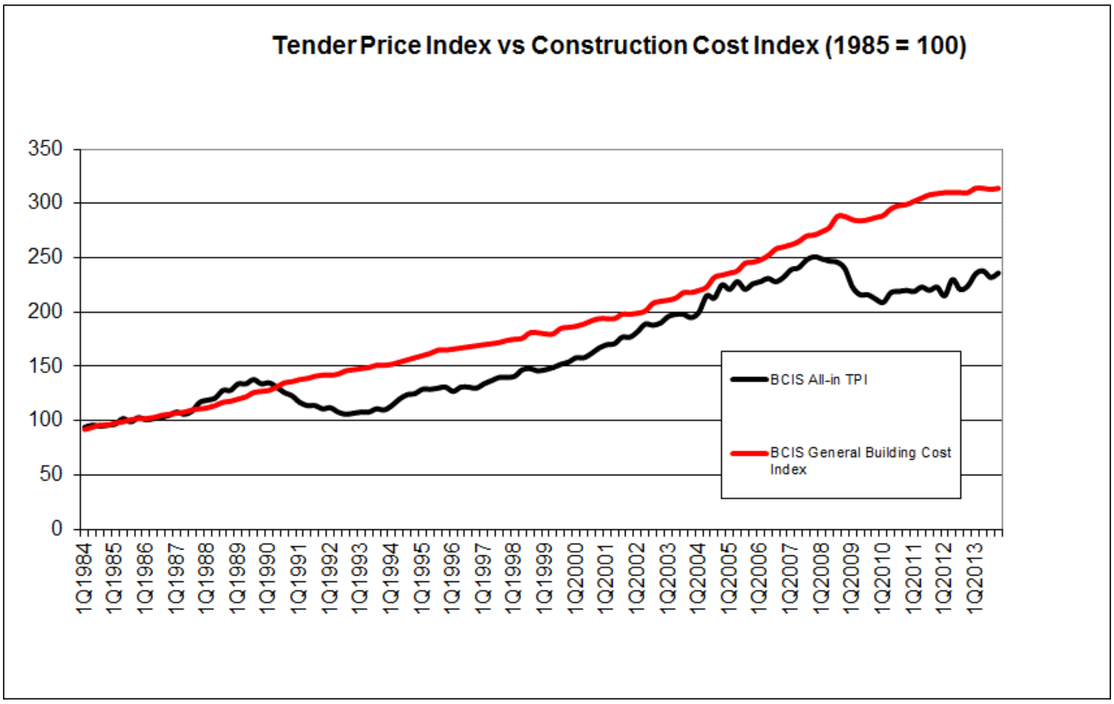

Figure 3.1: BCIS All-in Tender Price Index (TPI) vs BCIS General Building Cost Index (CCI)

Source: BCIS On-line

The next two sections (3.3 and 3.4) describe the current TPI and CCI compilation methods widely adopted in Britain and the UK and their development and evolution, and section 3.5 provides an evaluation of the fitness for purpose of the TPI compilation methods and identify the most important areas to be addressed. In section 3.6, there is a discussion of the possible ways to improve the TPI. Section 3.7 evaluates the compilation methods of CCI and suggests ways of improvement.

3.3 Compilation Methods of Tender Price Indices in Britain

The Development of the Current Method

The Department for Business Innovation & Skills (BIS) produce the most extensive public sector TPI. The Building Cost Information Service (BCIS), the building information research arm of the Royal Institution of Chartered Surveyors (RICS), compile their own building TPI drawing on their wide reach to private and public projects through the willingness of RICS members to supply data to their own chartered professional institute. Davis Langdon (DL), one of the largest quantity surveying practices, also publishes its own tender price index. However diverse the sources of information these three institutions receive, and however different the resulting indices signalling the market conditions, the TPI compilation methods behind their array of indices are very similar and the origin of the method can be traced back to a joint task force of representatives of the RICS, University College London (UCL), and the then Ministry of Public Building and Works.

Under the auspices of the Ministry of Public Building and Works and the RICS, Professor Bowley and Mr Corlett of UCL produced a report on trends in building prices (Bowley and Corlett 1970). The building price indices being published at that time by the government were input cost indices of labour and material cost which would from time to time differ from the trends of tender price of the building industry primarily due to changing productivity and / or market conditions[25]. It was against this background that Bowley and Corlett reviewed several possible methods to compose a true tender price index of the building industry and the method described in chapter 5 of their report became the workhorse method used in the then Department of the Environment (which became then DTI, now BIS), BCIS and DL ever since.

Descriptions of the current method adopted in Britain

This section will first describe the method used in BIS and then highlight differences in the methods adopted in BCIS and DL. Mitchell (1971) was the first attempt to document the method used in the then Department of the Environment (now BIS).

[25] Fleming (1965) was an earlier attempt to produce an output price index of the construction industry from the bottom-up approach. The method is to measure the movement of the factors which determine the movement of the output price namely, labour cost, material cost, productivity, and overhead and profit (OHP) of the construction firms. However, productivity and OHP are notoriously difficult to gauge. Since Fleming (1965), it has become more popular to measure output prices by using the tender price indices.

The following description mainly relies on a manual produced by the then Quantity Surveyors Services Division (QSSD) for internal use.

BIS Public Sector Building (Non-Housing) Tender Price Index

First of all, the data BIS collect for compiling their public non-housing tender price index are the accepted bills of quantities (BQs) of the building projects procured in a quarter of a year (known as the reference period). Under the traditional procurement route, the client of a building project employs quantity surveyors to quantify the building work as much as possible from the design, which facilitates the construction firms to prepare their bids on a common framework. The bills of quantities comprise a number of bills and each bill traditionally covers a separate trade[26] such as *in situ* concrete, brickwork, plumbing and painting. The bill items measure the quantity in suitable physical units, such as cubic metres, of, for example, in situ concrete to be contained in the finished building as 'taken off' the drawings prepared by the architect. The construction firms compete by attaching different prices to each unit of measured work.

In addition to the measured work, there is a section called Prime Costs and Provisional Sums. Prime costs usually are allowed for specialist work (not designed by the architect) such as lifts, heating system, air-conditioning system and electricity supply system; whereas provisional sums are for the work for which the design is not detailed enough to allow quantification, for example, landscaping. Therefore works allowed in the Prime Costs and Provisional Sums section will be adjusted in the future according to the actual cost incurred, and the construction firms compete on the mark-up to these works which is supposed to cover their profit and their overhead expense incurred because of these works. Traditionally, there is also a section of BQs called Preliminaries which covers the contractors' general cost for executing the work as a whole. Therefore, the tender price is the summation of the bill items, prime costs and

[26] Elemental bills have become more popular recently, in which each bill covers a major element or component of the building such as external walls, internal walls & partitions, and wall finishes.

provisional sums, the preliminaries, and other adjustments such as commercial discounts.

BQs provide a rich collection of information about the prices and quantities of various elements of the measured work of building projects at the reference period. To construct a price index, the prices at the base period (here, 1995) are also needed. BIS have utilised the former Property Services Agency (PSA) Schedule of Rates for Building Works as the main source of the base prices. When BIS analyse a BQ, they will re-price it by the rates in the PSA Schedule of Rates of the base year, supplemented with some BQ rates they have collected at the base year. The BIS Public Sector Building (Non-Housing) TPI is called a fix-based match-item Paasche index, for reasons that will become clear. (Laspeyres, Paasche and Fisher indices are defined in Appendix.)

To produce an index for each project (project index), from each trade of the project the items are re-priced in a descending order of value until the re-priced items are more than 25% of the value of the trade and all items with values greater than 1% of the measured work total are re-priced. Therefore it is a current weight Paasche index. As only items that can be matched will be compared, so it is a match item index. The following trades are usually re-priced:

- Excavation and earthworks;
- In-situ concrete and sundries;
- Membranes;
- Reinforcement;
- Formwork;
- Precast concrete;
- Brickwork;
- Blockwork;
- Asphalt;
- Slate and tile roofing;
- Sheet metal roofing and flashings;
- Decking;

- Corrugated and troughed roofing;
- Felt roofing;
- Woodwork carcassing
- Woodwork 1st and 2nd fixings and composite items;
- Insulation;
- Structural steelwork;
- Metal windows;
- Metalwork other than windows;
- Plumbing;
- Wet finishes;
- Dry finishes;
- Glazing;
- Painting and decorating;
- Drainage;
- Roads and pavings

The sum of all items re-priced at the rates of the Schedule of Rates is divided by the sum of the corresponding values at the bill rates with the allocated adjustments on measured work in the BQ to obtain a Schedule Factor.

$$Schedule\ Factor = \frac{Sum\ of\ the\ selected\ items\ being\ repriced\ at\ the\ Schedule\ of\ Rates}{Sum\ of\ the\ selected\ items\ at\ the\ bill\ rates + allocated\ adjustments\ on\ measured\ work}$$

The adjustments on measured work are the adjustments made on the main summary of the BQs such as head office overhead, correction of arithmetic errors, and commercial discount. These adjustments are allocated to the selected items *pro rata* to their values.

With the Schedule Factor, the project index is computed by this formula:

Project Index

$$= \frac{Contract\ Sum\ less\ Dayworks\ and\ Contingencies}{[Contract\ Sum\ less\ Preliminaries, Dayworks\ and\ Contingencies]x\ Scheduled\ Factor}$$

The reason for deducting the preliminaries from the contract sum in the denominator is that the rates in the Schedule of Rates include allocated preliminaries.

Since *location* and *function* of the building are believed to be main cost drivers, and BIS want to reflect the general building price over time independent of the changes of these factors, each project index number is adjusted for these factors. The published index number is then the median value of these adjusted project index numbers in the quarter and is smoothed by use of a three quarter moving average.

It is a fix-based index because as mentioned in Appendix the Paasche index is a bilateral Index. To construct a multilateral time series price index, BIS choose the same base year, say 1995, to compare all the subsequent BQ rates. Therefore all the later year indices are compared against the 1995 Schedule of Rates. BIS have from time to time changed the base Schedule of Rates. In the past the base Schedule of Rates was changed every 5 years but rebasing has become less frequent than before, and the latest PSA Schedule of Rates produced by Carillion (one of the UK's largest construction contractors) was rebased in 2005 prices.

BCIS All-in Tender Price Index

The BCIS index is also a fix-based match-item Paasche index. It matches comparable items and uses the current quantities in the BQs to weight the prices. BCIS use the same Schedule of Rates for the base prices as BIS. They only sample projects over £100,000. The difference between the BCIS and BIS methods lies in the way they adjust and aggregate project indices. From 1984, each BCIS project index has been adjusted for the *size*, *location* and *contract type (firm price or fluctuating price)*[27] before aggregating into the published indices (whereas BIS adjust for *location* and *function)*. The other salient difference is that BCIS takes the geometric mean rather than the median of the adjusted project indices. The BQs are supplied by the RICS members, and cover both public and private sectors.

DL Tender Price Index

The DL TPI is a chain-linked match-item Paasche index. The obvious difference is the application of the chain-linked system to join up the bilateral indices. Chain-linked system means the reference period of the previous bilateral index becomes the base period of the succeeding bilateral index. For example, if 2012Q4 is the base period and 2013Q1 is the reference period in the first quarter, then in the second quarter, the base period is 2013Q1 and the reference period is 2013Q2. As DL publish a price book – Spon's Architects' and Builders' Price book – annually, the base prices are actually updated every year (not quarterly). The index is, therefore, more accurately called an annually chain-linked index, and as such is similar to the Consumer Price Index and Retail Price Index compiled by the Office for National Statistics (ONS). Since the sample is confined to the projects in which DL is involved in Britain, and the sample size in number of projects is therefore smaller, more than 25% of items in terms of value are sampled in each project to reduce the sampling errors. The adjustment factors of the project indices are *size*, *location* and *building function* and the geometric mean is used to aggregate the project indices. The two advantages of the method used by DL are a) that it is chain-linked not fixed-based, b) that there are 3 adjustment factors not 2, but its disadvantage is that DL has a smaller and less representative sample of BQs.

[27] The two types of contracts are firm price new works and fluctuating price new works the latter of which now hardly exist.

3.4 Compilation Methods of Construction Cost Indices in the UK

BCIS, BIS and DL publish general construction cost indices to reflect the inflation of the input prices paid by contractors in various sub-sectors of the construction industry. These cost indices develop from the Price Adjustment Formulae indices, also known as NEDO indices (originally compiled for the Construction Committee of the National Economic Development Office).

Price Adjustment Formulae for Construction Contracts

Construction contracts with fluctuation provisions allowed contractors to pass on to their clients the increase in input cost, such as wages and material prices, in the period between the date of tender and the work being carried out. The Steering Group on Price Fluctuations Formulae of the National Economic Development Office (NEDO) published a report in 1969, which proposed a formula based method to calculate input price (i.e. cost) fluctuations in building contracts. It suggested dividing the contract sum into trade based work categories (such as brickwork and concrete) and to adjust by the published indices of each work category. By analysing 60 completed questionnaires, the report concluded that the administrative cost of agreeing the fluctuations by the recommended formula method would be 0.16% of the contract sum compared with 0.75% by the conventional method of auditing suppliers' invoices and the wages set by the appropriate wage-fixing bodies.

The formulae methods of adjusting fluctuations in civil engineering contracts began in 1973 and in building and specialist engineering commenced in 1974. Each work category index is a weighted index of various labour wages, material prices and plant cost to reflect the cost structure of that particular work category. No productivity growth is assumed in the work category indices.

The sources of the labour wages are largely based on national labour agreements. At the time quite a large proportion of the construction workforce had wages based at least in part on rates set by the national agreements. This it seems is no longer the case. The current wage agreement bodies for different trades are summarised in table 3.2.

Wage Agreement Body	**Trade**
Construction Industry Joint Council	Building and civil engineering
Building and Allied Trade Joint Industrial Council	Building and civil engineering
The Joint Industry Board for the Electrical Contracting Industry; Scottish Joint Industry Board for the Electrical Contracting Industry	Electrical installation
The Joint Industry Board for Plumbing Mechanical Engineering Services in England and Wales; Scottish and Northern Ireland Joint Industry Board for the Plumbing Industry	Plumbing
Joint Conciliation Committee of the Heating, Ventilating and Domestic Engineering Industry	Heating and Ventilation

Table 3.2: Wage Agreement Bodies

These wage agreement bodies have representatives from employers and unions. For example, the Construction Industry Joint Council consists of 9 employers' organisations and 3 trade unions.

The construction material price indices are compiled by the Office for National Statistics (ONS) as part of the whole-economy producer price indices. BIS publishes the material price indices in its *Monthly Statistics of Building Materials and Components.*

The plant cost, including the cost of the operator, is a weighted average of depreciation, building labour cost, and consumables such as tyres and fuel cost.

The weighting of labour wages, material prices and plant cost for the work categories have been revised infrequently since the first series was published in 1974. The second version, Series 2, was published in 1977 and the latest version, 1990 Series (also known as Series 3), was published in 1995.

The double digit inflation that plagued the UK for the majority of the 1970s and 1980s made the fluctuation construction contracts very popular and the Price Adjustment Formulae indices then had an important role to play. Inflation in the UK has come down under 5% since the mid-1990s and consequently fluctuation contracts have become exceptions rather than the norm.

BCIS Building Cost Indices

BCIS publish nine building cost indices on a monthly basis:

- General building cost index
- General building cost, excluding Mechanical and Electrical (M&E), index
- Steel framed construction cost index
- Concrete framed construction cost index
- Brick construction cost index
- Mechanical and electrical engineering cost index
- Basic labour cost index
- Basic materials cost index
- Basic plant cost index

These BCIS indices are based on the work category indices as compiled for Price Adjustment Formulae for Building Contracts published in 1977 (Series 2). BCIS (1997) explains that it has analysed 54 bills of quantities to work out different weightings of the various work category indices for each of the above building cost indices.

Since the weightings are fixed in the base year (1977), the BCIS Building Cost Indices are fix-based match-item Laspeyres indices. *Figure 3.2* uses the BCIS Brick Construction Cost Index as an example to illustrate the relationship with the work categories indices and the underlying input indices.

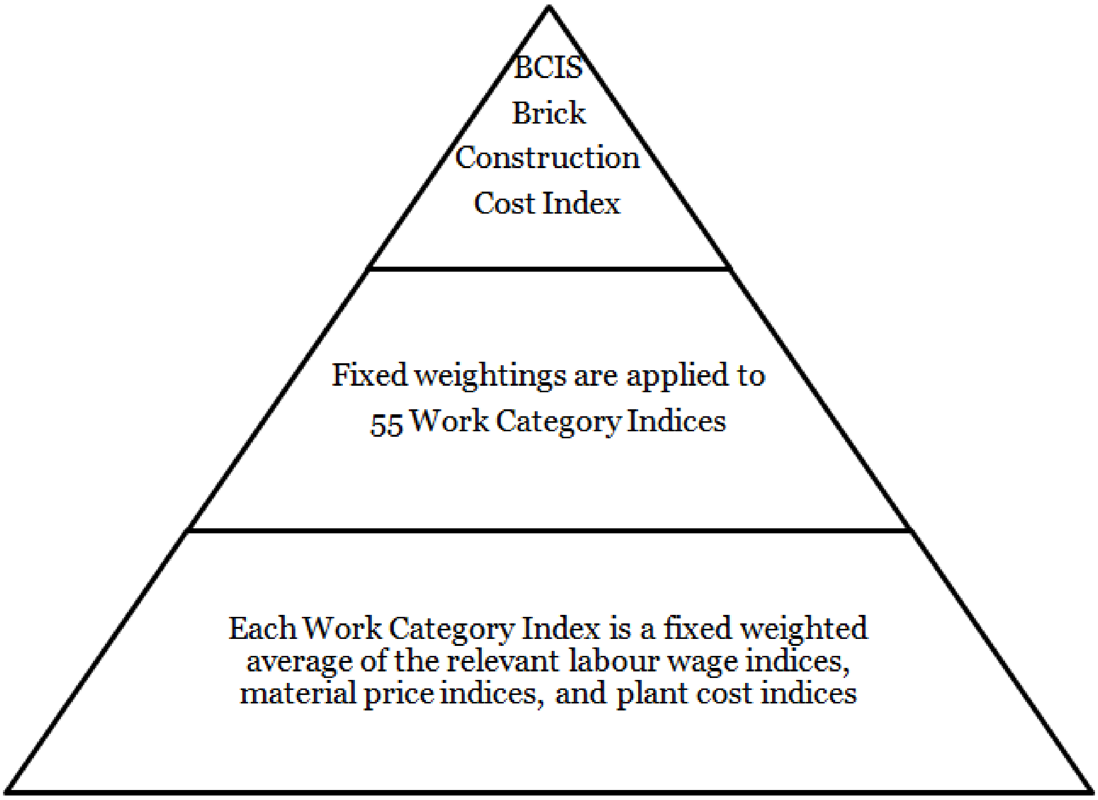

Figure 3.2: Relationships among construction cost indices, work categories indices and underlying input indices

BIS Construction Resource Cost Indices

BIS publish 35 resource cost indices for construction in the UK on a quarterly basis covering repair and maintenance as well as new work. *Table 3.3* summarises the availabilities of the cost indices in the different sectors and for the different inputs of the construction industry.

		Combined	Labour & Plant	Materials	Mechanical Work	Electrical Work	Building Work
New	Building Non-housing	Available					
	House Building	Available					
	Road Construction	Available			Not Applicable		
	Infrastructure	Available			Not Applicable		
Maintenance	Building Non-housing	Available					
	House Building	Available					

Table 3.3: Construction Resource Cost Indices published by BIS

These construction resource cost indices are weighted averages of the relevant work category indices compiled by the most recently Price Adjustment Formulae for Construction Contracts (1990 Series of Indices, also known as Series 3).

BIS (2012a) reported that the weightings of the new building non housing index had been assessed in the 1970s and the weightings of the rest were assessed by a panel of Chartered Quantity Surveyors in 1998.

3.5 Evaluation of the British Tender Price Indices and Opportunities for Improvements

Before making any recommendations for improving the British TPI compilation method, it must be acknowledged that, having attempted to review the many different compilation methods documented for other countries, as summarised for example in OECD and EUROSTAT (2001) and EUROSTAT (1996), the author is left with an overwhelming impression that the method adopted in the aforesaid three British organisations has led the world for a quarter of a century. Blessed with the availabilities of BQs, the British TPI does measure the output price of the building industry by making use of the contract prices as opposed to many other countries that use input prices such as labour wages and material prices as proxies for the output prices. For instance until recent years, the US agencies used input price for deflating the output of building industry, a procedure that has long been criticised in the United States (Gordon 1968 and Pieper 1989 and 1990). Although criticisms have finally led in the US to the introduction of a new building output price index by the Bureau of Labour Statistics and U.S. Census Bureau, its prices are either deduced from the property price including the land value or from questionnaires, and as such the validity is less than the contract price data from BQs in Britain.

Despite its many advantages over systems in use elsewhere, the following opportunities for improvements in the British system have been identified.

Mechanical and Electrical Service Items

Except for plumbing work, all mechanical and electrical service items including comfort cooling, heating system, lighting, electrical supply system, lifts, and fire detection system are not measured in the tender price index because mechanical and electrical services are usually included as prime costs or provisional sums in BQs. In some non-residential buildings such as offices and hospitals, mechanical and electrical services represent a significant portion, approximately 40%, of the total cost of the building. Leaving this out could result in significant measurement errors.

Figure 3.3 exhibits that during the 1980s the building *cost* index and the mechanical and electrical *cost* index tracked each other closely, but during the 1990s the mechanical and electrical *cost* index was consistently at a higher level than the non-mechanical-and-electrical building cost index. From around 2005, the trend has reversed. This reflects the fact that the mechanical and electrical service and building work input markets are subject to different short run cost drivers. Looking at the weightings of the cost indices, material prices have a higher weighting in the M&E cost index.

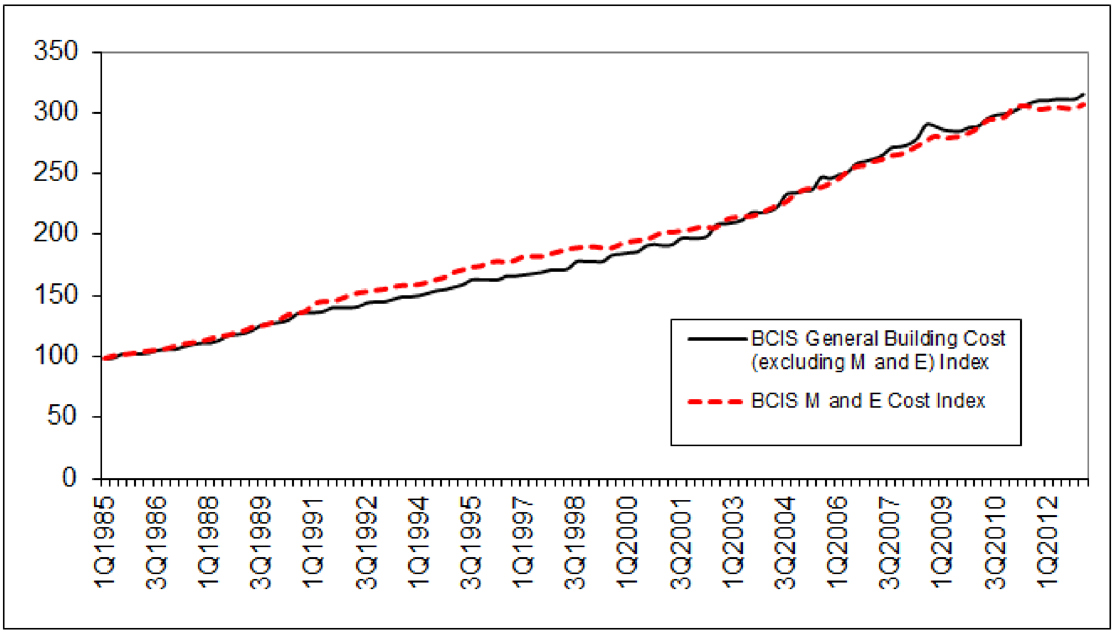

Figure 3.3: BCIS Building Cost and M&E Cost Indices (1985 = 100)

Source: BCIS Online.

As previously noted, the Building and M&E cost indices assume no productivity growth and are fixed-weight averages of the producer price indices of materials and of the wages in the national labour agreements. The weightings were obtained from the analyses of 54 bills of quantities for new building work (BCIS 1997).

It is generally observed that goods and services from a sector with higher technological progress and productivity growth have lower price inflation than those from a lower productivity growth sector. The personal computer is a typical example of the former whereas haircutting service is a widely cited example of the latter.

Nordhaus (1997) has waded through the historic record to construct a ‘true’ price index of light between 1800 and 2000. He concluded that if the price of lighting is correctly measured as price per lumen-hour, the *nominal* price of light has dropped to one hundredth of its base level over the last 200 years and the deflated (against CPI) price of light has dropped to about one ten-thousandth over the same period. The reason is the huge technological progress in producing light, from open fire, to candle, to oil lamp, to town gas lamp, to kerosene lamp and to electric lamp.

Mechanical and electrical services such as air conditioning and heating systems are reckoned to have been subject to higher productivity growth in the past than the more traditional building trades, like brickwork, being measured by the TPI. Anecdotal evidence from ICT cabling also suggests that the quality of the cable has increased, say from cat 5 to cat 6, but the nominal prices have been stagnant or even fallen. Another example is the significant drop of the domestic solar PV supply and installation price since 2010 in the UK.

New elements and Proprietary Items

Since the method is to compare the prices of BQ items with the prices in the base schedule of rates, the price of new goods or proprietary items that cannot be matched will not be measured in TPI. For new goods, frequently updating the base schedule of rates will alleviate part of the problem and that is the reason why ONS adopts annually chain-linked system for compiling the RPI and CPI. In other (fix-based) methods, the effect of introduction of new goods will not be measured and ignoring this will often result in an upward bias of the price index because new goods can usually achieve the same outcome at a lower price than the old goods being replaced. Nordhaus (1997) demonstrated that ignoring the introduction of new goods overestimates the true price of lighting substantially over time.

Despite its importance, the appropriate method to estimate the price change of a new good when it is introduced is controversial.

The problems of proprietary items such as curtain walling and glazed internal partitions are also thorny because the design of the proprietary item is specific to each project and this prevents them being matched or compared between projects over time.

Sample Coverage

RICS (2006 and 2012) revealed a clear overall shift of British procurement methods from lump sum design-bid-build (traditional procurement) with BQ to lump sum design and build over the period between 1985 and 2010. The share of workload procured under lump sum design and build has increased from 8.0 % to 39.2% by project value whereas the share for traditional lump sum with BQ has dropped from 59.3% to 18.8 %. This trend is unlikely to reverse because design and build procurement route is widely adopted in private commercial projects and Private Finance Initiative Schemes and its variants. However, BIS, BCIS and DL only survey the BQs of the traditional procurement method for their TPI calculation. With the dwindling popularity of the design-bid-build with BQ method, continuing to rely on BQs for compiling TPI would make TPI prone to larger sampling errors or even biases. Emphasis needs to be placed on measuring the price movements in design and build contracts.

Sample Size and Distribution

BCIS aims at sampling 80 projects in each quarter because it believes that if 80 projects are sampled, about 90% of the price indices of individual projects will cluster within a reasonable region (about ± 2.8 %) of the average. In the period between 1990 and 2012, the BCIS All-in TPI has an average quarterly sample size of **63** of which **36** are public sector non-housing building projects. By contrast, BIS has sampled **57** public non-housing building projects on average in each quarter over the same period for its Pubsec TPI. Since the index compilation method adopted in BCIS and BIS is similar and both BCIS Public TPI and BIS Pubsec TPI measure the inflation of tender prices of the same domain, there is room for collaboration and specialisation.

It would be advisable that BCIS focus its effort and resources on collecting private sector information, thereby increasing the sample size of private sector projects. Currently two sub-indices of the BCIS All-in TPI, namely BCIS Private Commercial TPI and BCIS Private Industrial TPI, serve as data that BIS use to construct the construction output deflator because these two indices capture the tender price movement of the private sector to which BIS has no access.

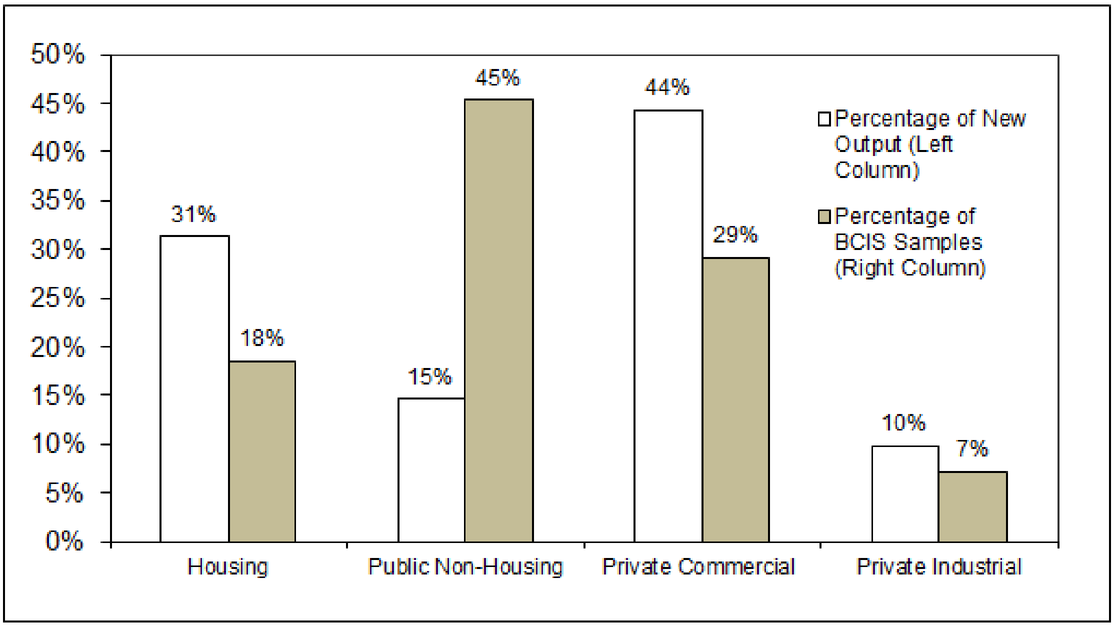

Figure 3.4: New building work output distribution compared with the BCIS Sample distribution, 1990 to 2012.

Source: Author's calculation, BCIS Online and ONS Statistical Bulletin: Output in the Construction Industry, various issues.

As mentioned in the introduction, *figure 3.4* shows that the distribution of BCIS samples over the period 1990 – 2012 is not aligned with the percentages of output of new building work. Of the 31% of all output that is in the housing sector, private work accounts for 26.7% while public work accounts for 4.6%. BCIS however note that the majority of their housing samples comes from social housing projects. Therefore, the public housing sector is over-represented but the construction price movement in the private housing sector is almost not measured in the TPI. Since speculative builders in the private housing market may perform the dual role of developer and main contractor, the tender prices of the construction work, let alone Bills of Quantities, are generally not available. This problem is not specific to Britain. For example, the US

Census Bureau estimates the value of construction work in the private housing market by applying a fixed ratio (currently at 84.24%)[28] to the average sales prices of houses.

Private commercial work also appears to be under-represented in the samples. It is noted that a significant portion of the private commercial work is major refurbishment of existing buildings which are not measured in the BCIS All-In TPI. However, using the same methodology, BCIS has introduced a refurbishment TPI since 1991 and the sample size is about 14 per quarter, so that potentially the All-in TPI samples could be extended to include commercial major refurbishment.

It is also noteworthy that since its sample size of private industrial projects has become too small, BCIS has adopted a different method to compile the TPI for the sector since 2010. In brief, it makes use of the trade price information collected in the BQs of other types of projects, and re-weights them using the historic BQs of private industrial projects.

3.6 Two Possible Ways to Move Forward

Following the above review and assessment of the existing TPI compilation methods, this section proposes some ways to improve them. These proposals divide into, first, suggestions of ways to improve the existing methods, and then proposals for an alternative supplementary method. Even with the suggested changes (see below) in the existing match-item Passche indices (1) to improve coverage and samples, and (2) to update them to annually chain-linked, it is difficult in the existing method to cater for the price movements of the diverse M&E items and the effect of quality changes on prices. Thus, the employment of hedonic techniques as a supplement is proposed and discussed.

[28] See the United States Census Bureau's document *Construction Methodology*, available at http://www.census.gov/const/C30/methodology.pdf

Improving the Existing Method

Regarding the sources of the price information, the diminishing popularity of the traditional design-bid-build with BQ procurement route is a real challenge. However, some design and build contractors produce full BQs for bidding or cost management purposes. One recommendation therefore is to pursue the accessibility and pervasiveness of such information.

Alternatively, the possibility and performance of using cost plans in the BCIS Standard List of Building Elements format deserve further research. A proportion (possibly a high proportion) of the design and build projects in the PFI market[29] and private sectors include cost plans in the contract documents and the rates in such cost plans are in principle comparable to schedules of rates such as those in the Approximate Estimates section of *Spon's Architects' and Builders' Price Book 2013*.

This cost information may be less reliable than BQs for reflecting the true prices of various components of buildings, but it is still better than totally ignoring this growing form of procurement. Also the quantities measured in those cost plans are useful input information for a hedonic index, something discussed in the next section. It is acknowledged that there is a potential for circular relationship because the TPIs are used in setting the cost plan rates to a certain extent. However, measures are taken in practice that mitigate this concern: a) contractors market-test the cost significant elements before submitting a firm price bid, and b) professional QS firms working for clients ensure the prices in Cost Plans reflect the market prices.

The current method only compares prices of items accounting for 25% of each measured trade by value. Mitchell (1971), Azzaro (1976) and BCIS (1983) show that the 25% rule was a practical compromise between stability of the index and the production cost given the computer technology of the early 1980s. Mitchell reports

[29] In PFI market, the Special Purpose Vehicle (SPV), formed by a consortium in private sector, enters a long period service provision contract with the public sector. The construction contract in the PFI project is made between the SPV and the Building Contractor.

that the number of items to be compared for 25%, 50%, 75% and 100% of the trade value are 40, 98, 175 and over 1000 respectively. Mitchell found the project indices of 80 BQs using the 25% rule to be as stable as those using full re-pricing (100% rule). However, the 25% rule produced an aggregate index 4.4% higher than the full re-pricing index in the study reported by Mitchell (1971) whereas the 25% rule underestimates the full re-pricing index by 1.1% in a separate study reported by Azzaro (1976). There is a case to repeat these studies with recent data. If this shows discrepancies in estimated levels, then, with the advance of computer technology over the last thirty years, it is practical, at least in the public sector projects, to extend the sample items to far more than 25% by value.

Annually chain-linked system is in essence to update the base schedule of the base-linked system every year, which gives an earlier chance of the new items be included in the base schedule and allow comparison of the price movements. DL has adopted the annually chain-linked system which allows them to compare rates of new items earlier than the base-linked system in BCIS and BIS with their less frequent revisions of the base schedule of rates. As early as in 1887, Alfred Marshall[30] suggested that the chain-linked system would be a better measure of the price impact of invention of new commodities. The main difficulty to be overcome to allow converting the current indices in BCIS and BIS to annually chain-linked indices is the need to update their base schedules of rates annually. RICS acquired a well-established building price book publisher in 2005 and merged it with BCIS, enabling, perhaps, BCIS to convert its TPI to an annually chain-linked system by using their building price book published annually rather than the dated PSA Schedule of Rates[31] for the base period rates. The methodology[32] for compiling the PSA/Carillion Schedules of Rates and the

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[30] See Marshall (1887).

[31] A private firm, Carillion, continues to produce the PSA Schedule of Rates after the PSA dissolved in 1993. The major application is for measured term contracts for maintenance and minor new works. Please see their webpage for details. http://www.tpsconsult.co.uk/psa.

[32] The rates in PSA Schedule of Rates compiled by Carillion and in common building price books are compiled by using the historic labour constants (updated infrequently), labour wages, material and plant prices. The Schedule of Rates compiled by the then PSA is believed to have better captured the market rates because the Schedule of Rates are believed to have been tested against cost information

building price book are much the same. With the many annually published UK based building price books such as BCIS Wessex, Griffiths, Hutchins, and Laxton's and the similarity of the methodology between these price books and that of the PSA/Carillion Schedule of Rates, it is feasible that BIS could also switch to an annually chain-linked system for their TPI.

Hedonic Construction Price Index

Hedonic regression technique has been gaining acceptance among statistical agencies such as ONS in the UK and US Census Bureau for compiling their price indices. Ball and Allen (2003) reported that the statistical agencies in Canada, Finland, France, Germany, Sweden and US have used hedonic technique to adjust for quality changes in electrical goods such as personal computers, dishwashers and TVs in the price indices. ONS have used hedonic technique to adjust for the quality improvement of personal computers, digital cameras, laptops and mobile telephone handsets since 2003 (Fenwick and Wingfield 2005). In real estate and construction statistics, the US Census Bureau has used hedonic technique to produce their single-family house construction price deflator since 1968 (Musgrave 1969)[33] and ONS have applied it to estimations of imputed rents for owner-occupiers' houses (Richardson and Dolling 2005). In both cases, the hedonic regression techniques are used to adjust the heterogeneities among buildings rather than adjust for the improvement in quality over time. Noting that the traditional price indices reviewed in this paper do not reflect qualitative improvement over time, Meikle (2001) suggested hedonic construction price indices as an area for further research.

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for the large amount of projects procured by PSA. Davis Langdon also report that they have cross-checked some of the rates in their price book against the rates in accepted BQs.

[33] The US Census Bureau's hedonic model of single-family house "under construction" price index (as opposed to another index called single-family house "sold" price index) includes these attributes and explanatory variables: size of house, geographic location, metropolitan area location, number of bedrooms, number of bathrooms, number of fireplaces, type of parking facility, type of foundation, presence of a deck, presence of a patio, construction method, primary exterior wall material, and heating system and central air conditioning.

What is a hedonic function? People value a good for its attributes or characteristics. Therefore, goods can be regarded as bundles of attributes and their values are the sums of the values of the attributes within the bundles. Hedonic function refers to the relationship between the price of the good and the implicit prices of the various attributes embodied in the good. If quantities of attributes are measurable, regression techniques are commonly used to estimate the hedonic function of the good from the historical data.

One of the promising applications of hedonic price indices is to extend the coverage to projects that do not have BQs. *Figure 3.4* suggests that the current BQs based TPIs would be unrepresentative of the private housing, private commercial and private industrial sectors. Although hedonic price indices have been applied to single-family housing in the US and lessons can be learnt from the relevant research (e.g. Somerville 1999 and Dyer *et al* 2012), it is probably not the most rewarding sector for the application of hedonic price indices in the UK because of the difficulty of separating the construction price from the total sale price. In the UK, any US type assumption that land value accounts for a constant proportion of house prices (in cross-section or over time) would be fundamentally unsound.

However, a growing number of studies estimate the relationships between various attributes of buildings and their construction prices. Emsley *et al* (2002) and Lowe *et al* (2006a, 2006b and 2007) have identified some construction price driving attributes in the UK. *Table 3.4* summarises the significant price driving attributes reported by some of the studies.

Research	Data	Attributes
Thalmann (1998)	15 residential projects in Switzerland	▪ Total useable floor area ▪ Proportion of openings in external wall ▪ Proportion of external walls that lie underground
Elhag and Boussabaine (1999)	36 office buildings	▪ Gross floor area ▪ Project duration

Kim *et al* (2004)	530 residential projects in Korea	▪ Gross floor area ▪ Stores ▪ Units ▪ Project duration ▪ Roof types ▪ Foundation types ▪ Usage of basement ▪ Finishing grades
Chan and Park (2005)	87 projects in Singapore covering residential, industrial, offices, and schools	▪ Function of the buildings
Chen and Huang (2006)	132 school reconstruction projects in Taiwan	▪ Floor area ▪ Project duration
Emsley *et al* (2002) Lowe *et al* (2006a, 2006b, 2007)	286 projects in the UK covering industrial, commercial, educational, health, recreational religious, and residential.	▪ Gross internal floor area ▪ Function ▪ Project duration ▪ Mechanical installations ▪ Piling or not
Stoy and Schalcher (2007)	290 residential projects in Germany	▪ Gross floor area ▪ Median floor height ▪ Share of the ancillary areas for services ▪ Project duration ▪ Compactness of the building
Blackman and Picken (2010)	36 residential buildings in Shanghai	▪ Gross floor areas ▪ Height of the buildings
Ji *et al* (2010)	124 apartment buildings in Korea	▪ Gross floor areas ▪ Number of apartment units ▪ Number of floors

Table 3.4: Attributes driving Construction Price reported in selected literature

Of the studies reported in *table 3.4*, those by Emsley *et al* (2002) and Lowe *et al* (2006a, 2006b, and 2007) deserve attention for further study because their results are based on building projects in many different sectors in the UK.

To construct the hedonic price index, the dependent variable of the model is the price that the clients pay for the construction of the buildings. Hedonic functions of construction price for base period and reference period are estimated respectively. By inputting the attributes of a building built at base period into the hedonic function for the reference period, the reference period construction price of the building can be estimated. A Laspeyres index can be constructed by comparing the derived reference period prices to the base period prices. It is obvious that a Paasche index can be constructed by using the attributes of reference period buildings and hedonic functions. Fisher ideal index can then be constructed from the Laspeyres and Paasche indices[34]. The price driving attributes identified in the literature are mainly applied to adjust the heterogeneities among buildings, such as the floor areas and functions of the buildings, rather than to adjust for aggregate average quality improvement over time.

The Tender Price Index of Social Housebuilding (TPISH) published by BIS is a step closer to a hedonic price index than other tender price indices. BIS (2012b) states that the project price indices are compared with the base prices in accordance with the type and style of the project. Matching the housing projects with their types and styles is controlling the price driving attributes to an extent, but it falls short of a full hedonic model explicitly adjusting for all price driving attributes.

Quality adjustment is more salient in the hedonic price index for computers (Cole *et al* 1986, Pakes 2003, and Silver and Heravi 2004). The common attributes in the hedonic functions include the speed of the CPU and the memory of the hard disk. It can be called ‘vertical’ attributes since consumers prefer more of these attributes (faster CPU and ‘larger’ hard disk) than less. These attributes capture the quality improvement of computers over time.

It is not pretended that there exists a definitive solution for measuring the inflation of the mechanical and electrical services in buildings over time in detail. However, it

[34] Other than this method, there are a few alternatives to construct hedonic price index. Triplett (2004) is a comprehensive treatment.

will be argued that hedonic regression technique can shed light on this topic and the following offers some pointers for further research. Performance specifications for mechanical and electrical service system are usually produced by professional engineers, appointed by clients. The first task is to translate these performance specifications into measurable input and output attributes of the systems. Prominent resource and input cost heterogeneities between systems such as underfloor heating system versus traditional profiled surface radiator system should be included in the hedonic model as dummy variables. Focus, however, needs to be given to the vertical (output, performance) attributes and the suggestion here is that **capacities** of the system and energy **efficiencies** of the system are two main attributes to be captured in a hedonic model. Capacities refer to the maximum power (kVA) of electricity generators, maximum loading of lifts, etc. The total or net area affected by the M&E system is a good example of the capacity of the system. Energy efficiency is the unit of effective output of the system per energy input. The Seasonal Efficiency of Domestic Boilers in the UK (SEDBUK) for gas, LPG or oil boilers and luminaire-lumens per circuit-Watt of the lighting system are two examples of measures of energy efficiency of mechanical and electrical services. When Ohta (1975) produced a quality-adjusted price index for the US boiler and turbogenerator industries, he applied a hedonic technique to cater for the efficiency and capacity improvement of the boilers and turbogenerators over time. Berry *et al* (1995) also found that the capacity variable (horsepower per weight) and efficiency variable (miles per dollar) played a key role in their hedonic model of automobile prices.

After measuring the attributes of mechanical and electrical service systems, the next task is to collect price information for the system. For building projects being procured via traditional route, the sum can be found in a section of the BQ called prime cost. The prime cost sums used to be fairly accurate since they usually used to reflect the fixed prices agreed between clients and nominated subcontractors. With the adoption of new standard forms of contract such as JCT 2005, nominating subcontractors has become less popular and the usual arrangements to procure M&E and other specialist trades in traditional route are now via Contractor's Design Portion. Contract sum analysis of the M&E services are usually provided which provide useful information for hedonic analysis. In design and build procurement, the mechanical and electrical service costs normally become part of the fixed price lump sum of the contract and can be discerned in the cost plan of the contract documents.

The hedonic index of mechanical and electrical services, if adequately developed, will be a significant supplement to the existing TPI method since it captures the price movement of the most cost significant component of buildings unmeasured by the existing method. Perhaps, with the richness of tender price information, a hedonic index of non-M&E tender prices could also be developed. If so, its performance could then be monitored against the TPI compiled by the existing method. The challenge would be to develop performance measures for non-M&E elements of buildings as relevant and potentially precisely measurable on a continuous scale as the performance measures developed for M&E service. It is, however, encouraging to note that performance specification has grown in popularity in the US infrastructure construction sector (Guo *et al* 2005) and performance based contracting has been proposed in UK (Gruneberg 2007).

A school of thought in the industry is that the rates in BQs are distorted by front-end loading strategies, opportunistic bidding behaviour of applying low rates to small quantity items, idiosyncratic method to allocate preliminaries, overhead and profit in BQs and so on. Therefore, one of the advantages of hedonic TPI over the traditional TPI is that it does not rely on the rates in BQs but on market prices of subcontracts. Moreover, the factors such as locations, sizes and functions of buildings that BIS, BCIS and DL adjust for in the TPI compilation process could, with a hedonic index, be explicitly modelled.

The diagrams below summarise the coverage of the current TPI method in the new building work sector and the areas that hedonic and other alternatives can potentially add to coverage.

	Projects with traditional procurement with BQs	Projects with non-traditional procurement without BQs e.g. Design and build, PFI
Traditional trades	Covered	Not Presently Covered
Most mechanical & electrical services and proprietary items	Not Presently Covered	Not Presently Covered

3.7 Evaluation of the UK Construction Cost Indices and Opportunities for Improvements

Weightings

The construction cost indices reviewed above are fix-based match-item Laspeyres indices. Since the indices use the weighting fixed in the base year, each index does not allow for substituting cheaper inputs for more expensive inputs in the reference year, and would tend to overstate inflation or understate deflation. This problem can be alleviated by updating the weighting more frequently. However, the last update of weightings of the Price Adjustment Formulae was in 1995.

Quality of the Input and Productivity Growth

It is important to emphasise that construction cost indices are not intended to reflect reduction in cost due to productivity growth in construction sector. In brief, productivity growth means requiring less input for producing the same output. When contractors find a way to use less man hours or less amount of material to produce the same output, their "input cost" should drop but the current compilation method of the construction cost index would not capture it[35]. A related but different issue is the quality of the input. The quantity and quality of the input are multi-dimensional and the input price can only be based on one dimension of the quantity. For example, wage is usually based on time, and concrete and steel quantities are based on weight. The other dimensions of the quality input are assumed to be constant such as the skill level of the labour and the strength and durability of steel, which may not be the case and would bias the cost indices.

Material Prices

A common criticism of the construction cost index is that the material prices are 'list prices' and discounts are ignored. However, ONS (2014a) reports that they do attempt to collect the real transaction price for compiling their producer price indices and it is outside the scope of this thesis to verify this. This very much relies on the approximately 4,000 firms being surveyed in each monthly for produce price indices reporting the real transaction prices (ONS 2014b), because the data collection method is markedly different from that adopted in compiling consumer price indices that ONS send members of staff to collect directly observed prices in shops (ONS 2012). UK Statistics Authority (2011b) reviewed methods of the *Monthly Statistics of Building Materials and Components* produced by BIS, and confirmed their status as National Statistics.

Labour Wages

The labour wage component of construction cost indices based on the national labour agreements is a cause of more concern. There could be a variable time lag between market conditions and the wage rates in the national labour agreement. In addition,

[35] This contrasts with the concept of unit labour cost which is the cost of labour for a fixed unit of output. Therefore the growth rate of the unit labour cost would be broadly equivalent to the growth rate of labour cost less the labour productivity growth rate.

given the change in the unionisation in the UK construction industry over time, there is a possibility that such national wage agreements may deviate from market wages.

Table 3.5 and *figure 3.5* compare the labour cost indices based on national wage agreements and the survey based labour cost collected by ONS.

Labour Cost Indices	Source	Growth rate between 2000 Q1 and 2012Q1
BCIS Labour Cost Index	Price Adjustment Formulae (Series 2); all Wage Agreement Bodies listed in *table 3.2*	72%
Civil Engineering Labour Index	Price Adjustment Formulae (1990 Series); Civil Engineering Construction Conciliation Board for Great Britain (now Construction Industry Joint Council)	75%
Construction Average Weekly Earnings (Total Pay)	Monthly Wages & Salaries Survey [employer based survey]	48%
Construction Average Weekly Earnings (Regular Pay)	Monthly Wages & Salaries Survey [employer based survey]	50%
Median Gross Weekly Earnings	Annual Survey of Hours and Earnings [employer based survey]	45% [April 2000 to April 2012]
Median Hourly Earnings excluding Overtime	Annual Survey of Hours and Earnings [employer based survey]	55% [April 2000 to April 2012]

Construction Average Gross Weekly Earnings of Full-Time Employees	Labour Force Survey [36] [household based survey]	49%
Construction Average Gross Hourly Earnings of all Employees	Labour Force Survey [household based survey]	56%

Table 3.5: Construction Labour Cost Indices in the UK

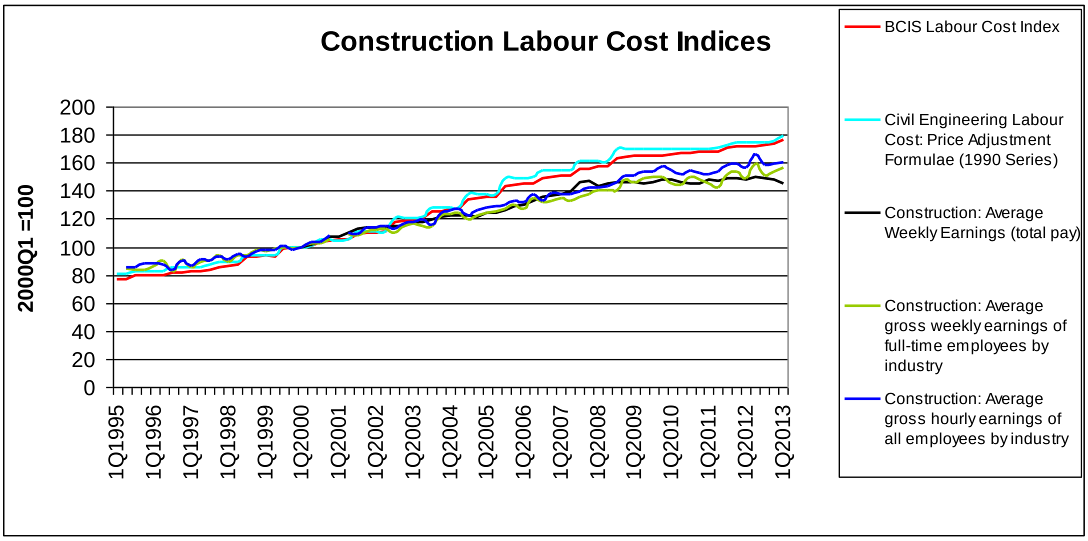

Figure 3.5: Construction Labour Cost Indices

The national labour wage agreement indices (BCIS Labour Cost Index covering building and Civil Engineering Labour Cost covering civil engineering) show a higher

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[36] ONS note that the gross weekly and hourly earnings data are known to be underestimated in the Labour Force Survey primarily because of proxy responses. In addition respondents with hourly pay of £100 or above are excluded from the estimates. However, this would impact on the level estimate and not necessarily on the growth estimate.

growth (over 70% between 2000 and 2012) than other measures of construction labour cost or earning indices (*circa* 50%) reported by various ONS's surveys.

While a detailed examination of various labour cost indices is outside the scope of this thesis, a few observations can be made after comparing these indices.

The Monthly Wages and Salaries Survey is an employer based survey. Its average weekly earnings of regular pay and total pay (including bonus) in construction industry shows a growth of 50% and 48% between 2000 and 2012. This suggests bonuses shrank slightly compared to regular pay.

One of the possible reasons to explain the difference between the ONS indices and the national wage agreement based indices is a drop in working hours of the construction workers over time. This appears to be part of the explanation. The two hourly indices collected from the Labour Force Survey and Annual Survey of Hours and Earnings showed a higher growth (56% and 55% respectively [37]) compared to the weekly earnings indices (49% and 45% respectively) between 2000 and 2012. This is consistent with the 5.2% drop in average weekly hours of work in construction industry collected by Labour Force Survey. The experimental index of labour costs per hour published by ONS also reports a 55% increase of labour costs per hour in construction between 2000 and 2012.

Another possible reason is the change in composition of the construction labour force. If the proportion of low skill construction workers increases over time, the average earnings growth would be lower than the rate of increase in the hourly rate in the national labour agreement. This would require a significant change in the composition to explain the difference, and if such composition change occurs, one would then

[37] According to the Index of Labour Costs per Hour published by ONS, the growth of labour cost per hour in construction industry between the first quarter of 2000 and the first quarter of 2012 was 50%. Please note this statistics has not been submitted to the UK Statistics Authority for assessment, and thus is currently "experimental statistics", whereas the other ONS labour cost statistics in table 5 have been approved by the UK Statistics Authority and are National Statistics.

question the fixed weighting in the construction cost index, which would overstate the labour cost inflation by not allowing for substitution. However, Franklin and Mistry (2013) data suggests that the labour quality has marginally improved by 2% between 2000 and 2012.

There seems to be no good measure of the labour cost holding the quality and composition of the labour force in construction constant but a comparison of the hourly rate of a few occupation in the construction industry between the 2000 and 2012 Annual Survey of Hours and Earnings provides an intriguing result as in *table 3.6*.

	Generic	Trade Specific			
	Skilled Construction and Building Trades	Bricklayers and masons	Roofers, roof tillers, and slaters	Carpenters and joiners	Painters and decorators
2000	£7.66	£7.77	£7.09	£7.71	£7.48
2012	£12.01	£11.49	£10.96	£11.05	£10.53
Growth	57%	48%	55%	43%	41%

Table 3.6: **Average Hourly Pay (excluding overtime) as reported in Annual Survey of Hours and Earnings**

Generally the growth of the hourly pay of the generic “skilled construction and building trades” is in line with the ONS hourly earnings statistics (Median Hourly Earning excluding Overtime, and Construction Average Gross Hourly Earnings of all Employees, in *table 3.5*), while the hourly rate of specific trades displayed a slower growth. This seems to suggest that the wages of the traditional trades covered by the national wage agreements (as reflected in BCIS Labour Cost Index and Civil Engineering Labour Index in *table 3.5*) should grow more slowly, not faster, than the ONS hourly earnings statistics.

Recommendations for Construction Cost Indices

With regard to the CCI, this thesis recommends a detailed study of the labour cost indices. ONS's household and employer based surveys report a lower growth than the national wage agreement based indices. The few observations in the previous section suggest that focus should be given to analysis of the change in composition and skill levels of the labour force.

The Price Adjustment Formula based weightings were last updated in 1995 and could benefit from a more recent update.

3.8 Conclusion

This chapter surveys the compilation methods of the three most renowned Tender Price Indices for new buildings in Britain and the two sets of construction cost indices in the UK.

Having reviewed the compilation method and the source of data, it concludes that the TPIs published in Britain tend to overstate the inflation of the contract prices. The reason is that TPIs only measure the inflation of the traditional trade items such as the structure and the internal finishes works in conventional BQ procurement route, but mechanical and electrical services items and proprietary items such as curtain walls ,which are subject to higher productivity growth, are not measured in the indices. Moreover, quality of building work such as energy efficiency and safety driven by building regulations tends to improve over time and the lack of measurement of quality will tend to overstate the prices over time. In theory, the current expenditure weighting nature of TPI will tend to understate inflation but the effect will be limited by new items not being matched to the items in the dated schedule of rates.

Moving forward, measuring the price movement of M&E items and broadening the sample base to design and build contracts are two areas well worth pursuing to restore the representative nature of the indices. For design and build, acquiring access to contract price information such as contract cost plans and the possibility of using such cost information to produce TPI deserve further study. Because of the diversity of the M&E items used to achieve comparable performance, it is difficult to stretch the existing current match item index method to measure the price movement of the M&E items. Therefore, there is a need to depart from the presently adopted method and a hedonic index is an appealing alternative. Although the indices may become less consistent than the existing pure item matching method, this is a trade-off for improving representativeness.

The CCIs, with an infrequent revision of the base basket, suffer the general base basket index shortcoming of overstating inflation. The CCIs also are not designed to reflect productivity growth. Looking at the components, the least reliable would seem to be the labour cost components and an in depth study is recommended with specific focus on the change in the composition and skill levels of the construction labour force. These three factors – base basket weights, no reflection of productivity growth and the labour cost components of the CCIs – all tend to bias the indices upward.

Chapter 4 The Inconsistencies of the Construction Order and Output Statistics in the UK: New Methodology and Old Problems

4.1 Introduction

A review jointly undertaken by the Department of Trade and Industry (DTI) and the Office for National Statistics (ONS) in 2005 (DTI and ONS 2005) concluded that the responsibility for collecting and publishing construction statistics should be transferred from DTI to ONS. DTI was replaced by the Department for Business Enterprise and Regulatory Reform (now Department for Business, Innovation and Skills, BIS) in 2007, which subsequently transferred the responsibility to ONS on 1st March 2008. From the transfer until 2010, ONS has continued to collect and publish the major construction statistics such as quarterly construction output and monthly construction new orders by using the DTI methodology. BIS, with the help of RICS's Building Cost Information Service, remains responsible for the publication of the construction price and cost indices[38] such as the quarterly public sector building non-housing tender price index.

ONS published a consultation paper on their proposed changes to the methodology of collecting and compiling construction statistics in January 2009 (ONS 2009a) and set out their response to the public consultation later that year (ONS 2009b).

Crook and Sharp (2010) and ONS (2010a and 2010b) provide an excellent summary of the new methodology and process. Some of the important changes are as follows:

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[38] See the webpage of the BIS Construction Price and Cost Indices: https://www.gov.uk/government/collections/price-and-cost-indices
(accessed on 3 April 2014).

1. Builders Address File (BAF), the former sampling frame, was replaced by Inter Departmental Business Register (IDBR). IDBR includes circa 35,000[39] PAYE only businesses that were not in BAF, but IDBR excludes Local Authority Direct Labour Organisations, which were included in BAF.
2. Construction output survey is conducted monthly instead of quarterly.
3. Construction new orders survey is conducted quarterly instead of monthly.
4. The output result based on the DTI methodology contained an estimate of unrecorded output which is excluded in the new method.

The last monthly construction new orders series to December 2009 following the DTI methodology was published on 11 February 2010 and the last quarterly construction output series to Q4 2009 based on the DTI methodology was published on 5 March 2010. The first construction output statistics based on the new methodology were published on 18 June 2010 and those of construction new orders on 16 July 2010.

4.2 Construction New Orders series

It is widely accepted that construction new orders should be a leading indicator of construction new output. Akintoye and Sommerville (1995), Ilmakunnas (1990), Merkies and Bikker (1981), Nicholson and Tebbutt (1979), and van Alphen and Merkies (1976), have developed construction output models based on this common belief.

However, Ball and Tsolacos (2002) analyse the British construction data between 1980 and 1999 and suggest that there is an orders – output "credibility gap". They illustrated that the output figures were consistently higher than the orders figures from 1989 in the commercial sector and a similar divergence existed in the industrial sector between mid-1980s and 1999. *Figure 4.1* illustrates that such credibility gap between

[39] See minutes of the meeting of 3 December 2009 of the BIS Consultative Committee on Construction Industry Statistics, which is available at https://www.gov.uk/government/publications/cccis. See also van den Brink and Anagobso (2010)

the DTI new construction output and new orders continued until the series were superseded in Q4 2009.

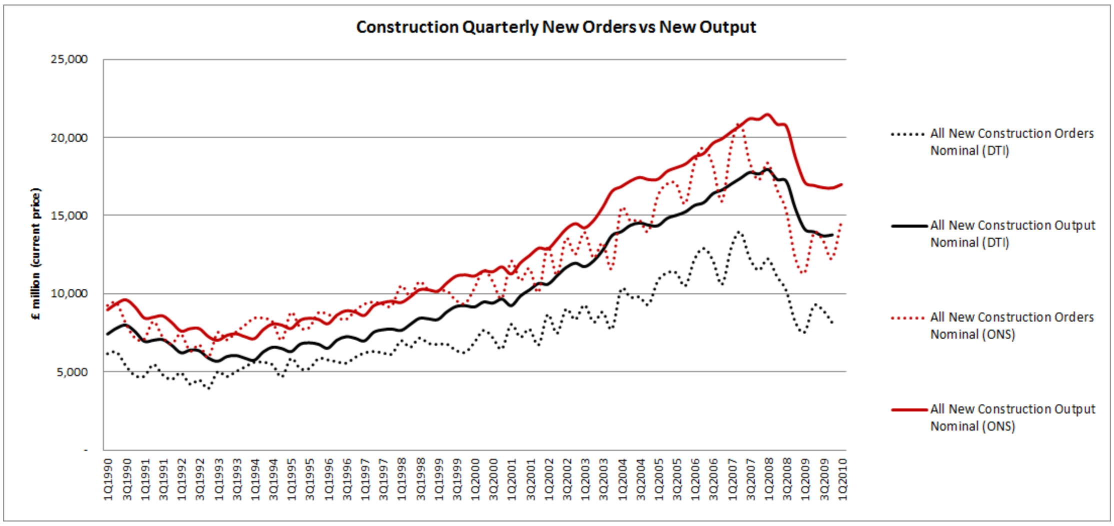

Figure 4.1: Construction Quarterly New Orders vs New Output at Current Market Prices, Q1 1990 to Q1 2010

The sampling frame of the DTI methodology was BAF which contains circa 200,000 construction business units, whereas the sampling frame of the new ONS methodology is IDBR which contains circa 230,000 construction units. In principle the BAF based order survey and its successor IDBR based order survey[40] only sample those construction units with main contractor status – businesses that received orders of construction work from customers outside the construction industry[41]. However, in addition to businesses classed under the Divisions 41 and 42 of the SIC (2007)[42] where one would expect to find main contractors, both BAF and IDBR based order surveys sample many firms classed under the Division 43 "specialised construction activities". These are firms recorded in the SIC (2007) as specialist contractors

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[40] For businesses with fewer than 20 full time equivalent employees in the construction industry (Section F of the Standard Industrial Classification (2007)), the IDBR based order surveys *sample* the whole population in IDBR but only require those that have operated as main contractors to report the value of their main contracts received.

[41] Speculative builders also fall into the category of main contractors.

[42] BAF covered business which were classed under Division 45 of the SIC (2003). For comparison, ONS (2010a) categorises the businesses in BAF according to the SIC (2007).

(implicitly subcontractors) that in fact take or also take main contracts – mostly small ones. The number of these small main contractors was significantly underestimated in BAF in 2009. There were only 17,000 businesses in BAF classed under Division 43 of the SIC (2007) treated as main contractors, whereas the IDBR survey includes 69,500 firms[43] classed to Division 43 of the SIC (2007) treated as main contractors.

Owing to the underestimation of the number of main contractors in BAF, the values of new orders were understated when sample orders were "grossed" to estimate the value of orders of the population of firms. The £8,139 million construction new orders at market price in Q4 2009 based on the DTI methodology was adjusted to £12,231 million under the new methodology. ONS applies the ratio of the revised to the old Q4 2009 estimates (i.e. 12,231 / 8,139) to the old construction new orders series to obtain the revised historic construction new order series. The obvious advantage of this adjustment is that the historical growth rates of the construction new orders remain unchanged.

The construction new orders series compiled under the new methodology was first released in July 2010. As shown in *figure 4.1*, the revised ONS construction new orders at current price series appears to track the ONS all new construction output at current price series better than the respective series based on the DTI methodology between 1990 and 2010. The "credibility gap" seemingly has vanished. This error appears to have been corrected at the time of first publication of the ONS construction new orders series.

However, the "credibility gap" has re-emerged since. *Figure 4.2* shows the ONS construction new orders series and construction new output series between the first quarter of 1998 and the fourth quarter of 2013. It is expected that the construction new order series leads the construction new output series by 4 to 8 quarters, which is the usual duration of a construction project. However, a gap between the level of the new orders and new output series re-appears at around 2010 and shows no sign of being closed.

[43] The estimate is based on the Business Register and Employment Survey 2009 (ONS 2010a: pp 2).

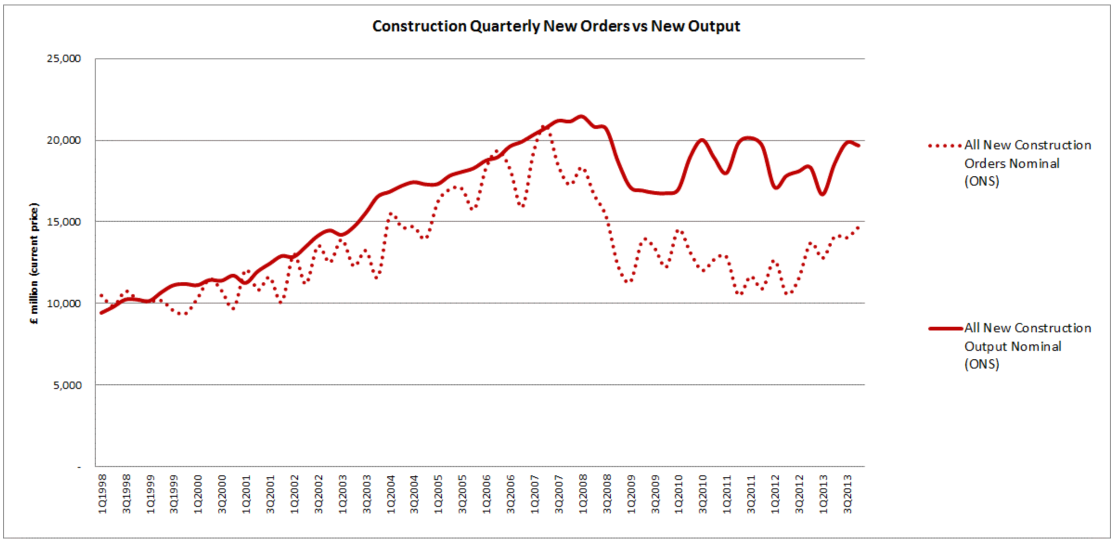

Figure 4.2: Construction Quarterly New Orders vs New Output at Current Market Prices, Q1 1998 to Q4 2013

Figure 4.3, which traces the series between 1958 and 1990, shows that the historic ONS construction new orders series is now consistently higher than the ONS historic all new construction output series, while the old DTI series track each other relatively well.

Although some new orders may not turn into actual output because of contracts being cancelled, and there is unknown delay between placing a new order, and recording the output, one would expect that the level of construction new orders be similar to, if not higher than (due to cancellation), the level of construction new output. After all, both statistics are compiled by sampling the same population i.e. the circa 230,000 construction units in IDBR[44].

Three possible reasons for explaining the historic and more recent gaps are as follows:

- the estimate of the number of main contractors in BAF was relatively accurate up to 1980s but worsened over time since. This may also apply to its successor IDBR, i.e. that an increasing number of firms are not captured under IDBR;

[44] According to ONS (2010a and 2010b), ONS sample 8,000 firms in IDBR per month for the construction output statistics and 9,000 main contractors in IDBR per quarter for the construction new orders statistics.

- the proportion of the construction new output undertaken by the underreported small contractors has increased since 1980s;
- some of the construction new orders placed before the early 1970s recessions were delayed or cancelled and thus never became output, which could also explain the gap in the late 1980s.

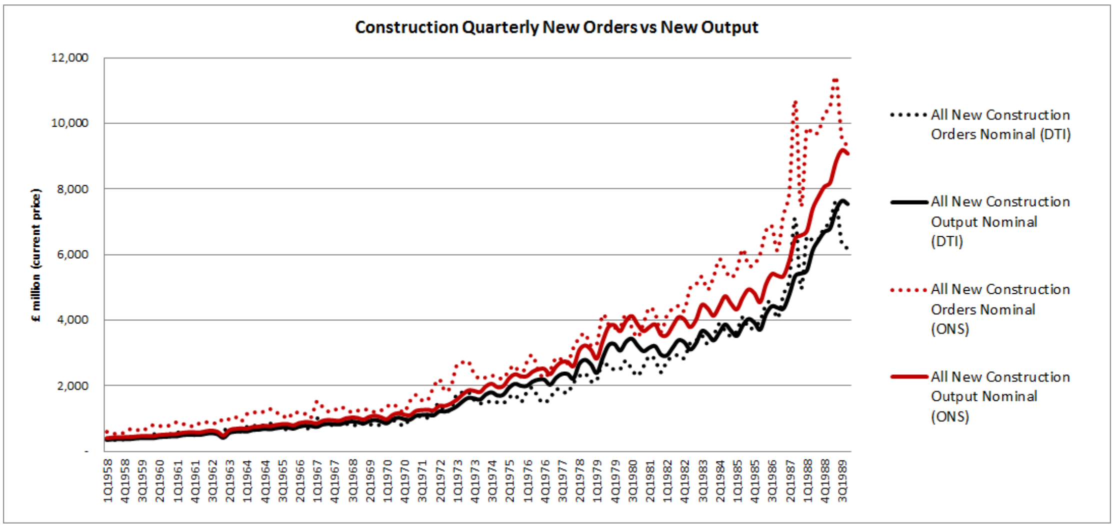

Figure 4.3: Construction Quarterly New Orders vs New Output at Current Market Prices, Q1 1958 to Q1 1990

Even accepting that these factors caused the divergence between the ONS series between 1958 and 1990, it is difficult to rectify the historic construction new orders series without making some very bold assumptions which may be more questionable. However, at the very least researchers making use of the historic construction new orders statistics should place some weight on the superseded DTI series.

Figure 4.4 presents the DTI and ONS construction new orders and new output series at constant (2005) prices and seasonally adjusted between 1964 and 2013. A similar pattern emerges that the DTI series were more consistent with each other up to mid-1980s and ONS series track each other better in more recent times up to around 2010.

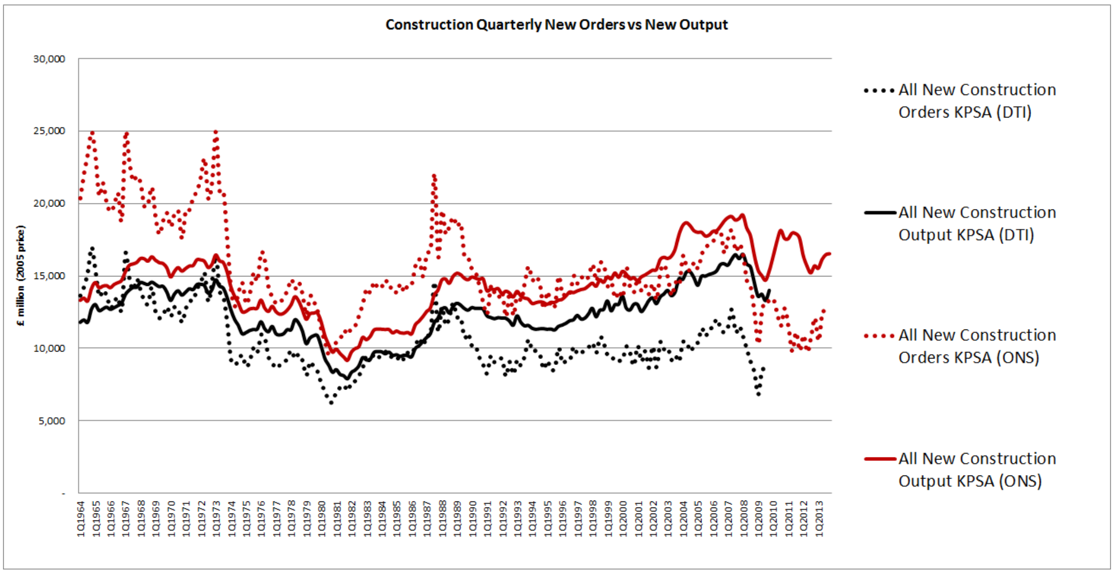

Figure 4.4: Construction Quarterly New Orders vs New Output at Constant (2005) Prices Seasonally Adjusted, Q1 1964 to Q4 2013

The natural places for further exploration of the recent gaps between the construction new orders and construction new output are in the patterns in the sub-sectors.

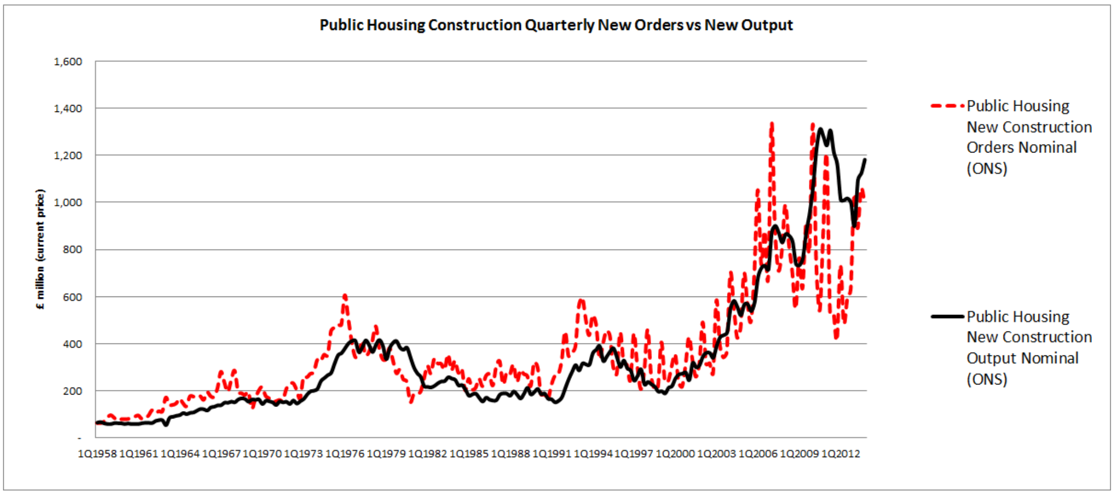

Figure 4.5: Public Housing Construction Quarterly New Orders vs New Output at Current Market Prices, Q1 1958 to Q4 2013

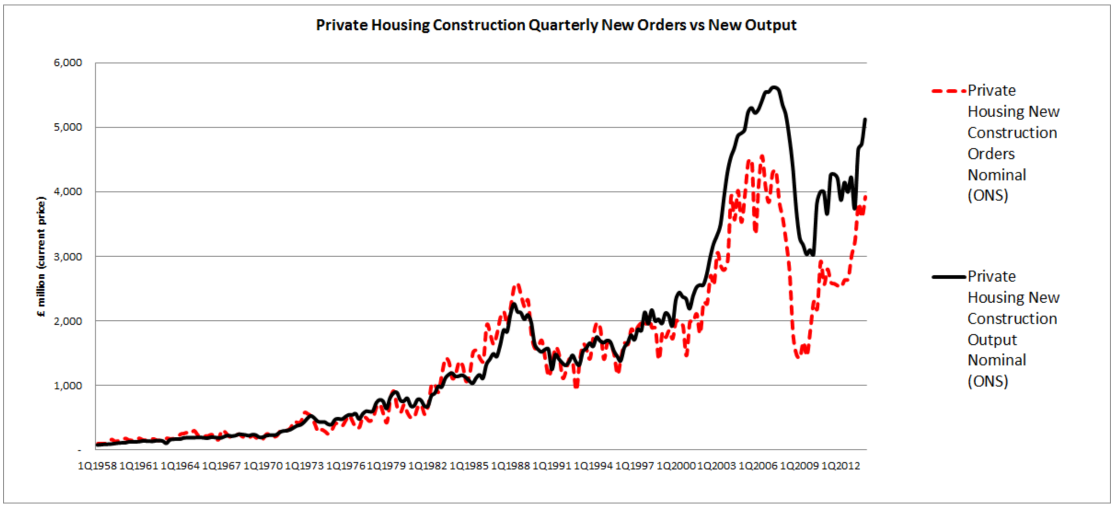

Figure 4.6: Private Housing Construction Quarterly New Orders vs New Output at Current Market Prices, Q1 1958 to Q4 2013

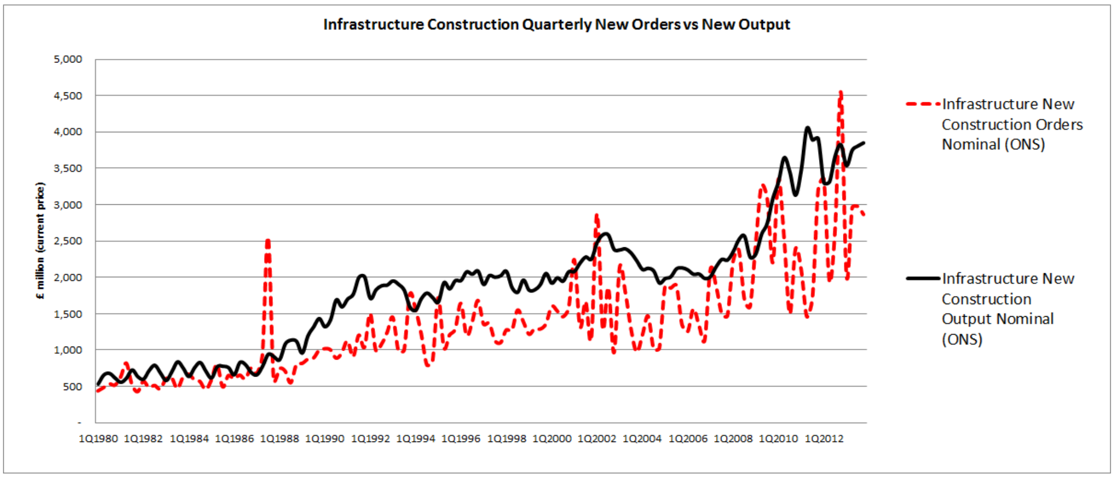

Figure 4.7: Infrastructure Construction Quarterly New Orders vs New Output at Current Market Prices, Q1 1980 to Q4 2013

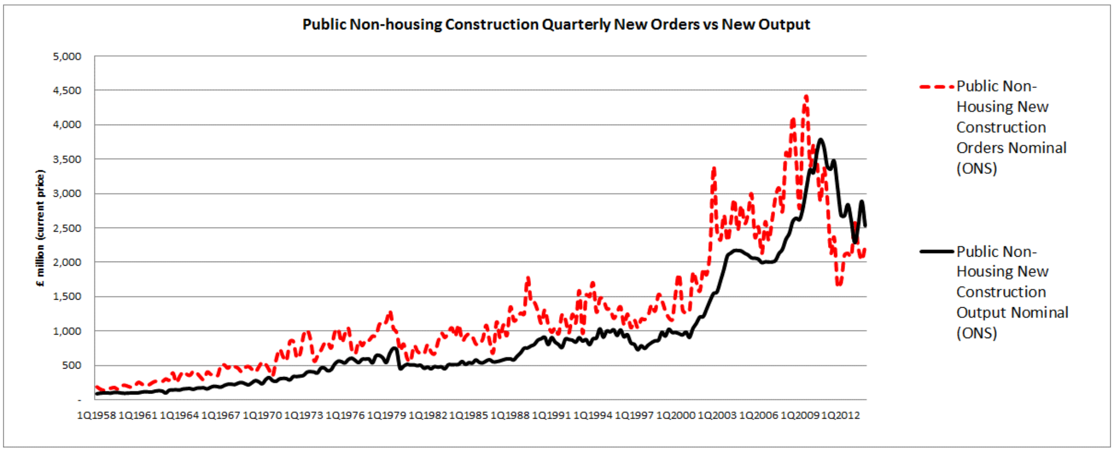

Figure 4.8: Public Non-Housing Construction Quarterly New Orders vs New Output at Current Market Prices, Q1 1958 to Q4 2013

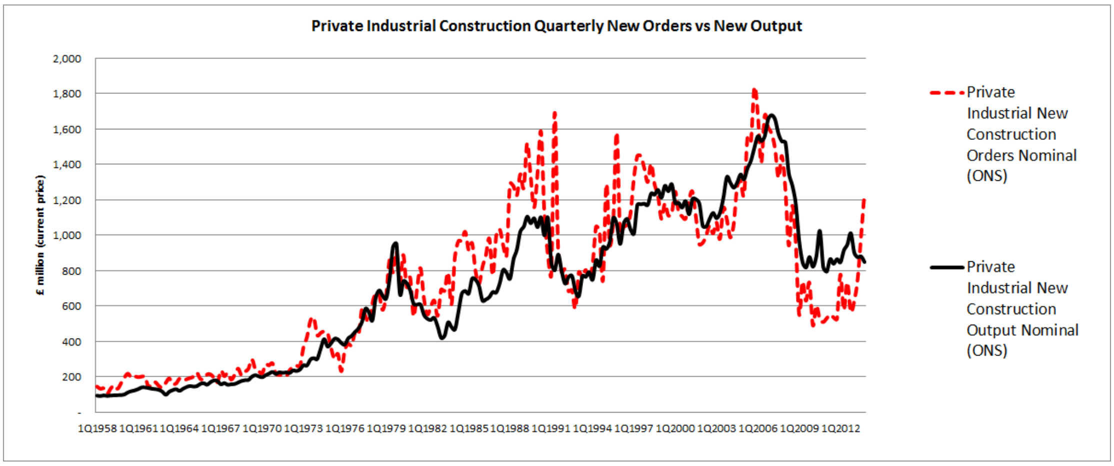

Figure 4.9: Private Industrial Construction Quarterly New Orders vs New Output at Current Market Prices, Q1 1958 to Q4 2013

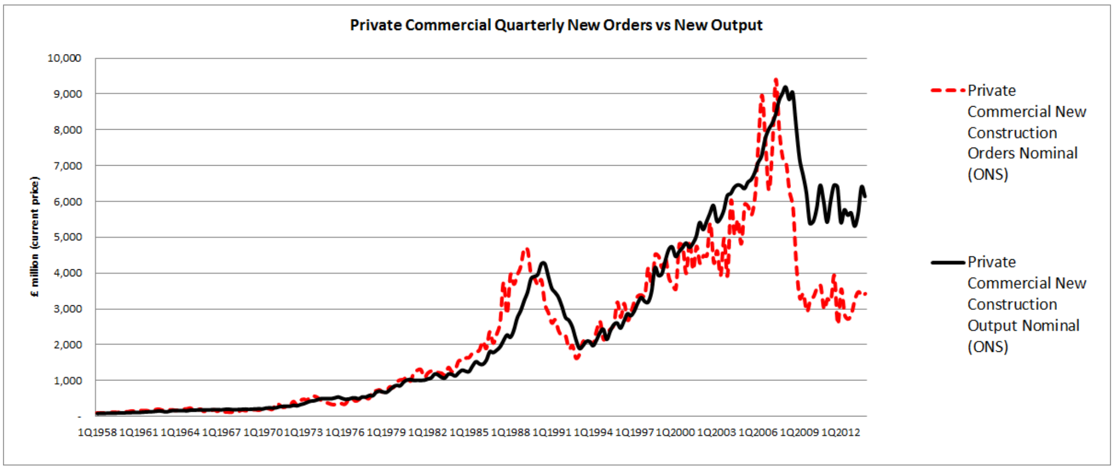

Figure 4.10: Private Commercial Construction Quarterly New Orders vs New Output at Current Market Prices, Q1 1958 to Q4 2013

The general picture that emerges from *figures 4.5* to *figure 4.10* is that the construction new orders series in the public sectors (housing and non-housing) trace the new output series better than those in the private sectors (housing, industrial and commercial). Further research would be needed to pin down the reasons for divergences and ways to improve the statistics but focus should be given to reviewing the sampling framework of private sector orders and output.

4.3 BIS Output Price Indices for New Construction

BIS Output Price Indices for New Construction are said to be used to deflate construction output at current price to construction output at constant price (ONS 2010c). They are also accepted as objective measures of general inflation in their respective sectors of the construction industry. For example, the demand model prepared by Deloitte and Experian in OGC (2006) focuses on the BIS Output Price Indices and many financial and construction contracts in regulated infrastructure sectors use "BIS Output Price Index for New Construction: all new construction" (COPI) or "BIS Output Price Index for New Construction: infrastructure" to adjust for inflation.

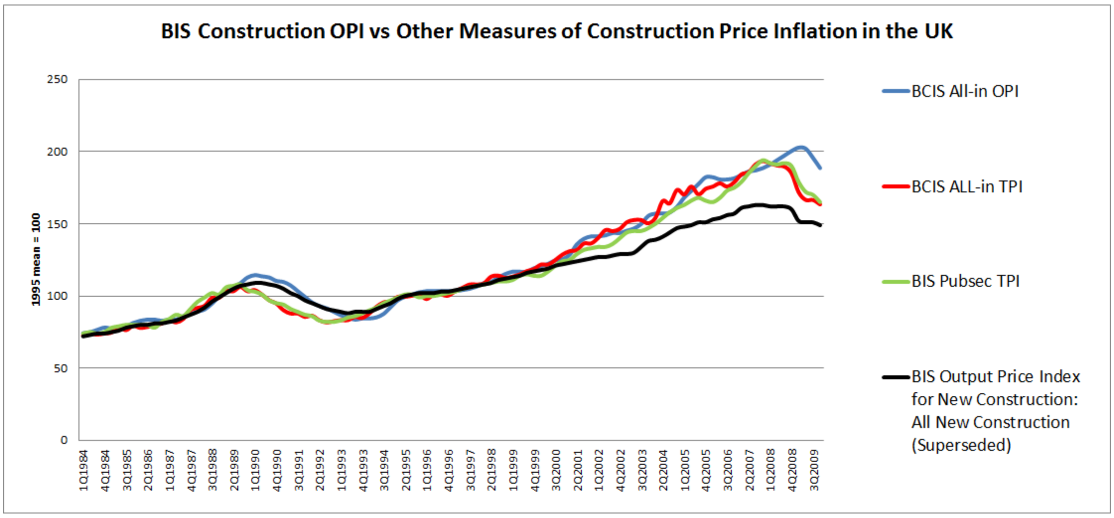

Figure 4.11: BIS Construction Output Price Index vs Other Measures of Construction Price Inflation in the UK, Q1 1984 to Q1 2010

Figure 4.11 compares the now superseded[45] COPI taken from ONS (2010c and 2010d) with other common measures of inflation in the construction industry such as BCIS All-in output price index and All-in tender price index, and BIS public sector building non-housing tender price index. It is evident that the COPI has been consistently lower than the other three measures since 2001. If the deflator is understated, the real output would have been overstated.

[45] See below

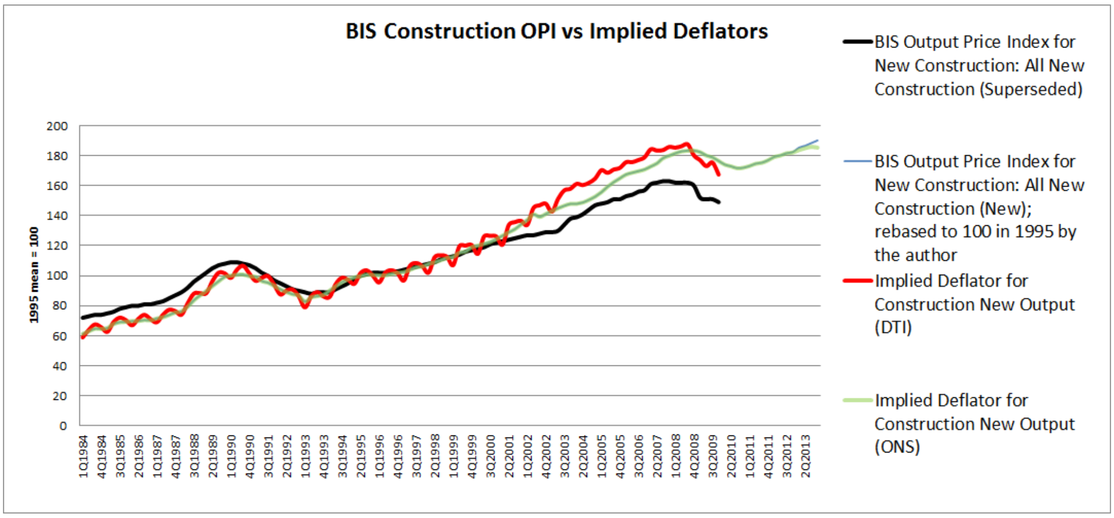

Figure 4.12: BIS Construction Output Price Index vs Implied Deflators[46], Q1 1984 to Q4 2014

Figure 4.12 illustrates the ONS implied construction new output deflator which is the quotient of dividing construction new output at current price by construction new output at constant (2005) price[47]. Surprisingly this implied deflator was more in line with the three other measures of construction inflation in *figure 4.11* than the COPI. Contrary to what was stated in ONS (2010c), the COPI has clearly not been used to deflate new output to constant prices. Thus, discontinuing the old COPI and replacing it by the new BIS COPI corrects the second error.

As part of the methodology review, ONS has also introduced changes to the BIS Output Price Indices. The full set of new BIS Output Price Indices was first published in September 2010. The indices are rebased to 100 in 2005 and, more importantly, some of the indices including COPI have been revised. BCIS (2010b) suggests 1.466 be the conversion factor aligning the superseded with new COPI. If the superseded series is used for adjusting inflation in a construction contract, the superseded index

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[46] The DTI implied deflator displays seasonality because the DTI constant price series was available only in seasonally adjusted format, whereas the ONS provides constant price series both before and after seasonal adjustment.

[47] The DTI implied deflator displays seasonality because the DTI constant price series was available only in seasonally adjusted format, whereas the ONS provides constant price series both before and after seasonal adjustment.

should be used up to the last available firm index, which is Q2 2009, and should be succeeded by the new index adjusted by the conversion factor.

Figure 4.12 shows that the new COPI, rebased to 100 in 1995 by the author, appears to be virtually the same as the ONS implied deflator and more in line with other measures of construction inflation. The problem of the superseded COPI since 2001 seems to be rectified, while the actual causes of the errors have not been published.

4.4 Conclusion

ONS in the UK has developed and adopted a new methodology and system for collecting and publishing construction statistics since 2010. Construction new orders series and BIS Output Price Indices have been substantially revised following the adoption of the new methodology by ONS. *Figures 4.1* to *4.10* show that the correction of the estimate of main contractor numbers has removed the credibility gap in the new ONS series from 1990 to 2010, when the new ONS series was first published. Although this chapter provides some tentative reasons to explain why the old data appears to be more accurate than the back series of the new data up to mid-1980s as highlighted in *figures 4.3* and *4.4,* a full explanation will require further research effort. Care should be taken when using the revised orders series for historic research because the 'credibility gap' exists between the two back series prior to 1990.

It is a worrying development that the credibility gap re-emerges in the subsequent releases of the new ONS series to the end of 2013 and the consistency of the new orders and new output data in the private sector data is more questionable. Attention should be given to reviewing the sampling framework of the private sector.

Figures 4.11 and *4.2* illustrate that the BIS Output Price Indices for New Construction, which appeared to underestimate the inflation in the past, have been corrected. However, BIS has not explained the reason for the past errors.

Chapter 5 Structural Model for Construction Inflation and Output Growth

> "Whether you can observe a thing or not depends on the theory which you use. It is the theory which decides what can be observed." – Albert Einstein

> "There are two possible outcomes: if the result confirms the hypothesis, then you've made a measurement. If the result is contrary to the hypothesis, then you've made a discovery." – Enrico Fermi

5.1 Introduction

Modelling is a matter of simplifications and selections. Quantitatively, modelling also involves specification and estimation. The construction price index models reviewed in Chapter 2 can be viewed as simplifications of the economic process determining the price of construction output. Those construction price models specify the functional form of the relation between the selected observed data of the economy (such as the past construction output price, volume of construction output, the price of input materials, the wages and labour cost, the cost of capital, the size of the economy, and the competitiveness of the construction industry) and the construction output price. They also estimate quantitatively the impact of the selected variables on the price of construction output. The purposes of the models – ranging from forecasting the future construction price index to understanding the underlying forces that determine the change in construction price index – provide guidance on what variables should be studied in the models.

This chapter explains the concept of building a simple two equation price and quantity model developed from the underlying theories of demand and supply. The theory of supply and demand guides the simplification and selection process of modelling. However, identifying both demand and supply equations from the observed price and quantity data is less than straightforward because the functional forms of the two equations, which in their simplest form contain the same price and quantity variables, are indistinguishable. The issue of simultaneity in the usual demand and supply equations makes the task of identification even thornier. The chapter explains what conditions or exogenous variables are required to identify the supply and demand equations.

Applying the method proposed by Haynes and Stone (1985), this chapter goes on to estimate a simple demand and supply model for construction price inflation and output of the British new building work market. The result relieves some of the discomfort with the academic models pinpointed in Chapter 2 and provides some support for the industry models such as those of BCIS and EC Harris. More importantly, as the building blocks of the construction price inflation models are brought to the fore, it allows better understanding of the driving forces of the construction inflation and perhaps results in better forecasting.

The final section of the chapter turns to a more atheoretical approach, vector autoregressive models, to see if the identification restrictions made in the construction price inflation model derived from Haynes and Stone (1985) can be observed in a more flexible description of the time series data.

5.2 Statistical demand and supply curves – a two equation structural model

Economic models are simplifications of complex economic processes, and economic theories provide a vantage point to select data or observations to be studied in economic models. Economic theories predict the relationships between some variables and thus provide guidance on what data should be included in the economic model and their qualitative relationship. The law of demand postulates that the quantity demanded for a commodity is negatively correlated with the price of such commodity, whereas the law of supply postulates that the quantity supplied is positively correlated with the price. However, the quantity observable is at one and the same time the quantity supplied and demanded. A simple demand and supply model is as follows:

Demand:	$Q = a + bP + e$	[5A]
Supply:	$Q = c + dP + v$	[5B]

where Q is observable quantity of the commodity; P is the observable price of the commodity; a, b, c and d are unobservable parameters (a, c, d >0 and b<0); e and v are white noise random disturbances with zero means and fixed variances.

For a set of price and quantity data for the commodity, it is not possible to estimate the parameters for both demand and supply curves without further restrictions, because as shown above the functional forms (i.e. the variables included and not included in the equations) are the same. The observed quantities and prices are in fact the intersection points of both curves. By solving the demand and supply curves, the following is obtained:

$$Q = [(a + e)\, d - (c + v)\, b] / (d - b) \quad [5C]$$

$$P = (a + e - c - v) / (d - b) \quad [5D]$$

Prices and quantities are dependent on the parameters of both demand and supply curves and the disturbances of both curves. The disturbance terms (e and v) shift the demand and supply curves on the price-quantity plane. If both disturbance terms (e and v) have similar variance, the curves (solid lines on *figure 5.1*) would shift within similar range (dotted lines on *figure 5.1*). The observable intersection points would be a cluster of points with no discernible relationship like *figure 5.2*.

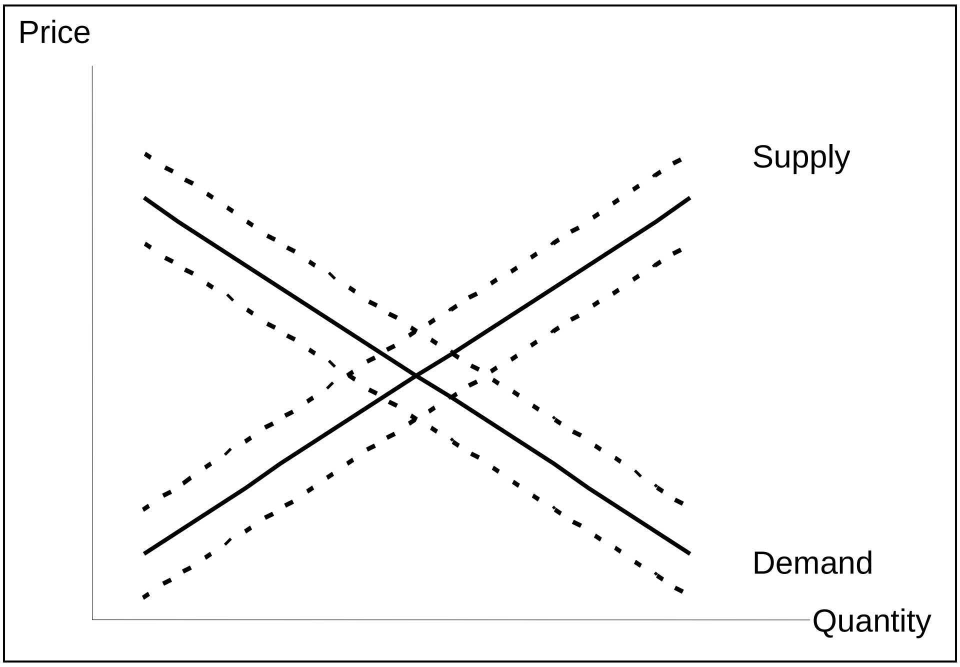

Figure 5.1: Interactions of the Demand and Supply Curves

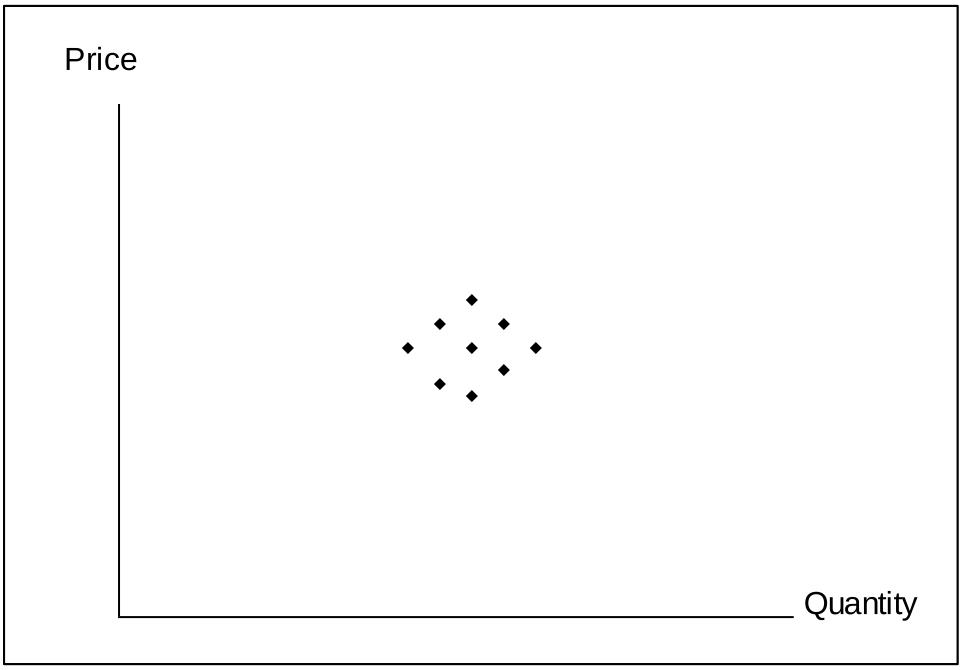

Figure 5.2: Intersections of the Demand and Supply curves

Working (1927) demonstrates that if the supply curve shifts in greater magnitude than the demand curve in the price-quantity plane and the shifting of the curves is not correlated, the fitted curve is a demand curve. *Figure 5.3* depicts the more variable supply curve with a relatively stable demand curve. The intersection points as shown on *figure 5.4* trace the demand curve. On the contrary, if the demand curve shifts widely and the supply curve shifts a little, the intersection points observed should trace the supply curve. Working (1927) therefore concludes that if the shifting of the demand and supply curves is random, the relative variability of supply and demand determine whether the fitted curve approximates a supply or demand curve.

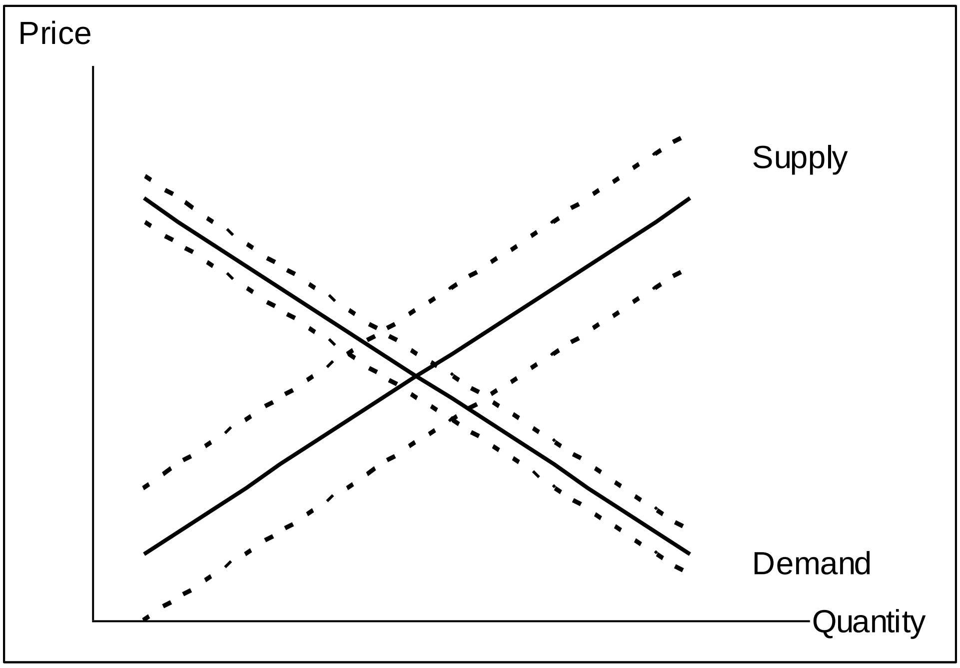

Figure 5.3: Variable Supply Curve and Relatively Stable Demand Curve

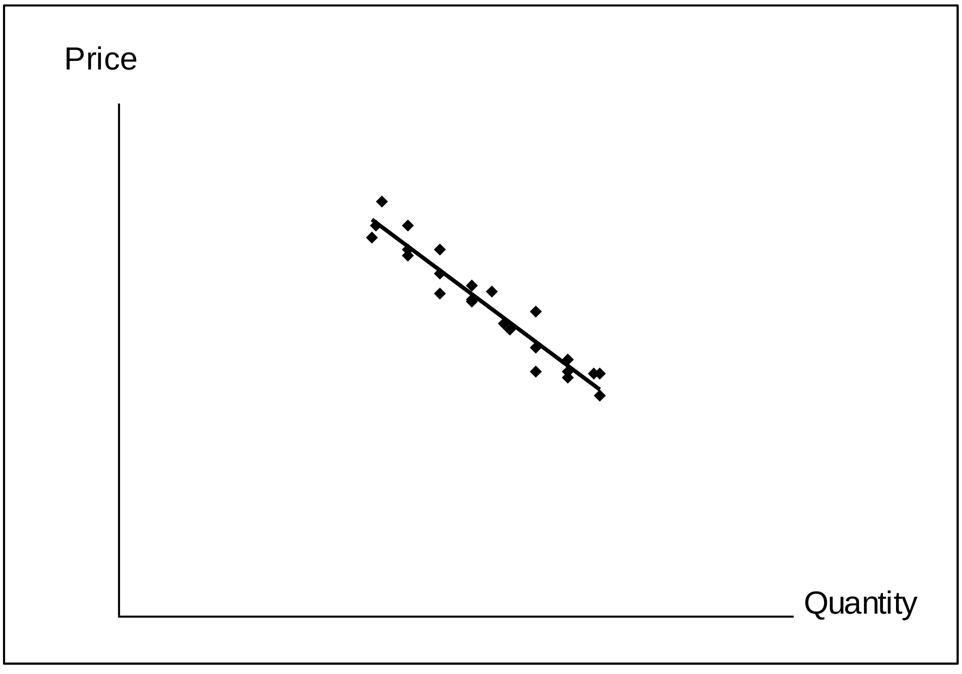

Figure 5.4: Statistical Demand Curve

The importance of *random* shifting of the demand and supply curve is that otherwise the slope of the fitted curve would be different from the true curve. For example, if the supply curve is more variable, and if when the supply curve shifts leftward the demand curve also tends to shift leftward, the fitted curve would be a downward sloping curve flatter than the demand curve.

To set Working's work in the context of the development of econometrics, he wrote the paper at a time when the simultaneous equation bias or simultaneity bias[48] was less understood and his analysis was illustrated by graphs rather than explicit models such as [5A] and [5D]. The problem is that Working does not explicitly tell us how to fit a curve to the points like *figure 5.4*.

Ordinary least squares (OLS) method commonly used in modern econometrics fits the supply curve like [5B] by finding a line (in this case the value of the parameters c and d) to minimise the sum of squared distance between the observed quantity data and the quantity on the line at the same given price. However, from the reduced form equation [5D], it can be seen that P is related to both disturbance terms (e and v) of the structural equations [5A] and [5B]. Therefore if ordinary least square technique is used to estimate the structural equations [5A] and [5B], the estimators for *b* and *d* would both be biased, breaking one of the assumptions of the Classical Linear Regression Model. In fact, in this case the OLS estimate would be the same for [5A] and [5B]:

OLS estimate of *b* = OLS estimate of *d* = $E[\frac{(Q-E(Q))(P-E(P))}{E[(P-E(P))^2]}]$

where *E(X)* is the expected value or the mathematical expectation of a variable *X*.

To further Working (1927)'s thesis and to cater for the simultaneous equation bias, Leamer (1981) proposes to treat the least-squares regression of quantity on price as an

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[48] Simultaneous equation bias is now well covered by modern textbooks of econometrics: for example Wooldridge (2003: chapter 16).

attenuated demand curve if the estimate of the slope is negative and to treat it as an attenuated supply curve if the estimate of the slope is positive, as long as the covariance of the demand and supply system (i.e. e and v in [5A] and [5B]) is zero.

By using maximum likelihood technique, Leamer (1981) demonstrates that the consistent maximum likelihood estimate for the slope parameter (b or d) in equation [5A] and [5B] falls between the OLS estimate for the slope parameter and the reverse OLS estimate for the slope parameter.

Supposing that the OLS estimate of the slope parameter is negative in the direct regression of quantity on price as [5A], Leamer (1981) proposes to run a reverse regression of price on quantity like [5E].

Reverse Demand: $P = g + hQ + u$ [5E]

The consistent (unbiased) maximum likelihood estimate of the slope parameter b in [5A] would be between the reciprocal of the (biased) OLS estimate of h and the (biased) OLS estimate of b. i.e.

$$OLS\ (b) < 0,\ 1/OLS\ (h) < ML\ (b) < OLS\ (b) \qquad [5F]$$

where OLS (x) is an OLS estimate of a parameter x, and ML(x) is a maximum likelihood estimate of a parameter x.

Leamer's result is symmetric such that if the OLS estimate of the slope parameter is positive, the consistent (unbiased) maximum likelihood estimate of the slope parameter d in [5B] would be between the (biased) OLS estimate of d and the reciprocal of the (biased) OLS estimate of h.

$$OLS\ (d) > 0,\ OLS\ (d) < ML\ (d) < 1/OLS\ (h) \qquad [5G]$$

The direct regression like [5A] is to fit a line to minimise the squared distance between the observed quantity data and the quantity on the line at the same given price, whereas the reverse regression like [5E] is to fit a line to minimise the squared distance between the observed price data and the price on the line at the same given quantity. By rearranging [5E] and ignoring the disturbance term, the equation becomes:

$$Q = -\frac{g}{h} + \frac{1}{h}P \qquad [5H]$$

Therefore, the reciprocal of OLS (h) is another way to estimate b in [5A]. However, OLS estimates for b and h are both subject to simultaneous equation bias. The intuition to understand Leamer's method is that although the OLS estimates are biased, they set out the bounds for the unbiased estimate.

Working (1927) argues that the data trace the supply curve if the demand is more variable than the supply. Accepting this argument, Leamer (1981) demonstrates that the additional condition to make the inverse of Working's argument true is that the squared correlation between the price and quantity data is larger than 0.5. That is, if the squared correlation between price and quantity is larger than 0.5 and if the quantity and price are positively correlated, the estimate of the supply variance (v in [5B]) is necessarily less than estimates of the demand variance (e in [5A]).

Despite the simplicity of the method, the key drawback of this method is twofold. It only provides a bound rather than an estimate of the slope parameter. Moreover, the bound is for either the demand or supply equation depending on the sign of the OLS estimate of the slope parameter.

If an exogenous variable that affects the quantity demanded but not the quantity supplied can be found, for example short term interest rate, the supply curve can be "identified". The reason is that the demand curve is shifted by the changes in short term interest rate in addition to the disturbance term as shown on *figure 5.5* which produces a scatter of intersection points tracing the supply curve as shown on *figure 5.6*. If an exogenous variable that only affects the quantity supplied can also be found, then both demand and supply curve can be identified. It is worthwhile to note that the OLS estimator is still biased due to the simultaneous equation bias. However, there are established estimation methods such as instrumental variable technique, two-stage least squares and Limited Information Maximum Likelihood, to deal with this bias.

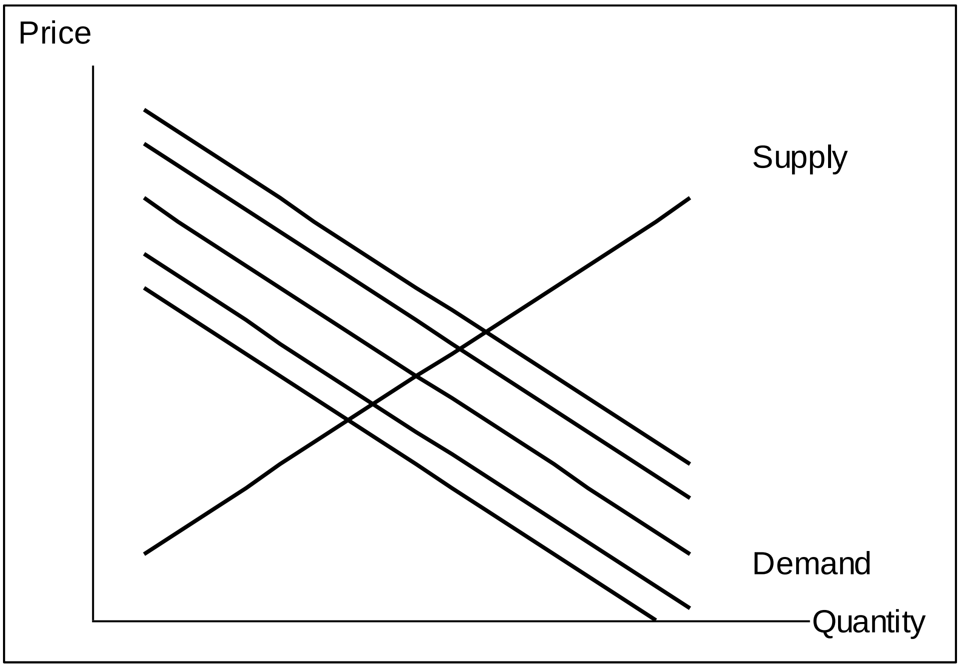


Figure 5.5: Demand Curve Shifted by an Exogenous Factor

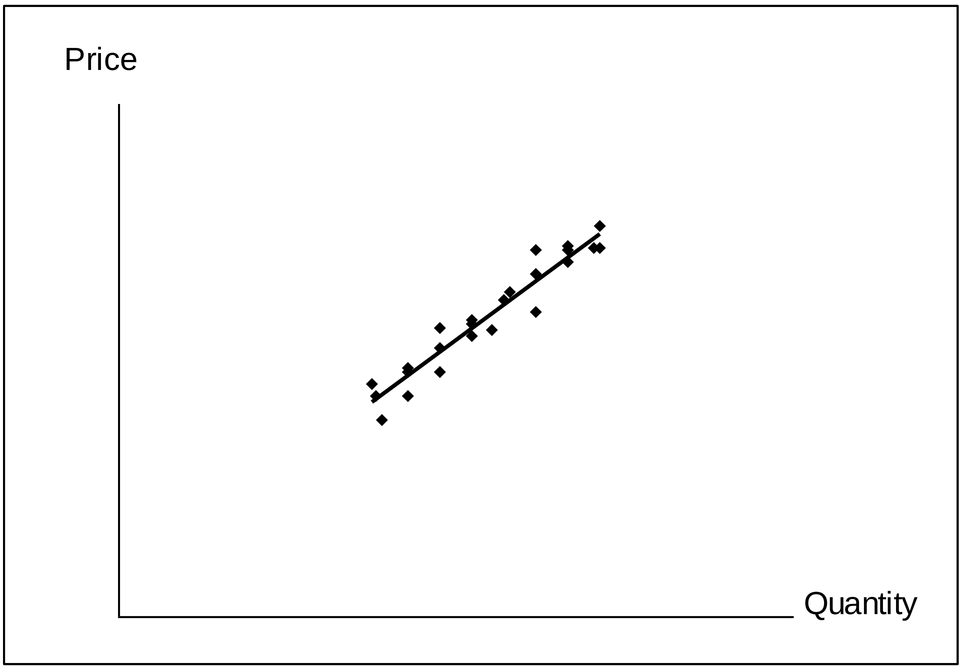


Figure 5.6: "Identified" Supply Curve

5.3 Some construction price inflation and output models

There is no shortage of research studying the relationship between the price of the construction output (the price the buyer of a new building pays the contractor) and the volume of the construction output. Chapter 2 provides a detailed review. The following literature illustrates the potential problems of studying reduced form equations and the advantage of studying the structural model.

Wheaton and Simonton (2007) conclude that there is no correlation found between real construction price (excluding land) paid by developers and the level of building activity in their data covering 6 metropolitan areas in the US over the period between 1967 and 2004. The level of building activity is measured by the number of building permits issued for multi-family development and the completion of new office space in square feet compiled by real estate brokers. Their models are simple linear regressions of the real construction price (an index compiled by the authors and deflated by consumer price index) on either the number of building permits or the completion of new office space in square feet. Their results show that there is no statistically significant relationship between real construction price and building activity.

A possible reason for no correlation being found is that the two variables are indeed independent. However, as elucidated in earlier section, it is possible that Wheaton and Simonton (2007)'s regression model captures neither the supply nor demand curve but the intersection points of them, and due to similar variability of both curves there is no discernible correlation between the price and the quantity found by studying the intersection points.

Blackley (1999) by introducing exogenous variables to the supply equations (including real price of construction materials and real wage for skilled construction workers), finds a significant positive relationship between real residential construction and its real price. He also makes use of two-stage least squares technique to tackle the simultaneous bias problem. However, there were some perverse signs of the estimated parameters of his model which may be due to the inclusion of demand shifters in the equations.

On the other hand Somerville (1999) concludes that when construction price to developers rises, less building activity, as measured in single-family permits, is undertaken. Somerville (1999) regresses the number of single family building permits on change in house price and change in construction price. Instrumental variables are used for both change in house price and change in construction price to cater for the simultaneous bias problem. His model finds a statistically significant relationship between building permits and change in construction price. One of the interpretations of his model is that the change in house prices is one of the demand shifters for building activity, so that a demand curve is being estimated.

5.4 A construction price inflation and output model for British new construction: a two equation demand and supply model

Laws of supply and demand are the essence of economics. This section applies the theory of demand and supply to estimate the relationship between price and quantity of British new construction work. Equations derived from economic theories are called structural equations and they have behavioural interpretations. The demand equation attempts to capture the behaviour of the consumers such that the quantity demanded drops when the price increases, ceteris paribus. The supply equation aims at describing the behaviour of the suppliers such that they will increase the quantity supplied when the price increases, ceteris paribus. The market equilibrium is the result of the interactions between the consumers and suppliers such that the observed price and quantity are the intersection of the supply and demand curves.

The demand and supply equations to be estimated take the forms [5J] and [5K] respectively.

Demand: $$Q_t = \alpha - \sum_{i=0}^{n} \beta_i P_{t-i} + \gamma D_t + u_t \qquad [5J]$$

Supply: $$P_t = \lambda + \sum_{i=0}^{n} \phi_i Q_{t-i} + \theta S_t + e_t \qquad [5K]$$

where P is price; Q is quantity; D and S are exogenous variables; u and e are disturbance terms; n is the numbers of time lags in quarters and ≥ 1; β and ϕ are non-negative constants; α, γ, λ, and θ are constants.

As explained earlier, exogenous variables are needed to distinguish between the demand and supply equations. Both equations are usually expressed as functions of quantity on price and other variables, for example see Thomas (1993: chapter 9) and Young (1985). However, there is no prior reason not to express them as functions of price on quantity and other variables. Haynes and Stone (1985) propose that quantity in the short run is demand determined and price in the short run is supply determined. Therefore, they suggest specifying the demand equation as quantity being a function of present and lagged price, and specifying the supply equation as price being a function of present and lagged quantity. Young (1985) finds that the construction output growth in the US between 1948 and 1980 was mainly due to demand effects whereas the price change in the same period was primarily driven by supply effects.

The model can be interpreted as a learning and adjustment process by the consumers and suppliers based on existing market information. Consumers decide the quantity demanded by considering the observed price[49] and other demand factors such as income and interest rates; whereas suppliers set their price by considering the observed quantity supplied and other supply factors such as their cost of material and labour. Haynes and Stone (1985) illustrate the model by two examples: a) in an inflation and unemployment model, they estimate a supply curve (Phillips curve) by specifying inflation (price) as a function of lagged unemployment (quantity); and estimate a demand curve by specifying unemployment (quantity) as a function of lagged inflation (price); b) in a trade balances (ratio of export to import quantity) and terms of trade (ratio of export to import price) model, they also estimate a supply

[49] In construction market, it is likely that professional advisors would provide budget estimates for their clients which would affect their decision to proceed with the construction project or not.

curve by specifying terms of trade as a function of past trade balances and estimate a demand curve by specifying trade balances as a function of past terms of trade. Their method has been applied to study capacity utilisation and inflation (Bauer (1990)), agricultural markets (Choi (2010)), public and private investments (Eberts *et al* (1987)), interest rates and capital flows (Haynes (1988), aggregate imports and oil price shocks (Kleibergen *et al* (1999)), manufacturing industry in Germany (Seitz (1986)), international trades (Urbain (1995)), and aggregate demand and supply curves (Vinod (1987) and Wulwick and Mack (1990)).

Data and Methodology

Chapter 3 has pointed out that the tender price indices compiled by BCIS reflect the market price of the new building work, which accounts for more than 85% of new construction work. It reflects the price movement that the purchasers of new building work face when they make the investment decision. Land price and other development fees are not included. Therefore the quarterly all-in tender price index of new building work deflated by the GDP deflator is used as the measure of relative price.

In some industries, independent measures of quantities and prices are available. However, in construction no direct measure of quantities are available for the aggregate new construction work sector[50], only measures of value deflated by price indices or output deflators.

Conceptually, the deflated value of new orders of construction work compiled by ONS is appealing as the measure of the quantity of new construction work. However, the analysis in chapter 4 questions the quality and accuracy of the new orders data. Instead, therefore, new construction output at constant price, a measure of gross

[50] For the residential sub-sector, the Department for Communities and Local Government collects the numbers of permanent dwelling completions in the UK, which a measure of quantities independent of the values. However, the key drawback of the numbers of completions as measures of quantities is the lack of adjustment for variations in quality or floor space.

output of contractors in Britain, is used as the measure of quantity of British construction new work. ONS samples circa 8,000 businesses monthly (ONS (2013a)) and the data is used to compile the production measure of GDP. Many researchers such as Akintoye and Skitmore (1993), Gruneberg and Folwell (2013) and Nicholls and Murdoch (2003) have used construction output compiled by ONS as the measure of the quantity of the construction market's output.

Finding good exogenous variables is difficult in practice because their exogeneity cannot all be tested, and thus they are usually supported by logical arguments. Real GDP and short term interest rate (such as 3 month interbank sterling lending rate) are assumed to be exogenous demand factors. Real GDP is a proxy for income of the end users of new buildings and other new construction work. It drives the demand for the construction new work through the income effect for households and maintaining the capital to output ratio for business. Given the small size of construction or new building work in GDP in the sample period (between 6% and 7%), the impact of construction output on GDP is limited. Appelbaum (1982) and Young (1985) have used aggregate output as the exogenous variable in the demand equations of disaggregated industries.

Short term interest rate can be seen as a measure of the cost of capital which is believed to have an inverse relationship with the demand for capital projects such as new buildings. Interbank lending rates and Treasury bill rates are two common measures of short term interest rates (Pastor *et al* 2008, Davis and Henry 1994). Since the interbank lending rates are the lending cost faced by the banking industry whereas only the central government can borrow at the Treasury bill rates, the interbank lending rates should better reflect the cost of the capital borne by the purchasers of construction work in Britain (Akintoye and Skitmore 1994, Jiang and Liu 2011, Maisel 1963, Ng *et al* 2011). On the other side, Ive and Murray (2013) report that the UK construction contractors do not make heavy use of bank finance, so supply is less affected by the rate of interest of bank loans.

Admittedly, including a variable to capture the expected return of investing in new construction work would logically improve the demand equation. However, no reliable statistics to reflect such expected returns appear to be publicly available in the UK. Stock market movement is a potential candidate, but, after analysis of the data between 1962 and 2012, PwC (2013) find that UK stock market price movements, measured in quarterly growth of the FTSE All Share price index, are weak leading indicators of future GDP growth.

Unemployment rates and material price deflated by the GDP deflator are assumed to be exogenous supply factors. Unemployment rates reflect the labour market conditions and are believed to be inversely related to the cost of labour. The reason for using the aggregate unemployment rate instead of a more construction specific measure of labour cost is twofold. Firstly, there is no good measure of construction unemployment rate with long historic data[51]. Even if such labour market measures of the construction industry were available, they would be very responsive to the change in the output of construction market and thus not exogenous. The aggregate unemployment rate should be less affected by the status of any specific market. Likewise, any direct measures of construction labour cost such as average weekly earning statistics of construction industry collected by the ONS's Monthly Wages & Salaries Survey and BCIS Labour Cost Index, are likely very responsive to the booms and busts in the construction market and thus not exogenous.

The other supply shifter is the real material price. Being a small open economy, the construction material price in Britain is mainly decided by the world's import price and energy price. Therefore, it is believed the direction of causation is mainly from the construction material price to the tender price.

[51] Labour Force Survey, a household survey conducted by ONS, provides a consistent measure of unemployment rate by industry of last job since 1995. Before that there was claimant count unemployment rate for industries which was discontinued in 1980s.

Variables	Descriptions	Publishing organisation
YNK	volume of new construction output in Great Britain in constant (2005) prices;	Office for National Statistics (ONS)
TPIR	BCIS All-in Tender Price Index deflated by Gross Domestic Product (Expenditure) at market price deflator	Building Cost Information Service (BCIS) for the tender price index; ONS for the GDP deflator
GDPR	Gross domestic product at market prices chained volume measures (reference year 2009) of the UK	ONS
LIR	3 month average interbank sterling lending rates	Bank of England
BCMR	BCIS Material Cost Index deflated by Gross Domestic Product (Expenditure) at market price deflator	BCIS for the material cost index; ONS for the GDP deflator
U	quarterly unemployment rate (aged 16 and above) of the UK	Labour Force Survey - ONS
$dl(YNK)_t$	$= log(YNK)_t – log(YNK)_{t-4}$	
$dl(TPIR)_t$	$= log(TPIR)_t – log(TPIR)_{t-4}$	
$dl(GDPR)_t$	$= log(GDPR)_t – log(GDPR)_{t-4}$	
$dl(LIR)_t$	$= log(LIR)_t – log(LIR)_{t-4}$	
$dl(U)_t$	$= log(U)_t – log(U)_{t-4}$	
$dl(BMCR)_t$	$= log(BMCR)_t – log(BMCR)_{t-4}$	

Table 5.1: Variables and sources of Quarterly Data for the Period between 1978Q1 and 2012Q4

Table 5.1 provides a summary of the sources and notations of the variables. The notation $dl(X)_t$ is used to stand for the difference between the log of a variable X at time t and the log of the variable X at time $t-4$, which approximates annual growth rate of the variable X. Since the variable X is always compared with the prior X in the same quarter of the previous year, seasonal pattern in X is believed to be removed.

The series are tested for their stationarity, with the results of the augmented Dickey-Fuller (ADF) test shown in *table 5.2*. The null hypothesis of the ADF test is that α=0 in the following standard equation[52] of the time series X_t:

$$\Delta X_t = \mu + \delta T + \alpha X_{t-1} + \sum_{j=1}^{n} \beta_j \Delta X_{t-j} + u_t \qquad [5L]$$

where $\Delta X_t = X_t - X_{t-1}$; μ is a drift term and T is the time trend, n is the number of lags, and u_t is the error term. The lag length is selected by minimizing Schwarz Criterion and Akaike Information Criterion over a choice of lag length up to 13 quarters.

Time series variables	Level [*X*]			Growth Rates [*dl(X)*]	
	Lag Length	No Trend	Trend	Lag Length	No Trend
YNK	6	-1.285	-2.405	5	-4.982***
TPIR	3	-2.304	-2.290	4	-3.857***
GDPR	2	-0.379	-2.534	4	-3.039**
LIR	1	-0.660	-3.805**	9	-3.045**
BCMR	0	0.0889	-1.668	4	-3.800***
U	2	-2.564	-3.107	9	-3.219**

Note: *, ** and *** indicate significant at the 10%, 5% and the 1% levels, respectively. The critical values of the ADF statistics are −2.578, −2.882 and −3.477 without trend; and −3.146, −3.442 and −4.024 with trend, at the 10%, 5% and the 1% levels of significance, respectively.

Table 5.2: Results of the Augmented Dickey-Fuller Tests of the Variables

The ADF test shows that all of the variables are non-stationary in level terms, but they are stationary in their growth rate terms in the tests. Therefore growth rate variables are used for the econometric analysis to avoid spurious results.

[52] For example, see section 18.2 in Wooldridge (2003) and section 19.5 in Kennedy (2008).

Result and Discussion

Demand

[5M] is the simple demand model to be estimated for the British new construction market. Significant first-order autoregression is identified by the correlogram, so first order autoregressive term [AR(1)] is used as in [5N], where ε_t is a white noise. The coefficients of the models [5M] and [5N] α, β, γ, χ, and ρ are estimated jointly.

$$dl(YNK)_t = \alpha - \sum_{i=0}^{4} \beta_i dl(TPIR)_{t-i} + \sum_{i=0}^{4} \gamma_i dl(GDPR)_{t-1} + \sum_{i=0}^{4} \chi_i dl(LIR)_{t-1} + u_t \quad [5M]$$

$$u_t = \rho u_{t-1} + \varepsilon \quad [5N]$$

Following the widely adopted general-to-specific approach (Hendry 1987 and 2000), the aim is to find a parsimonious model. The general-to-specific model is particularly useful here because it is relatively clear which variables are included in the model but the exact lag structures of each variable are less clear (Thomas 1997). Forward stepwise regression technique is adopted to choose the appropriate lag structure of the explanatory variables. In brief, the method begins with the constant term and selects a specific lagged explanatory variable that would have the lowest p-value when it is added to the regression. The selection then adds the variable with the next lowest p-value from the other explanatory variables, given the inclusion of the first explanatory variable. The selection continues to check if the p-values of both the included variables are larger than 0.1. A variable with p-value larger than 0.1 will be removed. Once removed, the variable with next lowest p-value is added. This procedure stops when at least one from each of the three types of explanatory variables are selected. Table 5.3 summaries the result.

	I		II	
	Method = Least Squares Dependent variable = $dl(YNK)_t$		Method = Two-Stage Least Squares Dependent variable = $dl(YNK)_t$	
Explanatory variables	Coefficient	t-statistics	Coefficient	t-statistics
Constant	-0.040439	-2.56***	-0.084964	-5.89***
$dl(TPIR)_{t-3}$	-0.249229	-2.43**	-0.369471	-2.25**
$dl(GDPR)_{t-2}$	1.776742	4.75*	3.522051	7.08***
$dl(LIR)_{t-2}$	-0.050191	-2.75*	-0.118391	-5.90***
AR(1)	0.789500	16.40***	0.621726	5.95***
Adjusted R^2	0.81		0.75	
DW Statistics	1.84		1.96	
	Heteroskedasticity and Autocorrelation Consistent Covariance estimator			
No. of observations	140 (1978Q1 to 2012Q4)			
Note: *, ** and *** denote statistically significant at 10%, 5% and 1% level respectively.				

Table 5.3: Results of the Estimated Demand Equation

The column I of table 5.3 reports the result of using least squares method and heteroskedasticity and autocorrelation consistent covariance estimator because of the presence of autocorrelation. The estimates of the coefficient could be biased for the following reasons:

a) Simultaneity bias. It generally happens when the contemporaneous endogenous variables, *$dl(YNK)_t$* and *$dl(TPIR)_t$* in our case, are linked by more than one structural equation as explained earlier in this chapter. When the demand and supply are recursive (i.e. the explanatory variable is lagged, rather than contemporaneous, endogenous variables), the ordinary least squares estimator is consistent (asymptotically unbiased) if the errors are uncorrelated. Greene (2003: pp. 411) provides a good illustration. However, the error term of the demand equation is serially correlated as reported in *table 5.3,* so ordinary least squares estimator is biased.
b) Measurement error: the observations of the explanatory variables are likely to be subject to measurement error. There is no prior reason to justify the

assumption that variability of the measurement error of the explanatory variables is less than that of the dependant variable. Therefore the observed explanatory variables would tend to be negatively correlated with the error term. This results in the estimates of the coefficients being biased towards zero.

To overcome these problems, two-stage least squares technique is used and the column II of *table 5.3* reports the result. The four exogenous variables *dl(GDP), dl(LIR)*, *dl(U)* and *dl(BCMR)* and their lagged values are used as instruments in the two-stage least squares. It is noteworthy that the absolute value of the coefficient of *dl(TPI)* has increased.

The signs of all explanatory variables are as expected, as the growth in real tender price and the increase in short term interest rates would reduce the demand for construction work whereas the increase in the GDP growth would boost the demand. All estimates are statistically significant at 10%, 5% or 1% levels.

Supply

[5P] is the simple supply model to be estimated for the British new construction market. Significant first-order autoregression is also identified by the correlogram, so first order autoregressive term [AR(1)] is used as in [5Q], where ε_t is a white noise. The coefficients of the models [5P] and [5Q] $\lambda, \phi, \theta, \omega$ and ρ' are estimated jointly.

$$dl(TPIR)_t = \lambda + \sum_{i=0}^{4} \phi_i dl(YNK)_{t-i} + \sum_{i=0}^{4} \theta_i dl(U)_{t-i} + \sum_{i=0}^{4} \varpi_i dl(BCMR)_{t-i} + e_t \qquad [5P]$$

$$e_t = \rho' e_{t-1} + \varepsilon' \qquad [5Q]$$

Similar to the demand analysis, forward stepwise technique is adopted to choose the appropriate lag structure. *Table 5.4* reports the result.

	I		II	
	Method = Least Squares Dependent variable = $dl(TPIR)_t$		Method = Two-Stage Least Squares Dependent variable = $dl(TPIR)_t$	
Explanatory variables	Coefficient	t-statistics	Coefficient	t-statistics
Constant	-0.002890	-0.17	-0.007550	-0.46
$dl(YNK)_{t-1}$	0.134363	1.76*	0.519144	3.89***
$dl(U)_{t-2}$	-0.161653	-2.02**	-0.180323	-2.73***
$dl(BCMR)_t$	0.583952	2.99***	0.411862	1.85*
AR(1)	0.838959	10.76***	0.817405	13.27***
Adjusted R^2	0.83		0.79	
DW Statistics	2.15		2.13	
	Heteroskedasticity and Autocorrelation Consistent Covariance estimator			
No. of observations	140 (1978Q1 to 2012Q4)			
Note: *, ** and *** denote statistically significant at 10%, 5% and 1% level respectively.				

Table 5.4: Results of the Estimated Supply Equation

Two-stage least squares technique is used to remove the potential bias to the estimates of the coefficients caused by simultaneity and measurement errors. The four exogenous variables *dl(GDP), dl(LIR), dl(U)* and *dl(BCMR)* and their lagged values are used as instruments in the two-stage least squares. It is noteworthy that the absolute value of the coefficient of *dl(YNK)* has increased.

The signs of all explanatory variables are as expected, as the higher growth in real construction output and real materials price would push up the growth in supply price whereas increase in the unemployment rate would reduce the growth in labour cost and thus suppress the growth in supply price. All estimates are statistically significant at 10%, 5% or 1% levels.

If the focus is given to the price and quantity and the lag structure is ignored, the results of the demand and supply curves estimated from two-stage least squares can be summarised as follows:

Demand: $dl(YNK) = -0.37 \times dl(TPIR)$ + *other variables* [5R]

Supply: $dl(YNK) = 1.93 \times dl(TPIR)$ + *other variables* [5S]

The supply equation is more price elastic than the demand equation. The explanation is that the price of the construction work, although an important outlay, is not the only price affecting the decision of the purchasers. As the construction work must build on a piece of land, land price (not captured in the model) would probably have a significant impact on the demand for construction work. On the other hand, being a small open economy, the British construction market is more flexible to expand by importing material and labour, particularly from other European countries.

Limitations

The model presented in this section is a simple one but appears to allow us to capture the behavioural structural equations for the purchasers and suppliers. Undoubtedly the model is subject to limitations. For example the model assumes linear relationship between growth of the economy and of the construction sector. However the Bon curve (Bon (1992), Pietroforte and Gregori (2006), Ruddock and Lopes (2006) and Strassmann (1970)) proposes a non-linear, bell-shaped, relationship in the long run.

For brevity the model does not allow a more elaborated autoregressive distributed lag structure, so the model is static. More importantly the exogeneity of the four demand and supply curve shifters cannot all be tested.

An atheoretical description of the data: Vector Autoregressions (VAR)

The chapter will finish by estimating a simple vector autoregression (VAR) model proposed by Sims (1980). Awarding the Nobel Prize in Economic Sciences to Christopher Sims in 2011, the Economic Sciences Prize Committee (2011) reviewed the VARs as an empirical statistical tool for macroeconomics which is widely adopted by policymakers and academics.

When Sims (1980) proposed the VAR approach, large Keynesian macroeconometric models, such as the HM Treasury Macroeconomic Model (Melliss 1988) and MIT-Penn-SSRC model (Brayton and Mauskopf 1985), with more than a hundred equations were popular. The equations of the large model were estimated one by one with ad hoc assumptions of exogeneity of the right hand side variables of the equations which very often are dependent variables in other equations. VAR, in its standard form, assumes all variables are endogenous and each variable is regressed on its own lagged values and the lagged values of all other variables. The impulse response analysis allows the study of the unexpected "exogenous" shocks to each variable.

The VAR approach has been widely adopted in monetary economics to understand the impact of monetary policy (Bernanke and Blinder (1992), Bernanke *et al* (1997), Christiano *et al* (1994) and Cochrane (1998)). Following Christiano *et al*'s (1994 and 2005) studies of quarterly data, 4 quarter lags are used here.

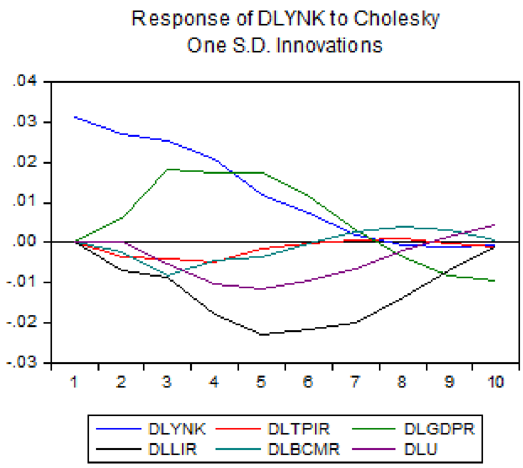
Therefore, a system of 6 equations, one on each variable *dl(YNK), dl(TPIR), dl(GDPR), dl(LIR), dl(BCMR)* and *dl(U)*, are estimated. *Table 5.5* reports the results of the construction output growth equation and the tender price growth equation.

		dl(YNK)	dl(TPIR)
dl(YNK(-1))	coefficient	0.784848	0.010668
	t-statistics	[7.94081]	[0.13056]
dl(YNK(-2))	coefficient	0.019138	0.001891
	t-statistics	[0.15718]	[0.01879]
dl(YNK(-3))	coefficient	-0.050982	-0.048555
	t-statistics	[-0.42106]	[-0.48510]
dl(YNK(-4))	coefficient	-0.019798	0.055981
	t-statistics	[-0.21630]	[0.73982]
dl(TPIR(-1))	coefficient	-0.175280	0.640015
	t-statistics	[-1.53570]	[6.78314]

dl(TPIR(-2))	coefficient	0.005025	0.222131
	t-statistics	[0.03745]	[2.00231]
dl(TPIR(-3))	coefficient	-0.109302	0.171509
	t-statistics	[-0.81938]	[1.55528]
dl(TPIR(-4))	coefficient	0.234645	-0.251903
	t-statistics	[2.16015]	[-2.80524]
dl(GDPR(-1))	coefficient	0.842683	0.289299
	t-statistics	[2.34529]	[0.97397]
dl(GDPR(-2))	coefficient	0.668019	0.569825
	t-statistics	[1.52694]	[1.57557]
dl(GDPR(-3))	coefficient	-0.890867	-0.643861
	t-statistics	[-2.08794]	[-1.82541]
dl(GDPR(-4))	coefficient	0.278331	0.376956
	t-statistics	[0.74459]	[1.21986]
dl(LIR(-1))	coefficient	-0.050707	0.009170
	t-statistics	[-2.24321]	[0.49072]
dl(LIR(-2))	coefficient	0.057304	-0.039895
	t-statistics	[1.61901]	[-1.36349]
dl(LIR(-3))	coefficient	-0.079909	0.028206
	t-statistics	[-2.21422]	[0.94543]
dl(LIR(-4))	coefficient	0.031376	-0.017369
	t-statistics	[1.29664]	[-0.86829]
dl(BCMR(-1))	coefficient	-0.223298	0.098838
	t-statistics	[-0.81534]	[0.43656]
dl(BCMR(-2))	coefficient	-0.388222	-0.289932
	t-statistics	[-1.09577]	[-0.98992]
dl(BCMR(-3))	coefficient	0.855524	0.281651
	t-statistics	[2.56610]	[1.02192]
dl(BCMR(-4))	coefficient	-0.444846	-0.187383
	t-statistics	[-1.79825]	[-0.91629]

dl(U(-1))	coefficient	0.004456	-0.261620
	t-statistics	[0.04417]	[-3.13654]
dl(U(-2))	coefficient	-0.168788	0.323530
	t-statistics	[-1.08763]	[2.52186]
dl(U(-3))	coefficient	0.106081	0.002359
	t-statistics	[0.67034]	[0.01803]
dl(U(-4))	coefficient	0.094936	-0.043817
	t-statistics	[0.91058]	[-0.50838]
C	coefficient	-0.022085	-0.016917
	t-statistics	[-2.26907]	[-2.10248]
R-squared		0.871580	0.890755
Adj. R-squared		0.842776	0.866252
Sum sq. resids		0.104776	0.071604
S.E. equation		0.031292	0.025869
F-statistic		30.25855	36.35224
Log likelihood		283.8562	308.9813
Akaike AIC		-3.922063	-4.302746
Schwarz SC		-3.376078	-3.756761
Mean dependent		0.007495	-0.007883
S.D. dependent		0.078919	0.070735

Table 5.5: Real Tender Price Index and Construction Output Equations in the VAR Model



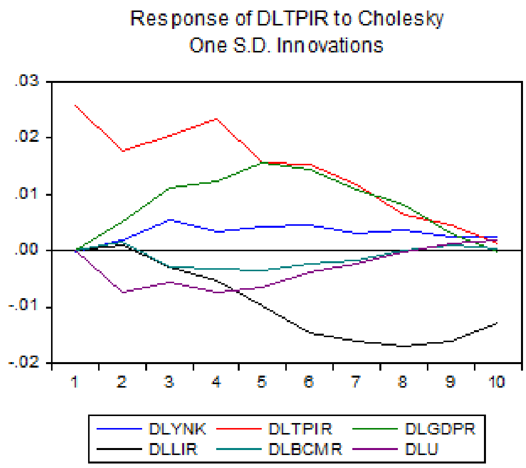


Figure 5.7: Impulse Response Function of the Growth of Construction Output (left panel) and Impulse Response Function of the Growth of Real Tender Price (right panel)

The graph on the left of *figure 5.7* presents the impulse response function of the growth of construction output to other variables whereas the graph on the right illustrates the impulse response function of the real tender price growth to other variables.

Table 5.6 summarises the relationship between the variables as represented on *figure 5.7* as compared with the simple demand and supply model[53].

Correlation	dl(YNK)		dl(TPIR)	
	VARs	Demand equation	VARs	Supply equation
dl(YNK)	Dependent	Dependent	Positive	Positive
dl(TPIR)	Negative	Negative	Dependent	Dependent
dl(GDPR)	Positive	Positive	Positive	Positive

[53] Reversing the order of the quantity and price in the VAR does not change the direction of correlation in the impulse response functions.

dl(LIR)	Negative	Negative	Negative	Negative
dl(BCMR)	Negative	Negative	*Negative*	*Positive*
dl(U)	*Negative*	*Positive*	Negative	Negative

Note: Difference are highlighted in italics

Table 5.6: Comparison between the Simple Demand and Supply Model and the VAR Model

The VAR result supports the specification of demand quantity as a function of price, and supply price as a function of quantity. The response of the construction output growth to the shock of the real tender price growth is negative (demand curve), whereas the response of the real tender price growth to the shock of the construction output growth is positive (supply curve). Other variables also have the same signs of correlation except the impact of unemployment on construction output growth and real materials price growth on real tender price growth.

In the simple demand and supply model, an increase in unemployment rate would shift the supply curve to the right. This will reduce the rate of change of the real tender price but increase the growth of construction output. Therefore, in the demand equation, the correlation between the change in unemployment rate and the construction output growth rate is positive, but impulse response function in *figure 5.7 shows a* negative correlation in the VAR model. In the supply equation, an increase in the real materials price would result in a higher tender price growth by shifting the supply curve to the left, but the correlation is negative in the VAR model as shown on the impulse response function in *figure 5.7*.

Other than the limitations described previously, the result of the perverse signs of the impacts of employment and material price is perhaps due to the inability to capture the effect of technological progress on the supply side. The next chapter will undertake a closer scrutiny on the long term supply side.

Chapter 6 Supply of Construction Output: Long Term Construction Price Inflation in the Light of Physical Productivity Growth

6.1 Introduction

The previous chapter has made use of quarterly data to explore and model the impact of short term economic forces on the price inflation of construction new work in the UK. While demand side factors may be dominating in the short run, productivity growth – the change in the ability to turn input to output – of a sector is believed to be the long run driving force behind the rate of the output price inflation: the higher the productivity growth of a sector, the slower the output price growth.

If the construction sector's productivity growth is slower than that of the economy, its relative output prices should rise over time. The real demand for construction as a percentage of the total output volume of the economy should drop in response to the increase in relative price provided that preferences and tastes are relatively stable in the long run. However, the impact of the relative price change on the nominal construction output as a percentage of the *nominal* output of the economy hinges on the elasticity of substitution between construction output and other output. For a special case of unity of elasticity (Cobb-Douglas), the nominal percentage would stay fairly constant. However, should the absolute value of the elasticity be less than one (i.e. inelastic compared to Cobb-Douglas), the nominal share of construction would grow because the impact of the increase in price on the total expenditures would outweigh the impact of the decrease in volume on the total expenditures.

The next section of this chapter will make use of the EU KLEMS database[54] (Timmer *et al* 2007, O'Mahony and Timmer 2009 and Timmer *et al* 2010), which covers some 40 years of economic data for dozens of European and OECD countries, to compare

[54] KLEMS is an acronym of the five inputs to the production function, namely capital (K), labour (L), energy (E), materials (M), and business services (S). The compilation of the database is funded by the European Commission and is available at http://www.euklems.net/.

the productivity growth of construction sectors to the whole economies and the manufacturing sectors. EU KLEMS groups countries into five sets (see notes to *table 6.1*), and the set used in this thesis is *EU-15ex* (see below).

The chapter then goes on to formally model the relationship between physical productivity growth and output price inflation in a two sector unbalanced growth model. The hypothesis derived from the model is then tested against the time series data of the UK, Germany and those 10 of the 15 EU member states as of 1 January 1995 that have long enough data series and sufficiently comparable economic backgrounds *(EU-15ex)*.

After confirming construction output price inflation is negatively correlated, across periods and across countries, with its productivity growth, this chapter examines if the real output of the construction sector has been shrinking across the *EU-15 ex*, and to report the change of its nominal share in the economy.

In the penultimate section of the chapter, longer time series data for the UK construction industry will be reviewed as a case study to compare construction output prices, construction input prices and the economy wide inflation.

6.2 Physical Productivity Growth of Construction Sectors

States	Sub-Group	From	to	Average Labour Productivity Growth in Manufacturing	Average Labour Productivity Growth in the Whole Economy	Average Labour Productivity Growth in Construction	Average Multi-Factor Productivity Growth in Manufacturing	Average Multi-Factor Productivity Growth in the Whole Economy	Average Multi-Factor Productivity Growth in Construction
UK	EU15ex	1970	2010	3.19%	1.86%	0.99%	1.61%	0.26%	0.46%
Germany	EU15ex	1970	2010	3.17%	2.36%	0.61%	1.41%	1.08%	0.24%
Austria	EU15ex	1970	2010	3.71%	2.60%	1.13%	2.21%	0.82%	0.65%
Belgium	EU15ex	1970	2011	4.58%	2.33%	2.39%	1.17%	0.08%	0.16%
Denmark	EU15ex	1970	2007	2.59%	1.96%	1.28%	0.19%	0.26%	0.38%
Finland	EU15ex	1970	2012	4.41%	2.42%	0.66%	2.60%	1.01%	-0.05%
France	EU15ex	1970	2010	3.67%	2.47%	1.45%	1.36%	0.62%	0.13%
Ireland	EU15	1970	2007	6.72%	3.41%	0.31%	2.44%	1.23%	-1.35%
Italy	EU15ex	1970	2010	2.70%	1.54%	0.21%	1.04%	0.16%	-0.89%
Japan	OECD	1973	2009	4.07%	2.46%	-0.08%	1.64%	0.45%	-1.02%
Netherlands	EU15ex	1970	2011	3.75%	2.11%	0.35%	1.65%	0.29%	-0.60%
Spain	EU15ex	1970	2010	3.01%	2.06%	1.36%	0.50%	-0.14%	0.20%
Sweden	EU15	1970	2011	5.37%	2.46%	-0.13%	4.45%	1.63%	0.49%
US	OECD	1977	2010	4.00%	1.49%	-1.16%	2.28%	0.17%	-1.74%
EU15ex	*Note 1*	1970	2007	3.30%	2.24%	0.95%	1.68%	0.65%	0.08%
EU15	*Note 2*	1970	2007	3.31%	2.26%	0.95%	N/A	N/A	N/A
EU10	*Note 3*	1995	2006	7.79%	3.59%	2.36%	N/A	N/A	N/A
EU25	*Note 4*	1995	2007	3.24%	1.71%	0.21%	N/A	N/A	N/A
EurozoneEx	*Note 5*	1970	2007	3.32%	2.31%	0.88%	1.55%	0.62%	-0.16%

Note 1	EU-15 ex represents the 10 out of the 15 EU member states as of 1 January 1995 for which total factor productivity measures are available including Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Spain, and the United Kingdom. The 5 excluded are Greece, Ireland, Luxembourg, Portugal and Sweden.
Note 2	EU 15 represents the EU member states as of 1 January 1995. It includes the EU-15 ex states, plus Greece, Ireland, Luxembourg, Portugal and Sweden.
Note 3	EU 10 represents the 10 EU members states joined on 1 May 2004, comprising Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovak Republic and Slovenia.
Note 4	EU 25 represents the 25 states in EU15 and EU10.
Note 5	EurozoneEx represents the 8 countries in the Eurozone for which total factor productivity measure are available, comprising Austria, Belgium, Finland, France, Germany, Italy, Netherlands, and Spain.

Table 6.1: Labour Productivity and Multi-Factor Productivity Growth Rates

Source: EU KLEMS ISIC Rev. 3 updated March 2011and EU KLEMS ISIC Rev. 4

Making use of the EU KLEMS database, the average labour productivity growth and multi-factor productivity growth of manufacturing sectors, construction sectors and the whole economy are calculated for the EU-15 ex and a number of other advanced economies including the US and Japan in *table 6.1*. Labour productivity growth is measured by the growth of gross value added output volume per hour worked and multi-factor productivity growth is measured by the difference between the gross value added output volume growth and the weighted capital and labour input growth.

In theory value added output volume should be derived using the double deflation method by separately deflating the gross output and intermediate inputs. However, value added output volume indices in EU KLEMS are based on the national accounts methodology of that particular country (Timmer *et al*t 2007: pp. 21), so the method used varies country by country.

For example, ONS (1998) explains that in the method used in the UK, double deflation is only used in agriculture and electricity because of the unavailability of timely information, particularly the deflators of the inputs, in other sectors. In other sectors, ONS assumes the value added output volume is proportional to the gross output volume in the short run. Every five years, ONS adjusts the ratio when ONS rebases the output measure.

For all countries and sets of countries, with the exception of Belgium, *table 6.1* provides strong evidence that average labour productivity growth of the manufacturing sectors across the sample countries is higher than the average labour productivity growth of the whole economies, which in turn is higher than the labour productivity growth of the construction sectors. The result is not surprising because manufacturing is a sector subject to substantial mechanisation and automation in the last few decades. On the other hand, the construction sector is widely criticised as a sector of low labour productivity growth. For example, Jorgenson and Stiroh (2000) report that construction had the lowest growth in average labour productivity of any sector in the US between 1958 and 1996.

This pattern by and large repeats in the multi-factor productivity growth as shown in *table 6.1*, with the list of exceptions expanding to include the construction sectors in the UK, Belgium, Denmark and Spain. Although total factor productivity growth is a more appealing concept in principle to measure productivity growth (Crawford and

Vogl 2006), this chapter focuses on the labour productivity measures for the following reasons:

- EU KLEMS data provides sectoral multi-factor productivity growth on value added output instead of sectoral total factor productivity growth on gross output[55], so the multi-factor productivity growth figures would include any embedded improvement in the intermediate inputs over time. *Figures 6.1 and 6.2* show that the intermediate inputs in the form of materials and business services accounted for more than 50% of the gross output of the UK construction sector, whereas capital compensation accounted for less than 10% most of the time. Therefore using the multi-factor productivity figures from EU KLEMS would continue to leave out direct measurement of the contribution of the intermediate inputs to productivity growth while inducing measurement errors of the capital service;
- Estimation of multi-factor productivity growth requires measures of capital services which involve estimation of the capital stock by the perpetual inventory method and various rental prices of the assets. These estimates would be less accurate than the estimate of labour input.
- Since the estimation methodology assumes the capital service is proportional to the capital stock in each capital stock category, therefore, from an industry's perspective, the estimate of the capital service cannot be reduced in the downturn of the economy other than via depreciation at an assumed constant rate. In other words, the multi-factor productivity measures would pick up the variations in capital utilisation rates at various times of the economic cycle.
- The capital stock should measure the amount used rather than owned by an industry. However, Timmer *et al* (2007a: pp. 42) states that the figures

[55] Earlier versions of EU KLEMS, released in March 2008 or before, reported total factor productivity indices for some industries. However, according to Timmer et al (2010: pp 89-90), the total factor productivity indices on gross output are based on the multi-factor productivity indices on value added. Under the restrictive assumption of separable production function, the growth of multi-factor productivity of value added output (ΔMFP) is proportional to the growth of total factor productivity of gross output (ΔTFP):

$$\Delta MFP = \frac{Value\ Added\ in\ Current\ Market\ Price}{Gross\ Output\ in\ Current\ Market\ Price} \times \Delta TFP$$

reported in EU KLEMS are in accordance with ownership. This is particularly problematic in construction as the bulk of its capital is transport equipment and other machinery and equipment. If this equipment is owned by the construction companies or hired (with operators) from plant hire firms themselves classed to the construction industry, they are counted as capital of the construction sector. However, if this equipment is leased or hired without operators from asset leasing companies not belonging to the construction industry, then the equipment itself is not counted as part of the industry's capital stock, but user charges are counted as intermediate inputs (Crawford and Vogl 2006: p212 and footnote 10). Given leasing of capital equipment is popular in construction, the capital stock and the capital service statistics are very unlikely to be representative.

- As Ive *et al* (2004) point out, multi-factor productivity measurement requires a series of assumptions about the production function, growth theory and income distribution theory, such as constant returns to scale, profit maximising behaviour, separable production function and competitive markets, that cannot be easily tested or verified. If these assumptions do not hold for the data, the multi-factor productivity measures would be distorted.
- Abdel-Wahab and Vogl (2011), which analysed the EU KLEMS database, Tan (2000) and Mao *et al* (2003) all reported negative multi-factor productivity growth of construction sectors of some countries for a more than a decade. This result is counter intuitive and may be taken as a sign of measurement errors.

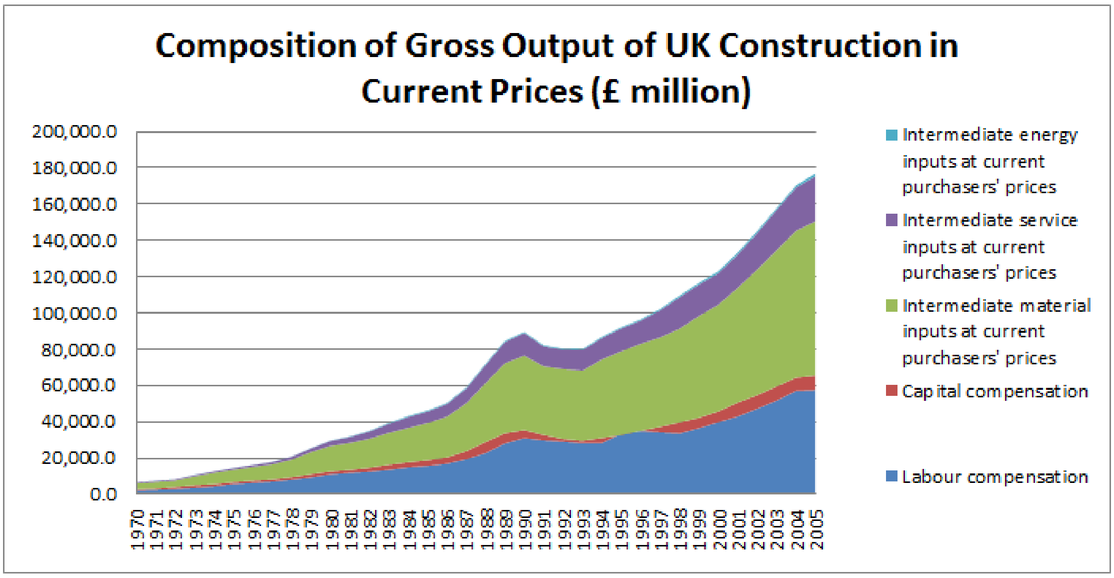


Figure 6.1: Composition of Gross Output of UK Construction in Current Market Prices (£ million), 1970 to 2005

Source: EU KLEMS March 2008 Release

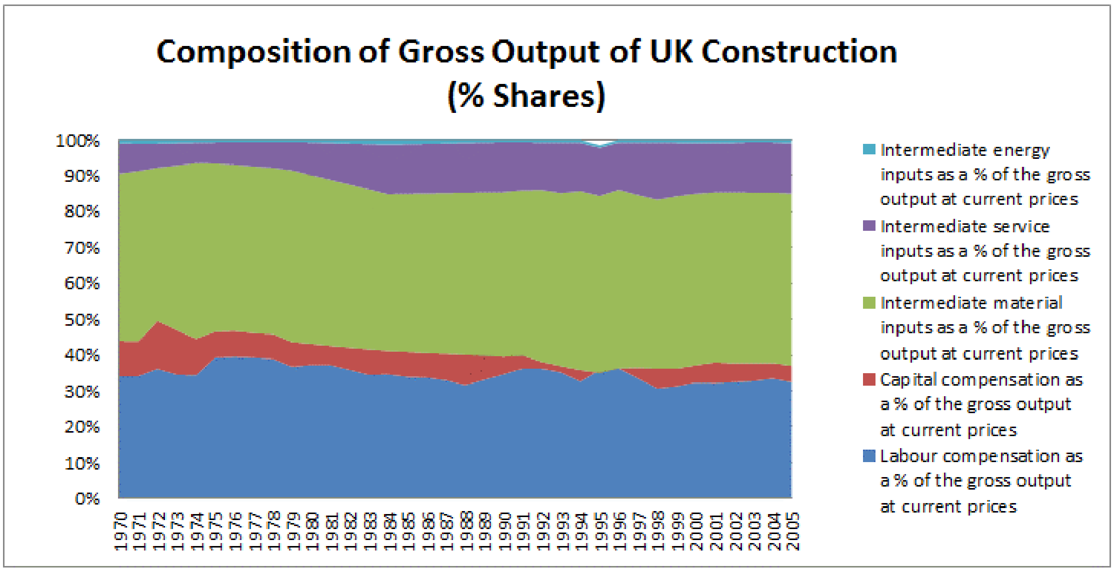


Figure 6.2: Composition of Gross Output of UK Construction in Percentage Shares, 1970 to 2005

Source: EU KLEMS March 2008 Release

6.3 Two Sector Unbalanced Growth Model

In a classic work, Baumol (1967) proposes a two sector model, which is expanded and modified in this section.

Consider an economy of two sectors

$$Y_{cit} = a_i \, L_{cit} \, (1 + g_i')^t$$
$$Y_{nit} = b_i \, L_{nit} \, (1 + g_i)^t$$

where Y_{cit} is the amount of value-added output of the construction sector (*c*), of country *i* in year *t*, Y_{nit} is amount of value-added output of the non-construction sector (*n*) of country *i* in year *t*, L_{cit} is the quantity of labour in construction of country *i* in year t, L_{nit} is the amount of labour in non-construction of country *i* in year *t*, g_i is the labour productivity growth of the non-construction sector of country *i*, g_i' is the labour productivity growth of the construction sector of country *i*, and a_i and b_i are positive constants.

Assume wages of both sectors grow at the same rate d_i[56], so

$$w_{cit} = w_{ci} \, (1 + d_i)^t$$
$$w_{nit} = w_{ni} \, (1 + d_i)^t$$

where w_{cit} and w_{nit} are average wage rates in construction and non-construction sectors of country *i* respectively, and w_{ci} and w_{ni} are the base year levels.

[56] According to EU KLEMS data, the growth rate of the labour compensation per hour for the total economy was 4.8% per annum between 1970 and 2007 in EU-15 ex, whereas that for construction sector was 4.7% per annum. Drawing on the Labour Force Surveys, ONS reports that the average gross hourly earnings of all employees in construction in the UK have grown at 7.9% between 1995 and 2013 whereas the same figure for the whole economy for the same period was 7.5%.

Unit labour cost of the two sectors of country *i* at time *t* will be as follows:

$$C_{Cit} = \frac{w_{cit}L_{cit}}{Y_{cit}} = \frac{w_{ci}(1+d_i)^t L_{cit}}{a_i L_{cit}(1+g'_i)^t} = \frac{w_{ci}(1+d_i)^t}{a_i(1+g'_i)^t}$$

$$C_{nit} = \frac{w_{nit}L_{nit}}{Y_{nit}} = \frac{w_{ni}(1+d_i)^t L_{nit}}{b_i L_{nit}(1+g_i)^t} = \frac{w_{ni}(1+d_i)^t}{b_i(1+g_i)^t}$$

Let R_{it} represent the ratio of the two unit labour costs of country *i* at time *t*. The expression $w_{ci}\, a_i / w_{ni}\, b_i$ is a country specific positive constant and can be represented by z_i. Then

$$R_{it} = z_i \frac{(1+g_i)^t}{(1+g'_i)^t}$$

Let P_{it} be the ratio of construction output price to non-construction output price in country *i*. Under the assumption of output price being a constant markup over labour cost, the ratio of the output price series would be same as the ratio of the unit cost series:

$$P_{it} = z_i \frac{(1+g_i)^t}{(1+g'_i)^t} \qquad [6A]$$

The hypothesis derived from the model is that if the labour productivity growth rate of the construction sector is lower than that of the non-construction sector ($g' < g$), the relative output price of the construction sector would increase over time, because $[(1+g)/(1+g')]$ is larger than 1.

Since it has been shown above that the labour productivity growth of construction has indeed been lower than that of non-construction, an observation of a higher growth rate of the construction output price than that of the non-construction sector would confirm the hypothesis that relative productivity growth rates drive (and explain) long term relative output price change.

A generalised version of this hypothesis is that the relative price movement of a sector should be negatively correlated with its relative productivity growth.

6.4 Cross Section Data of Average Output Price Growth for 14 Countries

States	Sub-Group	From	to	Average Gross Output Price Growth in Manufacturing	Average Gross Output Price Growth in the Whole Economy	Average Gross Output Price Growth in Construction	From	to	Average Gross Value Added Price Growth in Manufacturing	Average Gross Value Added Price Growth in the Whole Economy	Average Gross Value Added Price Growth in Construction
UK	EU15ex	1970	2007	6.08%	6.84%	7.87%	1970	2010	5.33%	6.56%	7.37%
Germany	EU15ex	1970	2007	2.46%	2.67%	3.32%	1970	2010	2.28%	2.63%	3.50%
Austria	EU15ex	1970	2007	2.30%	3.14%	3.97%	1970	2010	2.04%	3.21%	4.09%
Belgium	EU15ex	1970	2007	3.66%	4.23%	4.51%	1970	2011	1.93%	3.69%	3.84%
Denmark	EU15ex	1970	2007	2.59%	1.96%	1.28%	1970	2007	5.28%	5.16%	5.62%
Finland	EU15ex	1970	2012	2.96%	3.96%	4.72%	1970	2012	1.97%	4.05%	5.21%
France	EU15ex	1970	2007	3.78%	4.71%	5.62%	1970	2010	3.62%	4.91%	5.89%
Ireland	EU15	1970	2007	5.07%	7.02%	8.47%	1970	2007	5.31%	7.48%	8.47%
Italy	EU15ex	1970	2007	7.51%	8.21%	8.91%	1970	2010	6.32%	7.71%	8.48%
Japan	OECD	1973	2009	0.88%	1.62%	2.55%	1973	2009	-0.51%	1.56%	3.70%
Netherlands	EU15ex	1970	2007	3.04%	3.64%	5.35%	1970	2011	1.91%	3.21%	4.86%
Spain	EU15ex	1970	2007	6.72%	7.74%	8.85%	1970	2010	6.28%	7.93%	9.22%
Sweden	EU15	1970	2007	5.20%	5.55%	5.65%	1970	2011	-1.17%	1.26%	3.33%
US	OECD	1977	2010	2.54%	3.41%	4.21%	1977	2010	1.63%	3.50%	5.31%
EU15ex		1970	2007	2.48%	2.65%	3.32%	1970	2007	2.22%	2.71%	3.59%
EU15		1970	2007	2.49%	2.66%	3.32%	1970	2007	2.22%	2.67%	3.58%
EurozoneEx		1970	2007	2.47%	2.65%	3.32%	1970	2007	2.19%	2.70%	3.63%

Table 6.2: Average Gross Output Price Growth and Average Value Added Price Growth – manufacturing, whole economy and construction

Source: EU KLEMS ISIC Rev. 3 updated March 2011and EU KLEMS ISIC Rev. 4

Table 6.2 reports the average annual growth of the gross output price in manufacturing, total economy and construction across the EU-15ex and other advanced economies over circa 40 years. It also reports the growth of the value added price, but as explained in the previous section, double deflation is not strictly applied, so the value added price movements would by and large reflect the gross output price movements.

Since construction accounts for a small percentage of the total economy (less than 9% in the UK, see *figures 6.3 and 6.4*), the total economy would be a good proxy of the non-construction sector. *Table 6.2* shows that, with one exception of Denmark in gross value added price, the construction output price (measured in both gross output rice and gross value added price) has grown faster than the economy wide output price across the EU-15ex and other advanced economies. Therefore, *table 6.1* and *table 6.2* provide strong confirmation of the hypothesis that if the labour productivity growth rate of the construction sector is lower than that of the non-construction sector, the relative output price of the construction sector would increase over time.

6.5 Time Series Analyses of the UK, Germany and EU-15 ex Data

Data and Methodology

The following *table 6.3* provides the descriptions of the variables used in the time series analyses.

Variables	Descriptions
CGOP	Construction Gross Output Price Index
MGOP	Manufacturing Gross Output Price Index
TGOP	Total Economy Output Price Index
CLPI	Construction Labour Productivity Index (deflated gross value added per hour worked)
MLPI	Manufacturing Labour Productivity Index (deflated gross value added per hour worked)
TLPI	Total Economy Labour Productivity Index (deflated gross value added per hour worked)
CVAP	Construction Value Added Price Index
MVAP	Manufacturing Value Added Price Index
TVAP	Total Economy Value Added Price Index
$dl(CGOP/MGOP)_t$	$= \log(CGOP/MGOP)_t - \log(CGOP/MGOP)_{t-1}$
$dl(CGOP/TGOP)_t$	$= \log(CGOP/TGOP)_t - \log(CGOP/TGOP)_{t-1}$
$dl(CLPI/MLPI)_t$	$= \log(CLPI/MLPI)_t - \log(CLPI/MLPI)_{t-1}$
$dl(CLPI/TLPI)_t$	$= \log(CLPI/TLPI)_t - \log(CLPI/TLPI)_{t-1}$
$dl(CVAP/MVAP)_t$	$= \log(CVAP/MVAP)_t - \log(CVAP/MVAP)_{t-1}$
$dl(CVAP/TVAP)_t$	$= \log(CVAP/TVAP)_t - \log(CVAP/TVAP)_{t-1}$

Note: The notation $dl(X)_t$ is used to stand for the difference between the log of a variable *X* at time *t* and the log of the variable *X* at time t-1, which approximates annual growth rate of the variable *X*.

Table 6.3: Descriptions and Notations of the Variables used in the Time Series Analyses

Source: EU KLEMS ISIC Rev. 3 updated March 2011and EU KLEMS ISIC Rev. 4

The data is taken from the latest possible EU KLEMS dataset. The aggregate EU-15ex data and Gross Output Price Series in the UK and Germany are taken from EU KLEMS ISIC Rev. 3. Currently EU KLEMS ISIC Rev. 4 is the latest dataset, releasing on a rolling basis, and it provides updates to some of the series in the EU KLEMS ISIC Rev. 3, including Gross Value Added Price and Labour Productivity Index series in the UK and Germany. Therefore these updated series are used. Abdel-Wahab and Vogl (2011) and Ruddock and Ruddock (2011) have used the earlier version of EU KLEMS to examine the productivity growth of construction sectors.

For the time series analysis, a more flexible model than [6A] is considered

$$P_{it} = e_{it}\, z_i [\frac{(1+g_i)^t}{(1+g'_i)^t}]^x \qquad [6B]$$

where x is a parameter to be estimated and e_{it} is a white noise random variable with its mean equal to one. When e_{it} and x both equal to one, [6B] is effectively same as [6A]. Therefore [6A] can be regarded as a special case of [6B].

Taking logs of [6B] and re-arranging

$$\log(P_{it}) = \log(z_i) + x \log[\frac{(1+g_i)^t}{(1+g'_i)^t}] + \log(e_{it}) \qquad [6C]$$

By definition, the relative output price of construction of country i at time t, P_{it}, is as follows:

$$P_{it} = \frac{CVAP_{it}}{TVAP_{it}} \qquad [6D]$$

The growth rate of the labour productivity, g'_i, of the construction sector of country i is as follows:

$$CLPI_{i0} \times (1 + g'_i)^t = CLPI_{it} \qquad [6E]$$

where $CLPI_{it}$ is the labour productivity level of the construction sector of country i at time t, and $CLPI_{i0}$, is the initial base level.

Likewise, the growth rate of the labour productivity, g_i, of the total economy of country i is as follows:

$$TLPI_{i0} \times (1 + g_i)^t = TLPI_{it} \qquad [6F]$$

where $TLPI_{it}$ is the labour productivity level of the total economy of country i at time t, and $TLPI_{i0}$, is the initial base level.

Substituting [6D], [6E], and [6F] into [6C], the equation becomes

$$\log\left(\frac{CVAP_{it}}{TVAP_{it}}\right) = \log(z_i) + x \log\left[\frac{TLPI_{it}}{TLPI_{i0}} \Big/ \frac{CLPI_{it}}{CLPI_{i0}}\right] + \log(e_{it})$$

Re-arranging this becomes

$$\log\left(\frac{CVAP_{it}}{TVAP_{it}}\right) = [\log(z_i) + x \log(\frac{CLPI_{i0}}{TLPI_{i0}})] + x \log\,(\frac{CLPI_{it}}{TLPI_{it}}) + \log(e_{it})$$

Since *[log(*z_i*) + x log (*$CLPI_{i0}$*/* $TLPI_{i0}$ *)]* is a country specific constant, and the mean of e_{it} is one , so the mean *log(*e_{it}*)* is zero. *[log(*z_i*) + x log (*$CLPI_{i0}$*/* $TLPI_{i0}$ *)]* is replaced by a country specific constant c_i, and *log(*e_{it}*)* by a while noise random variable with zero mean, u_{it}

$$\log\left(\frac{CVAP_{it}}{TVAP_{it}}\right) = c_i + x \log\left(\frac{CLPI_{it}}{TLPI_{it}}\right) + u_{it} \qquad [6G]$$

[6G] is the version of the model that is to be estimated by regression analysis.

Results and Discussion

The series are tested for their stationarity, with the results of the augmented Dickey-Fuller (ADF) test shown in *table 6.4*. The null hypothesis of the ADF test is that α=0 in the following equation of the time series X_t:

$$\Delta X_t = \mu + \delta T + \alpha X_{t-1} + \sum_{j=1}^{n} \beta_j \Delta X_{t-j} + u_t \qquad [6H]$$

where $\Delta X_t = X_t - X_{t-1}$; μ is a drift term and T is the time trend, n is the number of lags, and u_t is the error term. The lag length is selected by minimizing Schwarz Criterion and Akaike Information Criterion over a choice of lag length up to 10 quarters [57].

The following table also reports the Phillips and Perron's (PP) test statistics of unit roots. While Augmented Dickey-Fuller test tries to remove serial correlation in the data by adding differenced terms, Phillips and Perron's test makes use of Newey-West estimator to be robust to serial correlation and heteroscedasticity.

The advantages of the PP test is that it does not require us to specify the form of the serial correlation of the differenced terms under the null. In addition, the PP test does not require that the error terms are conditionally homoscedastic, which is an implicit assumption in the ADF test.

If the ADF test is applied and the lag length (autoregressive order) is under-specified, the test will be mis-sized (i.e. rejecting the unit root null much too often when it is true). If the ADF test is applied and the lag length is over-specified, the test's power will suffer (i.e. often failing to reject the unit root null much when it is false).

These problems are avoided in the PP test, but ADF test is more powerful than the PP test if the lag length is correctly specified.

---

[57] Schwert (1989) suggests the following formula as the rule of thumb for determining the maximum lag length: [12 x (number of observations / 100) ^0.25]. Therefore, using this rule of thumb, the maximum lag length is 10 for 40 observations,

Time series variables	Level [X]		Growth Rates [dl(X)]
	No Trend	Trend	No Trend
UK – ADF			
log(CGOP/TGOP)	-3.10**	-3.92**	-4.08***
log(CVAP/TVAP)	-2.70*	-2.66	-3.36**
log(CLPI/TLPI)	-0.69	-1.23	-5.38**
log(CLPI/MLPI)	-0.12	-1.86	-4.85***
log(CGOP/MGOP)	-1.10	-2.29	-4.79***
log(CVAP/MVAP)	-1.59	-2.29	-3.65***
UK – Phillips Perron			
log(CGOP/TGOP)	-1.89	-2.25	-4.18***
log(CVAP/TVAP)	-1.66	-1.74	-3.35**
log(CLPI/TLPI)	-0.67	-1.32	-5.36**
log(CLPI/MLPI)	-0.41	-1.00	-4.85***
log(CGOP/MGOP)	-1.20	-2.24	-4.79***
log(CVAP/MVAP)	-0.94	-1.62	-3.78***
Germany – ADF			
log(CGOP/TGOP)	-0.93	-3.09	-3.70***
log(CVAP/TVAP)	-1.20	-4.15**	-2.90*
log(CLPI/TLPI)	0.00	-2.96	-6.12***
log(CLPI/MLPI)	-0.65	-2.71	-6.12***
log(CGOP/MGOP)	-1.16	-3.48*	-3.69***
log(CVAP/MVAP)	-0.59	-4.41***	-3.16**
Germany – Phillips Perron			
log(CGOP/TGOP)	-0.66	-2.49	-3.82***
log(CVAP/TVAP)	-0.22	-2.35	-2.98**
log(CLPI/TLPI)	0.14	-2.96	-6.11***
log(CLPI/MLPI)	1.11	-2.63	-5.92***
log(CGOP/MGOP)	-0.89	-2.17	-3.62***
log(CVAP/MVAP)	-0.30	-2.33	-3.16**
EU-15ex – ADF			
log(CGOP/TGOP)	-1.02	-3.07	-2.68*
log(CVAP/TVAP)	-0.36	-3.00	-2.60
log(CLPI/TLPI)	0.16	-1.35	-4.62***
log(CLPI/MLPI)	0.88	-1.70	-5.22***
log(CGOP/MGOP)	-1.18	-3.53*	-3.97**

log(CVAP/MVAP)	0.53	-1.68	-3.08**
EU-15ex – Phillips Perron			
log(CGOP/TGOP)	-0.68	-2.41	-2.68*
log(CVAP/TVAP)	0.35	-2.06	-2.83*
log(CLPI/TLPI)	0.16	-1.57	-4.65***
log(CLPI/MLPI)	1.15	-1.27	-5.17***
log(CGOP/MGOP)	-0.90	-2.13	-3.31**
log(CVAP/MVAP)	-0.03	-1.95	-3.08**

Table 6.4: Augmented Dickey-Fuller (ADF) and Phillips Perron (PP) Unit Root Test Results

As reported in *table 6.4,* the PP tests cannot reject the hypothesis that the relative level data are non-stationary whereas it can reject the hypothesis of non-stationary in favour of the alternative hypothesis of stationary in the growth rates data. The ADF tests provide very similar results with a few exceptions.

For simplicity the PP tests' results are adopted, treating the level data as non-stationary and growth rate data as stationary.

As the variables in [6G] are level data, and thus non-stationary, running ordinary least squares (OLS) regression on them would result in spurious and biased estimates unless the variables are co-integrated.

To overcome the potential problems in OLS on handling non-stationary series, the Dynamic Ordinary Least Squares (DOLS) approach proposed by Saikkonen (1992) and Stock and Watson (1993) was adopted for the estimation of co-integrated series. The series are tested for co-integration by the Hansen's Instability Test (Hansen 1992a and 1992b).

The estimation result of [6G] is shown in *table 6.5* for the UK, Germany and the aggregate EU15ex data. It reports the output price measured by both gross output price and gross value added price. The Hansen's Instability Tests cannot reject the null hypothesis that the series are co-integrated. Accepting the series are co-integrated, DOLS approach can be applied for estimation.

Dependent Variable	log(CGOP / TGOP)			log(CVAP/TVAP)		
Countries, *i*	UK	Germany	EU15ex	UK	Germany	EU15ex
Constant, c_i	0.11	-0.01	-0.07	-0.04	0.03	-0.06
	(3.65)***	(0.36)	(-2.58)**	(-1.43)	(1.20)	(-2.87)***
Coefficient of log(CLPI / TLPI), *x*	-0.95	-0.46	-0.75	-1.42	-0.49	-0.81
	(-2.46)**	(-8.12)***	(-6.40)***	(-3.88)***	(-8.26)***	(-9.74)***
Adjusted R-Squared	0.37	0.84	0.78	0.61	0.83	0.87
No. of Observations (after adjustments)	36		35	40	38	35
	1970-2008		1970-2007	1970-2009	1970-2010	1970-2007
Method	DOLS: 1 lead, 1 lag					
Cointegration Test: Hansen Parameter Instability: Lc statistics	0.015	0.021	0.016	0.013	0.022	0.018

Note: figures in brackets are t-statistics; *, ** and *** indicate significant at the 10%, 5% and the 1% levels, respectively.

Table 6.5: Results of Regressing Relative Price on Relative Productivity – construction and whole economy

The estimates of *x* reported in *table 6.5*, the relationship between relative construction output price and relative construction labour productivity, are all negative and statistically significant. This provides time series support to the hypothesis of the negative correlation between relative output price of the construction sector and relative productivity growth of the construction sector.

The two sector equation between construction and non-construction as in [6G] can be modified for a two sector equation between construction and manufacturing as below

$$\log\left(\frac{CVAP_{it}}{MVAP_{it}}\right) = c_i + x\log\left(\frac{CLPI_{it}}{MLPI_{it}}\right) + u_{it} \qquad [6H]$$

The estimation result of [6H] is shown in *table 6.6* for the UK, Germany and the aggregate EU15ex data. It reports the output price measured by both gross output price and gross value added price. The Hansen's Instability Tests cannot reject the null hypothesis that the series are co-integrated. Accepting the series are co-integrated, DOLS approach can be applied for estimation.

Dependent Variable	log(CGOP / MGOP)			log(CVAP/MVAP)		
Countries, *i*	UK	Germany	EU15ex	UK	Germany	EU15ex
Constant, c_i	0.24	0.04	-0.06	-0.17	0.06	-0.07
	(6.03)***	(0.71)	(-1.29)	(-2.89)***	(1.34)	(-1.57)
Coefficient of log(CLPI / TLPI), *x*	-0.73	-0.42	-0.52	-0.77	-0.46	-0.59
	(-6.87)***	(-5.79)***	(-6.36)***	(-4.97)***	(-7.41)***	(-8.01)***
Adjusted R-Squared	0.80	0.78	0.78	0.76	0.83	0.85
No. of Observations (after adjustments)	36		35	37	38	35
	1970-2007		1970-2007	1970-2009	1970-2010	1970-2007
Method	DOLS: 1 lead, 1 lag					
Cointegration Test: Hansen Parameter Instability: Lc statistics	0.021	0.015	0.015	0.015	0.013	0.013

Note: figures in brackets are t-statistics; *, ** and *** indicate significant at the 10%, 5% and the 1% levels, respectively.

Table 6.6: Results of Regressing Relative Price on Relative Labour Productivity – construction and manufacturing

The estimates of *x* reported in *table 6.6*, the relationship between construction output price relative to manufacturing and construction labour productivity relative to the manufacturing, are all negative and statistically significant. This provides further time series support to the hypothesis of the negative correlation between relative output price of the construction sector and relative productivity growth of the construction sector.

As stated earlier, a more flexible model is adopted for estimation. The model strictly derived from the unbalanced two sector model, [6A], has the value of *x*, as minus 1. This means that when the construction labour productivity growth is slower than that of the whole economy by 1% point, the construction output price will grow faster than that of the whole economy by 1% point.

The possible reasons that the estimates of *x* in *table 6.5* and *table 6.6* are not -1 are as follows:

- The two sector unbalanced growth model assumes no friction for adjustments and thus the full effect of the change in relative productivity on the change in relative output price will be reflected in annual data. In reality, it may take longer to allow the full effect to emerge in the data;
- The model ignores the impact of the capital and other intermediate inputs, and the expectation is that the change in relative price would be partly explained by the relative productivity of the capital and intermediate inputs;
- The two sector unbalanced growth model assumes tastes and preferences are constant. Over the forty year period for the 10 developed countries in Europe from 1970, it is possible that the demand for construction output has shifted downwards due to a slower rate of household formation. This would reduce the estimate of *x* towards zero.

Pooled Time Series Result

The EU KLEMS data provides the time series data for all 10 countries in EU-15ex. This section will make use of the panel data to estimate the relationship between the relative construction output price and relative construction labour productivity across the 10 developed European countries, namely Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Spain, United Kingdom.

The pooled time series data provide a lot more observations, so the time series data can be grouped under four sub-periods:

- 1970 to 1979
- 1979 to 1988
- 1988 to 2000
- 2000 to 2009

Nordhaus (2008) and Hartwig (2011) has used similar sub-periods for their analysis of previous versions of EU KLEMS and comparable US data. The four sub-periods are of similar length and broadly capture a business cycle. The attraction of using an average number over a longer period is that the data would be less influenced by the short term cycle, so that the long term trend would become more apparent.

Substituting *t-1* for *t* in [6G] gives:

$$\log\left(\frac{CVAP_{it-1}}{TVAP_{it-1}}\right) = c_i + x\log\left(\frac{CLPI_{it-1}}{TLPI_{it}-1}\right) + u_{it-1} \qquad [6I]$$

Then [6G] – [6I] becomes

$$\log\left(\frac{CVAP_{it}}{TVAP_{it}}\right) - \log\left(\frac{CVAP_{it-1}}{TVAP_{it-1}}\right) = x\log\left(\frac{CLPI_{it}}{TLPI_{it}}\right) - \ x\log\left(\frac{CLPI_{it-1}}{TLPI_{it}-1}\right) + u_{it} - u_{it-1}$$

$$dl\left(\frac{CVAP_{it}}{TVAP_{it}}\right) = x\ \mathrm{dl}\left(\frac{CLPI_{it}}{TLPI_{it}}\right) + \epsilon_{it} \qquad [6J]$$

where $\epsilon_{it} = u_t - u_{t-1}$, and *t* is not the annual period but 4 sub-periods. Therefore for each country, there are 4 observations.

The appeal of model [6J] is that by taking the first difference, the country specific constants are eliminated. Moreover, [6J] is dealing with growth rate data which are stationary.

Likewise, a similar model for construction and manufacturing is derived as follows:

$$dl\left(\frac{CVAP_{it}}{MVAP_{it}}\right) = x\ \mathrm{dl}\left(\frac{CLPI_{it}}{MLPI_{it}}\right) + \epsilon_{it} \qquad [6K]$$

Dependent Variable	dl(CVAP/TVAP)	Dependent Variable	dl(CVAP/MVAP)
Coefficient of dl(CLPI/TPLI), *x*	-0.67	Coefficient of dl(CLPI/MPLI), *x*	-0.88
	(-6.46)***		(-9.57)***
Adjusted R-Squared	0.12	Adjusted R-Squared	0.26
Observations	40	Observations	40
Method	Pooled Least Squares	Method	Pooled Least Squares
Durbin-Watson Stat	1.87	Durbin-Watson Stat	2.03

Note: figures in brackets are t-statistics; *, ** and *** indicate significant at the 10%, 5% and the 1% levels, respectively.

Table 6.7: Results of Regressing the Growth Rate of Relative Construction Output Price on the Growth Rate of Relative Construction Labour Productivity – construction, whole economy, and manufacturing

Table 6.7 reports the estimation result of equation [6J] and [6K]. The estimates of the coefficient *x* are negative and statistically significant, and can be interpreted as supporting the hypothesis. The absolute value of the estimate is again less than one, in line with the results obtained from the level data.

6.6 Long Run Trend of the Construction Sector as a Percentage of the Economy at Constant Prices and Current Market Prices – using gross outputs and gross value added

States	Sub-Group	From	to	Average Annual Gross Output Growth in Whole Economy at Constant 1995 Prices	Average Annual Gross Output Growth in Construction at Constant 1995 Prices	From	to	Average Annual Gross Value Added Growth in Whole Economy at Constant 1995 Prices	Average Annual Gross Value Added Growth in Construction at Constant 1995 Prices
UK	EU15ex	1970	2007	2.02%	1.72%	1970	2010	1.99%	0.99%
Germany	EU15ex	1970	2007	2.49%	0.24%	1970	2010	2.03%	-0.55%
Austria	EU15ex	1970	2007	3.14%	2.31%	1970	2010	2.70%	1.92%
Belgium	EU15ex	1970	2007	2.38%	1.83%	1970	2011	2.38%	1.56%
Denmark	EU15ex	1970	2007	2.49%	0.96%	1970	2007	1.95%	0.47%
Finland	EU15ex	1970	2012	2.70%	1.13%	1970	2012	2.31%	0.13%
France	EU15ex	1970	2007	2.70%	1.07%	1970	2010	2.27%	0.73%
Ireland	EU15	1970	2007	5.36%	3.08%	1970	2007	4.91%	4.15%
Italy	EU15ex	1970	2007	2.70%	0.85%	1970	2010	2.01%	0.19%
Japan	OECD	1973	2009	1.93%	-0.29%	1973	2009	2.36%	-0.67%
Netherlands	EU15ex	1970	2007	2.56%	0.10%	1970	2011	2.54%	-0.09%
Spain	EU15ex	1970	2007	3.40%	2.94%	1970	2010	2.91%	2.18%
Sweden	EU15	1970	2007	2.32%	0.90%	1970	2011	3.69%	1.14%
US	OECD	1977	2010	2.33%	0.33%	1977	2010	2.52%	-0.12%
EU15ex		1970	2007	2.60%	1.32%	1970	2007	2.39%	0.74%
EU15		1970	2007	2.64%	1.37%	1970	2007	2.45%	0.83%
EurozoneEx		1970	2007	2.72%	1.24%	1970	2007	2.45%	0.64%

Table 6.8: The Growth Rates of Gross Output and Gross Value Added at Constant (1995) Prices

Source: EU KLEMS ISIC Rev. 3 updated March 2011and EU KLEMS ISIC Rev. 4

The construction price relative to the economy general output price has been growing in the circa 40 year data covered by the EU KLEMS dataset. If preferences and tastes are fairly steady, consumers will substitute non-construction output for construction output and thus a higher growth rate in non-construction output than construction output at constant prices should be observed.

The growth rate of the construction output at constant price (measured in both gross output and gross value added at constant price) reported in *table 6.8* are all lower than those of the corresponding measures of total output. Construction as a proportion of the economy has been falling in these countries.

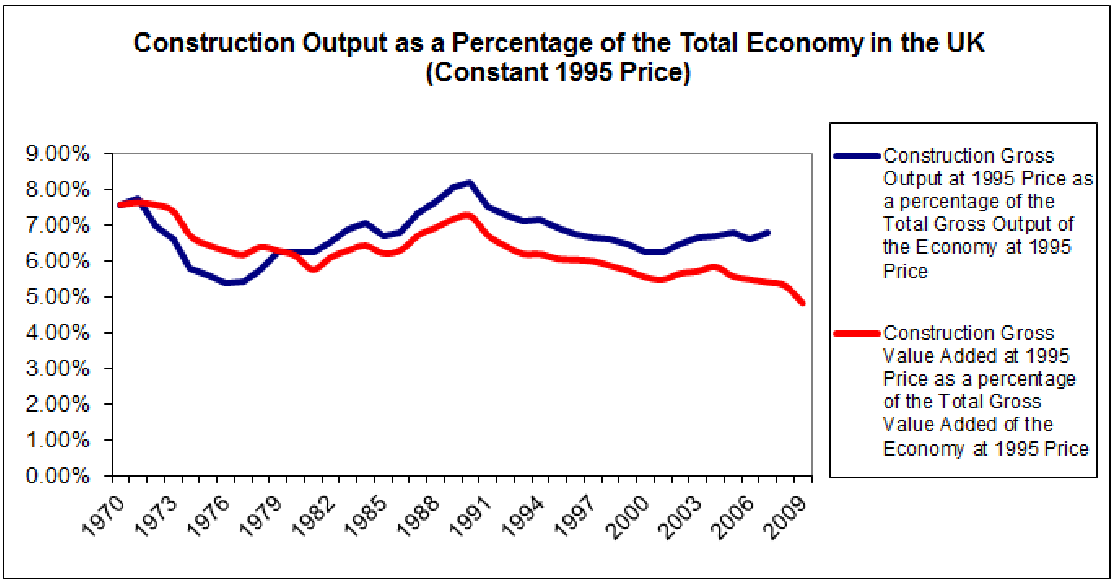


Figure 6.3: Construction Output as a Percentage of the Total Economy in the UK at Constant 1995 Price, 1970 to 2010

Figure 6.3 illustrates the construction output as a percentage of the total economy in the UK. The downward trend is more salient in the gross value added series. Both series began virtually at the same percentage level and the gross value added series has dropped faster. This pattern of divergence is repeated in the nominal series in *figure 6.4*.

The possible reasons for the divergence are that pre-fabrication has become more important and design and build procurement has become more popular. Pre-fabricated elements are counted as part of the gross output of construction but excluded from the gross value added, so if pre-fabrications becomes more common and substitutes for the value added work on site, that will explain part of the difference between the two series.

Design and build procurement method has been gaining market shares. In it, architects and engineers provide their services through subcontracting to the main contractor. If the value of those subcontracts are included in the gross output but excluded from the gross value added, the adoption of design and build procurement would also explain part of the difference.

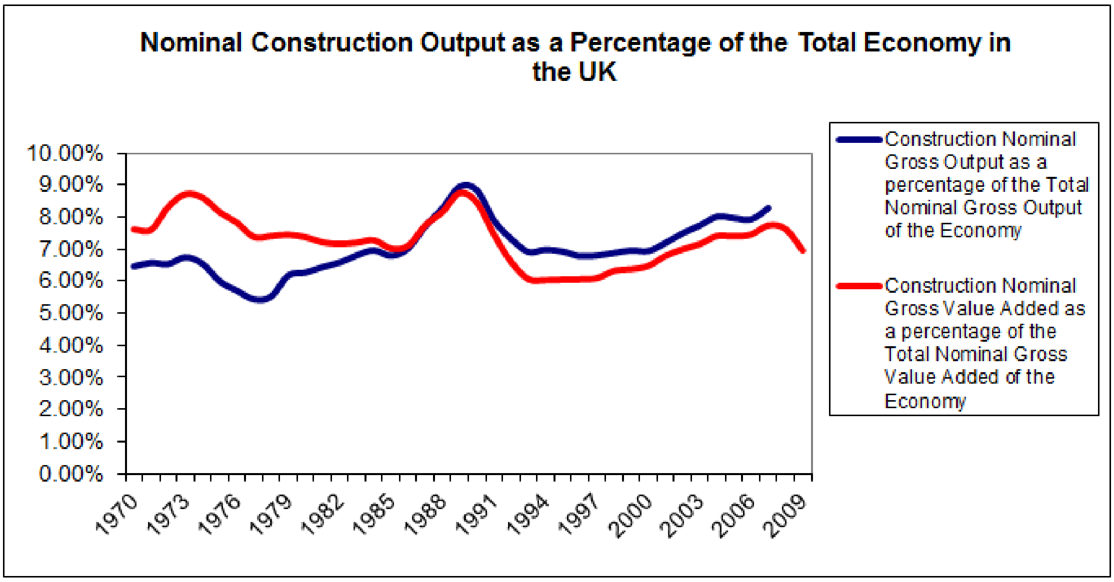


Figure 6.4: Nominal Construction Output as a Percentage of the Total Economy in the UK, 1970 to 2010

States	Sub-Group	From	to	Average Annual Gross Output Growth in Whole Economy at Current Market Prices	Average Annual Gross Output Growth in Construction at Current Market Prices	From	to	Average Annual Gross Value Added Growth in Whole Economy at Current Market Prices	Average Annual Gross Value Added Growth in Construction at Current Market Prices
UK	EU15ex	1970	2007	8.99%	9.73%	1970	2010	8.67%	8.43%
Germany	EU15ex	1970	2007	3.57%	5.23%	1970	2010	4.71%	2.94%
Austria	EU15ex	1970	2007	6.38%	6.37%	1970	2010	5.85%	5.34%
Belgium	EU15ex	1970	2007	6.72%	6.42%	1970	2011	6.16%	5.45%
Denmark	EU15ex	1970	2007	7.46%	6.39%	1970	2007	7.21%	6.12%
Finland	EU15ex	1970	2012	6.77%	5.91%	1970	2012	6.45%	5.35%
France	EU15ex	1970	2007	7.53%	6.75%	1970	2010	7.17%	6.43%
Ireland	EU15	1970	2007	12.76%	11.81%	1970	2007	4.91%	4.15%
Italy	EU15ex	1970	2007	11.13%	9.84%	1970	2010	9.88%	8.69%
Japan	OECD	1973	2009	3.59%	2.26%	1973	2009	3.96%	3.00%
Netherlands	EU15ex	1970	2007	6.29%	5.46%	1970	2011	5.84%	4.77%
Spain	EU15ex	1970	2007	11.40%	12.05%	1970	2010	10.75%	11.02%
Sweden	EU15	1970	2007	8.00%	6.61%	1970	2011	4.99%	4.50%
US	OECD	1977	2010	5.82%	4.55%	1977	2010	6.10%	5.19%
EU15ex		1970	2007	5.33%	4.68%	1970	2007	5.16%	4.36%
EU15		1970	2007	5.36%	4.73%	1970	2007	5.19%	4.44%
EurozoneEx		1970	2007	5.44%	4.60%	1970	2007	5.22%	4.29%

Table 6.9: The Growth Rates of Gross Output and Gross Value Added at Current Market Prices

Source: EU KLEMS ISIC Rev. 3 updated March 2011and EU KLEMS ISIC Rev. 4

While *table 6.8* confirms the drop of the share of construction output at constant price, the change in the share of the construction output at current market prices would hinge on the elasticity of substitution, because the increase in relative price and the decrease in real output share work in opposite directions.

Table 6.9 shows that in gross value added at current market prices, construction output grew slower than the total economy. The data in gross output at current market prices is less conclusive with some countries including the UK, Germany, Belgium, the Netherlands, Span and Sweden having seen construction sector gaining share on this measure. However, construction share measured in gross output at current market prices has been falling in Austria, Denmark, Finland, France, Ireland, Italy, Japan, and the US.

Tracing the housing investment for 11 countries (Australia, Belgium, Canada, Finland, France, Germany, Japan, Netherlands, Sweden, the UK and US), Ball and Wood (1999) concluded that the trended real housing investment had been flat from 1970 to 1992, and thus dropped as a percentage of national income at constant price. Housing investment as a portion of national income at current price displayed a pattern of falling shares from the mid-19th century to 1930s, then rising to around 1970s, and then falling. This suggests tastes and preferences play a role in the housing investment shares.

If the observation of falling nominal construction output shares is accepted and if tastes and preferences are constant, it leads to a conclusion that the relative price elasticity of demand for construction to non-construction is higher than one. It means that a 1% increase in price will result in more than 1% drop in output. This sounds unlikely for construction output that has no close substitute. An alternative explanation is that the rise in relative construction output price coincide with a drop in the demand (i.e. shift in tastes and preferences) for construction in the 40 years covered by the data. In the UK, a big reduction in public spending on construction has happened over this period. Also with the advance of information and communication technology, people can work from home which reduces the need for construction output in the form of office buildings.

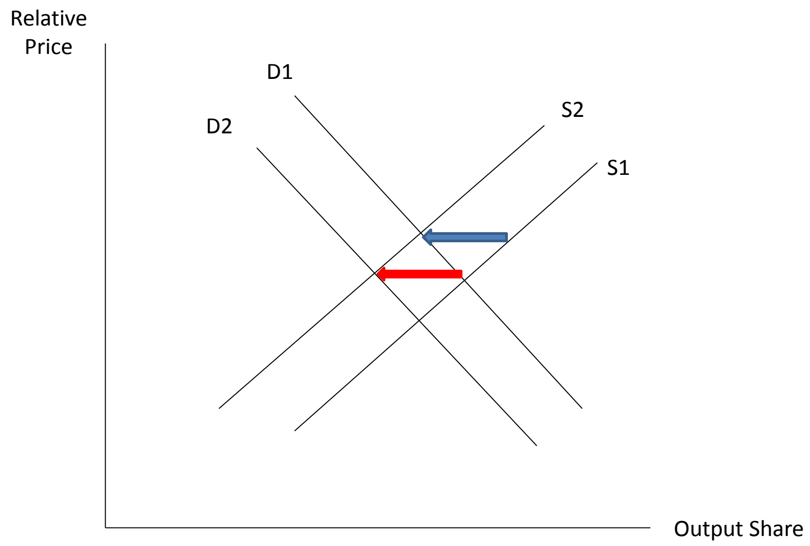


Figure 6.5: A Combined Effect of Relative Productivity induced Supply Curve Shifting and Demand Curve Shifting

Figure 6.5 depicts what was possibly at work. The relatively low labour productivity growth in construction pushed the supply curve leftward from S1 to S2. At the same time the construction demand shifted leftwards from D1 to D2. Therefore, the overall observed change in the output is the sum of the two changes, instead of purely the result of shifting the supply curve on the same demand curve.

6.7 Case Study: UK Construction

Figure 6.6 traces the construction output prices in the UK, measured by the implied output deflators, and the economy wide inflation, measured by GDP deflator and Retail Price Index (RPI) between 1955 and 2013.

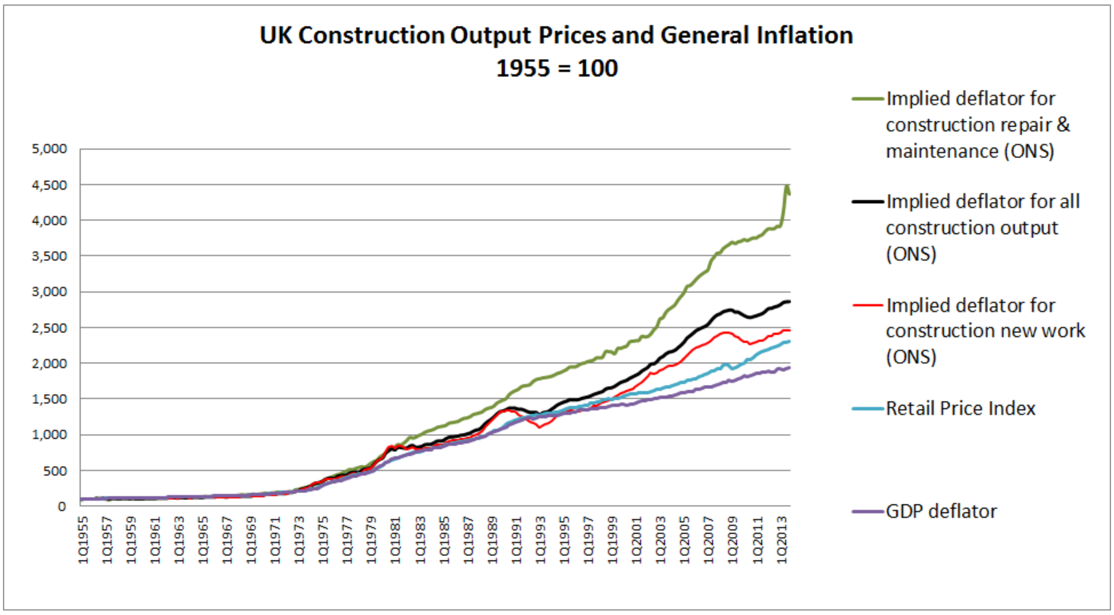


Figure 6.6: UK Construction Output Price Indices (Implied Deflators) and General Inflation Indices, 1Q 1955 to 4Q 2013

The growth of these price indices in ascending order are GDP deflator (5.23% per annum), RPI (5.54% per annum), construction new work output price (5.67% per annum), all construction output price (5.95%), and construction repair and maintenance output price (6.67%).

This UK post-war data lends further support to the pattern that the construction output prices have grown faster than the economy wide inflation. It is noteworthy that the construction repair and maintenance output deflator is an average of the repair and maintenance cost index and the BCIS labour cost index (Crook and Sharp 2010), and therefore no productivity growth is assumed. On the other hand, the construction new work deflator is derived from the tender price indices, which is a direct measure of the output price.

Figure 6.7 illustrates the trends of the input and output prices of the construction new work between 1974 and 2013. BCIS General Building Cost Index is a weighted index of labour and material cost for construction new work and has grown faster (6.47% per annum) than the implied deflator for construction new work (5.44% per annum). Chapter 3 has reviewed the compilation method of the BCIS General Building Cost Index and questioned the labour cost component being overstated.

However, *figure 6.7* shows that the material cost component alone has also grown faster (5.91%) than the implied deflator of the construction new work. As it is unlikely that the labour cost would have grown slower than the material price, BCIS Material Cost Index effectively sets the lower bound of the input price index. As a result, it can be concluded that the input prices of the construction new work have grown faster than the output price.

The interpretation of the observation that the output price has grown slower than the input prices is that the construction industry has positive productivity growth, although it may be at a rate lower than the average of the economy. The ability to convert the same amount of input to more and more output over time drives the output price downward compared to the input prices.

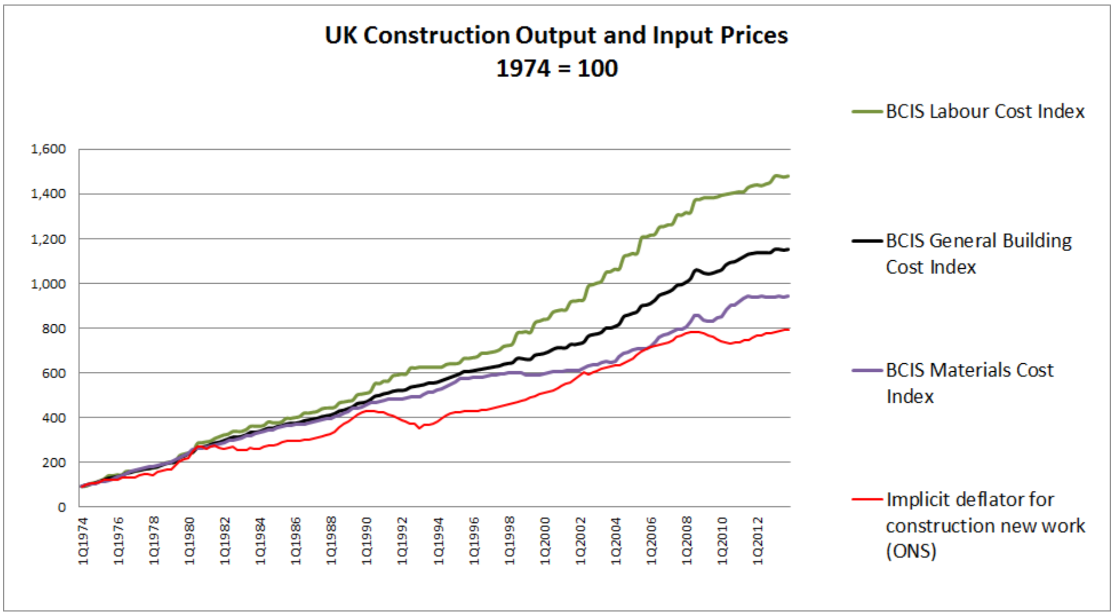


Figure 6.7 UK Construction Output Price and Input Price Indices, 1Q 1974 to 4Q 2013

6.8 Conclusion

This chapter has confirmed the belief that the labour productivity of construction industry has grown slower than in the whole economy or in the manufacturing sector.

The relative output price of construction has risen over time in comparison with the economy or manufacturing, measured in both gross output prices and gross value added prices. The real output (i.e. output at constant prices) share of the construction industry has generally dropped while the nominal output (i.e. output at current market prices) share varies in opposite directions in different countries.

In addition to lending further support to the comparison of the output prices between construction and the whole economy, the UK case study also provides evidence of positive productivity growth in the construction industry by comparing input and output prices.

Chapter 7 Summary of Findings, Conclusions and Recommendations for Research

7.1 Summary of Research Findings

The common theme of the circa fifty works in the literature of construction price or cost index modelling reviewed in chapter 2 is that none of them question the accuracy, representativeness and fitness-for-purpose of the price or cost indices they modelled. Some of them have not treated the non-stationary data appropriately, which renders their results potentially spurious. Productivity as a driver of the long term relative price is rarely explored.

Against this background, chapter 3 and chapter 4 respond directly to the data accuracy presumption made in the literature.

Chapter 3 surveys the compilation methods of the three most well-known Tender Price Indices (TPIs) of new buildings in Britain and the two main sets of Construction Cost Indices (CCIs) in the UK. It concludes that the British TPIs are derived from transactional based data which are unique and probably better than the counterparts in other countries. This study finds that TPIs only measure the inflation of the traditional trade items such as the structural and internal finishes works and only in conventional BQ procurement route, but that mechanical & electrical service items and proprietary items such as curtain walls are not measured in the indices. The price movements in private housing and private commercial subsectors are underrepresented and projects procured by the increasingly popular design and build methods are not measured at all in the TPI.

The CCIs, on the other hand, are generally based on listed prices which do not always reflect the actual transaction price. They continue to rely on the weighting set in the 1970s and the labour cost components are still based on the increasingly unrepresentative national wage agreements without any considerations of the possible substitution effects of long run productivity growth and change in labour composition.

Chapter 4 reviews the construction new orders series published by the then DTI up to 2009 and the successor of the series published by ONS. The DTI construction new orders series and construction new output series are found to track each other from 1958 up to about 1990 and since then the output series has been consistently higher than the new orders series. Having adopted a new method in 2010, ONS's construction new orders series were briefly more consistent with the output series. However, this leaves the revised historic construction new orders series before 1990 consistently higher than the corresponding output series. More worryingly, the "credibility gap" re-emerges in the recent data between 2010 and 2013, in which construction new output is again higher than the corresponding new orders.

On a more positive note, the errors in the BIS Output Price Indices for New Construction, which is shown as having understated inflation, have been corrected after the introduction of the new methodology.

Chapter 5 estimates a simple demand-and-supply model of construction new output (at constant prices) growth and deflated tender price index growth. Real GDP growth and 3 month average interbank lending rate changes are used as exogenous demand shifting factors, whereas deflated building material price index growth and the change in unemployment rate are used as exogenous supply shifting factors. Haynes and Stone's (1985) proposition that quantity be treated as demand determined and price be treated as supply determined is applied to the specifications of the model, and two stage least squares technique is applied to remove potential simultaneous equation bias. An economic theory driven and statistically significant model is reported in details in *table 5.3* and *table 5.4*. and is simplified as follows:

Demand: *Real Construction New Work Growth = - 0.37 x Deflated TPI Growth + other variables*

Supply: *Real Construction New Work Growth = 1.93 x Deflated TPI Growth + other variables*

The implication of this is that the price elasticity of supply is higher than the price elasticity of demand. The supply of construction new work is more sensitive to the change in tender price.

Having analysed appropriately 40 years of data for many European countries (including the UK and Germany), the time series, cross section, and panel data results in chapter 6 have all confirmed the belief that labour productivity in the construction industry has grown more slowly than in the whole economy or in the manufacturing sector. Expanding and applying Baumol's two sector unbalanced growth model, chapter 6 developed a model of inverse linking between the relative labour productivity and relative output price. The econometric analyses support the proposition that relative lower productivity growth in construction is correlated with higher relative output price in construction. Thus this chapter provides both correlation and theoretical explanation for this relationship.

The real output (i.e. output at constant prices) share of the construction industry has generally dropped in the countries studied in chapter 6 and this can be taken as a response to the increase in relative price given stable tastes and preferences. However, the nominal output (i.e. output at current market prices) share varies in opposite directions in different countries, reflecting the opposite effects of change in volumes and prices.

The UK case study in chapter 6 also confirms the input price of the construction industry has grown faster than the output price, which is consistent with the observation that productivity growth, despite being slower than average, is positive in UK construction.

7.2 Conclusion and Discussion

The compilation methods of the TPIs and CCIs were developed in the late 1960s or early 1970s and have been followed since. This thesis concludes that the TPIs published in Britain tend to overstate the inflation of the contract prices, because TPIs do not measure the inflation of the majority of the mechanical & electrical service items and proprietary items such as curtain walls, which are subject to higher productivity growth. Projects procured through design and build method that potentially provide bigger scope for the contractors to make savings and economise inputs, are also not measured in the TPIs. Moreover, quality of building performance such as energy efficiency and safety driven by building regulations tends to improve over time and the lack of measurement of the quality tends to overstate the rise in prices over time. In theory, the current expenditure weighting nature of TPI would tend to understate inflation but the effect would be limited by new items not being matched to the items in the dated schedule of rates.

The CCIs, with an infrequent revision of the base basket, suffer the general base basket index shortcoming of overstating inflation. The CCIs also are not designed to reflect response to productivity growth. Looking at the components, the least reliable would seem to be the labour cost components which has been consistently higher than other measures of labour cost published by ONS. These three factors – base basket weights, no reflection of response to productivity growth and the labour cost components of the CCIs – all tend to bias the indices upward.

The construction new orders series currently published by ONS is not consistent with the corresponding new output series, particularly in the private sector. Although ONS (2013c and 2013d) argue that new orders should not be used in forecasting the output, it seems unrealistic to expect users not to do so. The divergence poses a question of the accuracy of at least one of the series, most plausibly the new orders series. It is a worrying development that the tone and purpose of the consultation about the publication of the new orders series is to streamline, downsize, or completely remove their publication instead of on ways of improving its accuracy.

The tractable demand-and-supply model estimated in the thesis allows a better understanding of interaction of price and quantity through the demand and supply sides. For example, by knowing the impact of lowering interest rate on shifting the demand curve rightward, policymakers should expect the construction output and price to increase hand in hand in response to a reduction in interest rate.

The strong inverse relationship between relative labour productivity and relative output price in the construction industry confirms the importance of productivity as a long term driver of the output price. As construction outputs make a big contribution in investment in the economy, raising the productivity of the construction industry would lead via a lower price of the construction output to a higher amount of investment.

7.3 Hypotheses and Key Ideas

The following summarises and evaluates the key ideas and hypotheses proposed in chapter 1:

(a) Chapter 3 concludes that the main tender price indices (TPIs) published for the UK construction industry are transaction based indices capturing mainly the price movements of the traditional trades, and that the main BCI are list-based weighted input price indices within which the accuracy of the labour wage component is questionable;

(b) The construction new orders series and the construction new work output price index published by the then Department of Trade and Industry were not aligned with other comparable statistics. ONS has taken over the responsibility of publishing construction statistics recently and published these statistics compiled by their new method since 2010. Since these statistics are relevant to the understanding and modelling of construction price inflation, Chapter 4 scrutinises the new ONS construction statistics, and finds that there are significant doubts regarding the accuracy of the construction new orders but that the error in the construction new work output price index has been corrected.

(c) It is hypothesised that the TPIs are driven by demand side factors in the short run. This means that in the short run the observed relationship between price and output is primarily constrained by the law of supply (i.e. the slope of the short run supply curve). In graphical terms, the demand curve is shifting along the short run supply curve and the observations about price and output are mainly on one supply curve. Therefore most existing literature finds a positive correlation between construction output and price, but very little of that literature attempts to identify both supply and demand relationships. Chapter 5 manages to identify both the supply and demand relationship by making us of the theory driven specification proposed by Haynes and Stone (1985) and verified by the data driven VAR model proposed by Sims (1980).

(d) It is hypothesised that the TPIs are driven by supply side factors in the long run. In the long run, the more productive one industry is, the more abundant are its good and services. Competition holds prices down to just cover full economic costs. Therefore, in the long run, the relative price of a product is inversely related to the physical productivity of its industry. Chapter 6 uses the international data to confirm this hypothesis in construction and manufacturing industries.

(e) Chapter 6 also confirms the hypothesis that the trend rate of change of economy wide inflation (as measured by GDP deflator or Retail Price Index) is lower than that of construction output price inflation (measured by Tender Price Index or implied deflator), which in turn is lower than that of construction input price inflation (measured by Building Cost Index) in the long run, because the productivity growth of the economy as a whole is higher than that of the construction industry but the construction industry has positive productivity growth in the long run.

7.4 Limitations of the Study

This thesis relies heavily on empirical studies which are limited to some sub-sectors of the construction industry as well as countries. Therefore, one of the potential limitations is the applicability of the results to the sub-sectors and countries outside the scope of the data analysed.

Table 7.1 below summarises the subsectors of the construction industry and countries covered in the empirical studies in various chapters of this thesis.

<table>
<tr><th></th><th>Average Share in the output of UK Construction Industry, in Constant Prices, between 1980 and 2013</th><th>Chapter 3 Construction Cost and Price Indices in the UK</th><th>Chapter 4 The Inconsistency of the Construction Order and Output Statistics in the UK</th><th>Chapter 5 Structural Model for Construction Inflation and Output Growth</th><th>Chapter 6 Supply of Construction Output: Long Term Construction Price Inflation in the light of Physical Productivity Growth</th></tr>
<tr><td>Subsector</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>New Building
• public housing
• private housing
• public non-housing
• private industrial
• private commercial</td><td>53%</td><td>Tender Price Indices and Building Cost Indices are studied</td><td rowspan="2">Construction new orders and Output Price Indices are studied</td><td rowspan="2">Tender Price Indices and Output of New Work are studied</td><td rowspan="4">Construction Output Price Indices and Construction Output are studied</td></tr>
<tr><td>New Infrastructure</td><td>9%</td><td>✘</td></tr>
<tr><td>R&M Housing
• public housing
• private housing</td><td>19%</td><td>✘</td><td>✘</td><td>✘</td></tr>
<tr><td>R&M Non-housing
• Infrastructure
• public non-housing
• private non-housing</td><td>19%</td><td>✘</td><td>✘</td><td>✘</td></tr>
<tr><td>Countries</td><td></td><td>UK</td><td>UK</td><td>UK</td><td>UK, Germany and other European Countries</td></tr>
</table>

Table 7.1: Subsectors of Construction Industry and Countries Studied in the Thesis

Another major limitation is that despite the early parts of the thesis questioning the credibility of some published statistical series, the econometric analyses in the later parts of the thesis rely on the published data, for without it the econometric models cannot be built. The research in the early parts is used to choose the relatively more appropriate statistics in the national statistics or statistics derived from the national statistics. However, the accuracy and reliability of the data remain the key limitation and readers should bear that in mind when interpreting the results.

7.5 Recommendations for Further Study

With regard to tender price index compilation, this thesis recommends measuring the price movement of the M&E items and broadening the sample base to design and build contracts as two areas well worth pursuing to restore the representative nature of the indices. For design and build, acquiring access to the contract price information such as the contractor's contract cost plan and the possibility of using such cost information to produce TPI deserve further study. Because of the diversity of M&E items giving comparable performance, it is difficult to stretch the existing current match item index method to measure the price movement of the M&E items. Therefore, there is a need to depart from the presently adopted method and a hedonic index is an appealing alternative. Although the indices may become less consistent for long period analysis than the existing pure item matching method, this is a trade-off for improving the representativeness.

Looking at the components of the CCIs, the least reliable would seem to be the labour cost components and an in depth study is recommended with specific focus on the change in the composition and skill levels of the construction labour force.

This study suggests the private sector construction new orders series deserve closer examination with a view to explaining, and hopefully removing, , the *prima facie* inexplicable gap between the output and orders series. To avoid double counting, ONS currently samples only main contractors in the circa 230,000 construction units in IDBR for the construction new orders statistics, whereas for construction output statistics, they survey all contractors and deduct the amounts subcontracted to avoid double counting. Given the difficulty of ascertaining the proportion of specialist contractors obtaining work directly from clients, applying the same method that is used for sampling construction output to construction orders deserves further research.

The model presented in chapter 5 is supported by the result of the data driven vector autoregression (VAR) model except that out of the 10 pairs of relationships in the demand and supply model, the VAR model displays 2 pairs (output and unemployment, and tender price and building material price) as different from the demand and supply model. This study recommends including a measure of productivity, which is found important in driving long run relative construction output price, in the model. The model at present assumes linear relationship between growth of the economy and of the construction sector. However the Bon curve (Bon (1992), Pietroforte and Gregori (2006), Ruddock and Lopes (2006) and Strassmann (1970)) proposes a non-linear, bell-shaped, relationship in the long run.

For brevity the model does not allow a more elaborated autoregressive distributed lag structure, so the model is static. Extending and expanding the model to a dynamic system and making use of the demand and supply relationship as the long run driving force in the vector error correction autoregression framework would be a potentially rewarding next step of research.

Last but not least, inflation is a monetary phenomenon, so study of the transmission mechanism by which the central role of monetary policy affects the prices in different sectors of the economy is an overdue agenda item in the field of sectoral research.

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Appendix: Three Types of Price Indices

This section describes the three well-known methods of constructing price indices and their characteristics[58]. These methods can produce bilateral price index number of two periods. Multilateral price index number of many periods can be derived from these bilateral indices. The methods of constructing multilateral price indices from bilateral indices are covered later.

These three types of price indices are all the ratios of the weighted average of the prices in the reference period to the weighted average of the prices in the base period. The different ways to 'weight' the prices set them apart from each other.

1. Laspeyres Price Index

Laspeyres Price Index is a base weight index. The relative quantities of the base period provide the weighting for the respective prices. The following is the formula for calculating the Laspeyres Price Index

$$\frac{\sum_j p_{tj} \times q_{oj}}{\sum_j p_{oj} \times q_{oj}}$$

where p_{tj} is the price of the j^{th} good at time t (reference period); p_{0j} is the price of j^{th} good at time 0 (base period); q_{oj} is the quantity of the j^{th} good at time 0 (base period).

For example, one could construct the price index of 'cereals' comprising rice and wheat. In the base year, the economy produces 1,000kg of wheat and the price is £1/kg. It also produces 500kg of rice at £2/kg. In the reference year, the economy produces 1,000kg of wheat and the price is £3/kg. It also produces 1,000kg of rice at £3/kg. Setting the index at base year as 100, the Laspeyres price index of cereals in the reference year is

[58] For a survey on the index number theory, see Diewert (1987)

$$\frac{£3 \times 1000 + £3 \times 500}{£1 \times 1000 + £2 \times 500} \times 100 = 225$$

In the ideal case, the goods found in base period are matched with the exact goods found in the reference period. Therefore, Laspeyres index has a good control of the quality of the goods being indexed. However, it does not take into account the quantities in the reference period and people will tend to substitute a cheaper good for a more expensive one in case of a relative price change. In the example, as the price of rice has fallen relative to the price of wheat (from a rate of exchange of 1 kg of rice for 2 kg of wheat to a rate of 1 kg of rice to 1 kg of wheat), so consumers have switched towards consuming relatively more rice (from half as much rice as wheat to equal quantities). As a result, Laspeyres index is often criticised as subject to substitution bias (failure to capture substitution effects) which overstates the inflation.

2. Paasche Price Index

Paasche Price Index is a current weight index and its generic formula is as follows:

$$\frac{\sum_j p_{tj} \times q_{tj}}{\sum_j p_{oj} \times q_{tj}}$$

The only new notation is q_{tj} which stands for the quantity of the j^{th} good at time t (reference period).

This is more suitable for deflating output than the Laspeyres index as the current outputs are used as the weightings. However it is criticised as understating the inflation as it does not reflect the choice of goods under the base period prices.

The Paasche Price Index of the rice and wheat example is as follows:

$$\frac{£3 \times 1000 + £3 \times 1000}{£1 \times 1000 + £2 \times 1000} \times 100 = 200$$

3. Fisher Ideal Index

If one index tends to overstate inflation and the other tends to understate inflation, it is natural to take the average of them as a better approximation to the true measure of inflation (Fisher 1921). Irving Fisher exactly suggested this and dubbed it the "best form of index number". The formula of it is as follows:

$$\sqrt{\frac{\sum_j p_{tj} \times q_{oj}}{\sum_j p_{oj} \times q_{oj}} \times \frac{\sum_j p_{tj} \times q_{tj}}{\sum_j p_{oj} \times q_{tj}}}$$

It, in theory, should be a better measure of the true inflation. However, the advantage comes with a cost because it requires the information of quantities at both base and reference periods.

The Fisher Ideal Index of the rice and wheat example is as follows:

$$\sqrt{\frac{£3 \times 1000 + £3 \times 500}{£1 \times 1000 + £2 \times 500} \times 100 \times \frac{£3 \times 1000 + £3 \times 500}{£1 \times 1000 + £2 \times 500} \times 100} = 212$$

All these three methods assume complete price and quantity data for all goods are available. However, in reality new goods enter the market and old goods drop out. Certainty it is less than straightforward to ascertain how much a laptop computer should be priced at in 1900 as well as how much a Ford Model T should be in 2014.