Inflation Shopping: How Transport Infrastructure Project Cost Evaluation Is Affected by Choice of Inflation Index

Paul Chapman[1]*

Abstract

Transport infrastructure projects typically take a number of years to complete and there is a strong case for adjusting 'nominal costs' incurred in different years to 'real costs' in base year prices by using an inflation index. The literature on the funding and financing of transport infrastructure projects and investment in public works addresses the choice of inflation index as a metaphorical footnote on the treatment of costs incurred in different years. This article gives deeper consideration to this issue and identifies the substantial effect the choice of inflation index has on ex-post cost evaluation. 'Inflation shopping' can occur when there are alternative inflation indices to choose between, and where the choice of inflation index has a substantive effect on the outcome of ex-post cost evaluation and the allocation of inflation risk between parties. Data from Crossrail, a large rail scheme in London, is used to illustrate the effect of the choice of alternative inflation indices on ex-post cost evaluation outcomes.

Keywords

Transport infrastructure, Ex-post cost evaluation, Inflation, Inflation index

[1]*Senior Fellow, Saïd Business School, University of Oxford, Oxford, United Kingdom, paul.chapman@sbs.ox.ac.uk (Corresponding Author)

Introduction

Major projects cost a lot of money and take a long time to be delivered into operation. That is, these projects typically cost billions of US Dollars and their timespan between conception and delivery of the asset into operation frequently takes 10+ years. Infrastructure projects are the various subordinate, foundational and not unusually substantial undertakings needed for the operation of society and enterprise. These may be physical, such as energy production and power supply, buildings, roads and railways, telecommunications, etc., and can be a combination of physical and social factors such as education, healthcare and commercial. Of note to funders, policy makers, company Boards and project sponsors is the reported tendency for these large projects to experience cost and schedule overruns, and quality and benefits shortfalls (Flyvbjerg, 2014; Merrow and Yarossi, 1990; Merrow et al., 1988; Miller and Lessard, 2001). This paper focuses on a subset of infrastructure projects, so called "megaprojects", that is infrastructure projects for the transportation of people and/or goods (Priemus and Wee, 2013, p. 1).

Focus of the Research

This research examines the question: What effect does the choice between alternative inflation indices have on a project's delivery cost performance?

To delimit this study's focus, this work excludes other factors considered when undertaking ex-post cost analysis such as adjusting for the effect of working across national boundaries, eg, accounting for currency fluctuations and purchasing parity, and does not seek to assess value for money or conduct retrospective cost-benefit analysis. This work is also not ex-ante, ie, forward looking, where forecasted scheme costs and benefits would be subjected to discounting to reflect preferences for current consumption over future consumption and taking into account the opportunity cost of capital.

This article is structured by first considering the literature on transport infrastructure project delivery cost performance, then the role of ex-post evaluation of infrastructure project cost. This is followed by a review of how costs incurred in different years are dealt with, an examination of the use of inflation indices to adjust costs to a constant year basis and an assessment of a selection of relevant indices. The article concludes with a worked example of the effect that different inflation indices have on calculating total cost in real prices, using nominal cost data from 'Crossrail', a large, complex transport infrastructure project to deliver a new railway under London.

Transport Infrastructure Project Delivery Cost Performance

The nature and causes of project cost overruns continues to enjoy lively debate (Flyvbjerg et al., 2019; Love et al., 2019), and as a topic has been well explored, for example (Cavalieri et al., 2019; Holweg and Maylor, 2018). Despite this interest, a consensus on causes of poor performance remains elusive where Denicol et al. (2020) review of this literature identified 18 categories of causes and Chapman and Quang (2021) identify a schism between proponents who attribute poor project performance to one or other of two main causes, either: systematic errors in estimates at the project planning stage as a result of the decision-making heuristics and biases ascribed to the 'inside view', or; complexity manifesting during delivery of a project. Love and Ika (2021) present their summary of the state of knowledge, stating: "Despite the plethora of studies examining the cost performance of transport projects, we still do not *fully* understand why they exceed their agreed price for construction". Understanding the nature of project cost overruns is not assisted by methodological opacity where it proves difficult to assess the merits of much research, highlighting the need for consistent and reliable ex-post assessments of cost, and for authors to be transparent by listing the projects included in their studies to allow others to reproduce them independently, one of the key tenets of scientific enquiry.

Ex-Post Cost Evaluation of Infrastructure Projects

To provide for more consistent and reliable ex-post assessments of cost, measuring project delivery cost performance involves comparing the outturn performance of a project relative to the objectives set out in the final business case, against which the final decision was made to commit investment to the project (Pellegrinelli et al., 2007). Taking this baseline of estimation of costs at the time of decision to build has been described as, "the international standard for calculating cost development." (Flyvbjerg, 2007, p. 13) that is, "followed by academics, governments, and national audit offices around the world." (Flyvbjerg et al., 2019, p. 410).

Evaluating the financial performance of a project delivered over a series of years faces the challenge that general prices change over time, typically by increasing as a result of inflation. To provide an accurate picture of an infrastructure project's costs incurred in different years requires them to be considered as if prices had remained constant. This means that nominal costs in current year prices should be adjusted for cost changes over time, ie, inflation or deflation, to provide a figure for cost on a constant, or "real" basis.

There is general support for this approach, for example (Belli, 2001) notes that, "changes in the general price level that shift all prices up by the same proportion do not affect the comparison of a project's costs and benefits". This general position is employed in the assessment of capital projects, with costs measured at "constant prices, and against a consistent baseline" (Flyvbjerg et al., 2018). This convention applies in practice, as per guidance from the US Government Accountability Office, where, "The base year is used as a constant dollar reference point to track programme cost growth. Expressing an estimate in base year dollars removes the effects of economic inflation and allows for comparing separate estimates "apples to apples." Thus, a global ground rule is to define the base year dollars that the estimate will be presented in and the inflation index that will be used to convert the base year costs into then-year dollars that include inflation." (GAO, 2009, p. 81) This is also the case in the public sector in the United Kingdom, where, "The [UK Government Treasury] Green Book … requires that the valuation of costs and benefits to be expressed in "real terms", i.e. to remove the effects of future inflation in the analysis of impacts. For this reason, valuations and monetary impacts should be expressed to a consistent price base." (DfT, 2018b, p. 12).

Adjusting 'Nominal Costs' Into 'Real Costs' Using an Inflation Index

Having established the principle of the need to adjust in-year 'nominal' costs to 'real' costs in a consistent base year, a suitable deflator is required. One of the main uses of price indices is as a deflator to express financial data in real terms (Johnson, 2015, p. 28) and the normal means of adjusting nominal costs incurred on an infrastructure project is by using an index Royal Institution of Chartered Surveyors (n.d.).

There are a number of indices available, including those that measure changes in the general price level in an economy and those that measure changes to the prices of goods and services in particular sectors, which are discussed below.

Indices that measure changes in the general price level

The change in prices in the general economy can be measured in terms of changes in the size of a country's economy and also to prices of a particular sample of goods. As the US Dept for Commerce, Bureau for Economic Analysis notes, "The gross domestic product price index measures changes in prices paid for goods and services" while the, "personal consumption expenditures price index, or PCE price index, is a narrower measure. It looks at the changing prices of goods and services purchased by consumers" (U.S. Bureau of Economic Analysis (BEA) 2019).

There are examples for both approaches being employed to adjusting in-year capital expenditure where the World Bank is ambivalent on which index to use when calculating constant-price costs, noting that current price costs can be, "… converted to constant price terms in the project start year with the actual country CPI or GDP deflator for the implementation period." (Bacon et al., 1996, p. 85). In practice there seems greater use of an 'all economy' measure such as GDP rather than an index of consumer prices. A 'GDP deflator' can be used as a measure of general inflation and "is usually expressed in terms of an index, i.e. a time series of index numbers" (HM Treasury, 2014) that is calculated using a seasonally adjusted GDP series and indexed to a base year.

Examples of the use of general price indices include a study for the US Department of Transportation, Urban Mass Transportation Administration, Pickrell (1989, Pg33) which compares forecast and actual capital outlays in constant prices by converting nominal costs, "to the 1988-dollar equivalent … using the change in the economy-wide general price level [% increase in GNP] that occurred between the forecast year and 1988." In the United Kingdom the Department for Transport, "uses [UK Government Treasury] GDP deflator, which is a much broader price index than consumer price indices (like CPI, RPI or RPIX) as it reflects the prices of all domestically produced goods and services in the economy." (DfT, 2018a, p. 6).

An understanding of the basis on which a consumer price index is calculated is however useful, where these are, "derived from a fixed and supposedly representative basket of goods and services provided in the domestic market to measure a cost-of-living index" (Dabalen et al., 2016). The 'representative basket' is updated periodically to reflect consumer trends and will typically target a discreet section of society, for example households between the 70th and 90th percentiles of the income distribution, rather than attempting to accommodate a span across the extremes of the lives of the super rich or those in poverty. The underlying population may also be representative of or skewed towards a particular demographic, such as an urban population rather than a rural one.

Indices that measure changes in sector specific prices

Key points to take from the measurement of general price levels are that the relevance and performance of an index is highly influenced by the implied demographic, whether consciously targeted or not, and the content of the 'basket of goods' used as a reference. Both points are useful to note when considering indices that measure changes in sector specific prices.

Demographic groups

Different demographic groups will have general profiles in the goods and services they purchase, which presents the likelihood that cost growth of that overall profile will differ from a general measure and also between demographic groups. A similar difference has the potential to exist in an industrial context where the profile of spend on types of transport infrastructure project will be different to the profile of spend for a country at large. This means there is likely to be a difference between changes in prices experienced on a transport infrastructure project and those changes to the overall economy as measured by GDP.

Recognition of this has led to the adoption of indices that more closely reflect the inputs of transport infrastructure projects, as per guidance from the UK Department for Transport, DfT, which advises, "Analysts should consider current and forecast inflation from industry sources appropriate for their scheme." (DfT, 2017, p. 2). The Department for Transport (DfT, 2017, p. 19) goes on to recommend that in addition to general inflation, real increases in relevant costs should be taken into account. While that particular guidance relates to ex-ante cost forecasting it is the general principle of taking sector specific inflation into account that is relevant here. The Department for Transport provides a worked example, replicated below, to illustrate this.

Table A1 components of investment costs (£million)

Calendar Year	Construction Costs	Land Costs	Other Costs	Total
2016	7.9	5	1.5	14.4

Table A1 components of investment costs (£million)				
Calendar Year	**Construction Costs**	**Land Costs**	**Other Costs**	**Total**
2017	6.7	0	2.5	9.2

"General inflation is assumed to be 2.5% per year, while construction costs are forecast to increase by 3% until 2016 and 5% in 2017. Therefore the base investment costs, including real cost increases, can be calculated by:

In 2016 - £14.4 m (initial estimate) x (1.03/1.025) (the real cost adjustment) = £14.54 m the contribution of real cost increases is £0.14 m (£14.54 m - £14.4 m)

In 2017 - £9.2 m (initial estimate) x (1.03/1.025) x (1.05/1.025) (the real cost adjustment) = £9.52 m the contribution of real cost increases is £0.32 m (£9.52 m - £9.2 m)" source: DfT (2017, p. 19)

Further examples of deflating nominal costs to real costs using indices that track changes in sector specific prices include the US Federal Transit Administration which assesses project costs in their mandated in law 'Before-and-After studies', for example ('Mid-Jordan Light Rail Project; U.S. Department of Transportation, 2016'). These contain an evaluation of capital cost in year-of-expenditure (YOE) dollars and also on a constant basis by deflating using an inflation in construction costs index.

In the Netherlands, Statistics Netherlands produces an input price index for civil engineering inputs (in Dutch: Grond-, Weg- en Waterbouw (GWW)) Statistics Netherlands (n.d.), which is subdivided into separate indices for transport infrastructure input prices, including: roads; overhead and underground railways, and; bridges and tunnels. These indices are recommended by the Kennisinstituut voor Mobiliteitsbeleid (Institute for Transport Policy Analyses, part of the Ministry of Infrastructure and the Environment) for use on indexing rail projects and road projects (Cantarelli, 2011, p. 88).

Guidance in Sweden is to use an index related to relevant production input costs, eg, road construction index E84, to adjust the cost of investment in transport infrastructure into a base year (Trafikverket, 2020).

Baskets of goods

Another lesson to take from work to calculate general price changes is that the choice of the 'basket of goods' against which price changes are recorded is fundamental in understanding the appropriateness of an index. Neither the 'basket of goods' that consumers purchase nor the 'whole economy' measured by GDP will be representative of the inputs to a transport infrastructure project. Some sector specific projects will have a particular mix of inputs, and where these inputs experience distinct patterns of price change then indices that measure these changes can and have been developed in response. "Because all inflation indexes measure the average rate of inflation for a particular market basket of goods, the objective in making a choice is to select the one whose market basket most closely matches the programme to be estimated." (GAO, 2009, p. 103)

This is not a new observation and examples of sector specific indices include the Engineering News-Record 'Construction Cost Index' first calculated in 1908. This is based on a 'basket of goods' comprising, "200 hours of common labour at the 20-city average of common labour rates, plus 25 cwt of standard structural steel shapes at the mill price prior to 1996 and the fabricated 20-city price from 1996, plus 1.128 tons of Portland cement at the 20-city price, plus 1 088 board-ft of 2×4 lumber at the 20-city price." (ENR, 2021). While this is a simple basket, it seems to have stood the test of time for general construction. This has been used to deflate US rail transit costs, where for example, "annual construction out-lays were converted to 1983 dollars using changes from the year in which they were incurred to 1983 in construction cost indices for individual US urban areas reported in Engineering News Record" (Pickrell, 1985)

Indices that measure changes in prices of particular projects

"The specification of the deflator should match the output it is being used to deflate. For example, the change in prices at restaurants should be used to deflate spending in restaurants." (Johnson, 2015) pg30. Likewise for infrastructure projects, where, "A consideration of the most appropriate index should be undertaken, for example a civil engineering tender price index is more appropriate than a general building price index for normalising infrastructure projects as the data informing the tender price index are more directly relevant to the work being assessed" (Infrastructure and Projects Authority, 2019). A sector can also experience its own particular price changes, for example as a result of specialist inputs and the goods and services that make up their particular 'basket of inputs', for example in defence (Ministry of Defence, 2017).

Where there are 'typical' inputs, a degree of consistency over time and a level of scale that commands interest then indices can and have been created and calculated. Examples of this include:

- Military construction projects in the USA, where the Military Construction Programme (MCP) Index ('Army Facilities Pricing Guide, 2015) provides an annual Cost Escalation Factor.
- Water resource projects in the USA, where the US Department of Agriculture provides data on a series of price indices (Prices and Indexes | NRCS (n.d))
- US military shipbuilding, where the US Navy budgets on the basis of "what the Navy believes are more realistic inflation indices." (GAO, 2005, p. 25)
- US transportation and water infrastructure, where the US Congressional Budget Office uses "price indexes created by the Bureau of Economic Analysis that track government expenditures and investment [that] measures the prices of materials and other inputs used by state and local governments" (Congressional Budget Office, 2018)
- Highway construction costs in the USA. The National Highway Construction Cost Index (NHCCI) is a price index published quarterly by the Federal Highways Administration that measure average changes in prices. The source data and the detail of the methodology used to calculate the index is published on-line (Federal Highway Administration, 2019), where the index is based on data from winning bids submitted on highway construction contracts and therefore captures the prices for material, labour, and services across a representative range of purchased construction inputs.

This latter example is interesting as it moves away from being based on a pre-determined basket of goods and instead is based on winning bids and therefore reflects the actual mix of goods and services procured. This enables the index to dynamically reflect the spend profile of the sector however does introduce methodological issues around ensuring consistency and whether it is indeed measuring price changes and not inadvertently tracking other factors such as a shift in spend profile.

These examples point to there being merit in tracking general price changes in a particular sector, and using an index based on a representative profile of goods and services purchased by archetypal projects.

Support for using an index that tracks price changes in representative goods and services is however not universal. For example the Office of Road and Rail, the UK rail regulator advised the Secretary of State for Transport on the financial framework for Network Rail, the organisation that owns and operates the railway infrastructure in England, Wales and Scotland that Network Rail, "should not be provided with any protection from input prices either through specific adjustments to our efficiency assumption or by indexing capex to a specific inflation index such as the infrastructure output price index (IOPI)". (Office of Rail and Road, 2012). Instead funding for Network Rail is indexed against consumer prices.

Inflation Index Shopping

The availability of alternative indices presents the risk that, "users may seek the rate of inflation that gives the right number, rather than the appropriate measure" (Johnson, 2015, p. 10). This is no idle concern, where even in a setting where standards of Integrity and Objectivity (Cabinet Office, 2019) apply and, "using inflation indices fairly" (Economic Affairs Committee, 2019) should be a given, there is unease that, "different measures of inflation allow a government to engage in 'inflation shopping'" (Economic Affairs Committee, 2019, p. 40).

The effect of inflation shopping in a transport infrastructure context is illustrated in the following 'case study'. This worked example uses data from an actual transport infrastructure project and employs a range of indices to adjust nominal, in-year costs to a constant basis. In doing so it illustrates the effect of the choice of inflation index, and the implication of doing so on cost evaluation, particularly the affect this has on determining the 'success' of the project, ie, whether actual cost exceeded the estimated cost.

Crossrail: How Choice of Inflation Index Affects Adjustment of Nominal Costs Into Real Costs

Responding to the question, "are you genuinely interested in the best way to measure price change? Or are you... inflation shopping?" (Greeley, 2019), the effect of the choice of a range of inflation indices is explored in an infrastructure context in a worked example using data from the 'Crossrail' transport infrastructure project.

Crossrail is a large, complex transport infrastructure project to deliver a new railway under London, 73 miles (118 km) long with stops at more than 40 stations, including 10 new stations and 26 miles (42 km) of new tunnels. The project cost was estimated at £14.8bn (2005 prices; £13.9bn + $0.9bn contingency)[[1]]. Despite reports of good progress, the project hit a crisis in 2018 and appeared close to exceeding its budget, which was subsequently revised to £17.6bn (nominal cost). While the Crossrail project is not complete and a final cost not yet available, the available data is useful to bring realism to this worked example.

[1]Crossrail (Elizabeth Line) Briefing Paper. House of Commons Library. pg20

Data on nominal expenditure over a ten year period, 2008/09 to 2017/18, was sourced from a report produced by the UK Parliament library. Data on price changes over this period were sourced from indices published by the UK Office of National Statistics and the former government Department for Business, Innovation & Skills, details listed in Appendix A.

As can be observed from Figure 1, measurement of UK price changes over the period 2008/09 to 2017/18 varied depending on index, reflecting differing rates of price change in their respective baskets of goods and services. These indices were used to adjust nominal expenditure to real expenditure incurred from 2008/09 to 2017/18. A description of how nominal expenditure was adjusted to real expenditure is provided in Appendix B. Table 1 presents this data, starting with this expenditure in nominal prices shown in columns 2 and 3. Subsequent columns show this nominal, in-year expenditure adjusted using a variety of indices to 2005 prices so they are presented in a constant, or "real" basis.

Discussion

The bottom row of Table 1 shows cumulative expenditure adjusted using various indices being between £9.66bn and £12.51bn, a range of £2.85bn. For example, adjusting for "infrastructure" inflation to 2005 prices, expenditure on Crossrail is 22% lower than when totaling nominal, in year expenditure. Another observation is that adjusting overall cost to constant prices using (i) the infrastructure index, ie, £9.66bn, and (ii) the 'standard' index of GDP at 2%, i.e. £10.55bn, results in a difference of £0.89bn, or 9.2%. An immediate implication of this analysis is to illustrate the effect the choice of inflation index has on the apparent cost of a transport infrastructure project.

A practical implication of this analysis is to consider cumulative expenditure against the agreed budget for a project. Crossrail had been provided with a £14.8bn funding envelope, and as of 2017/18 nominal expenditure had reached £12.51bn so the budget appeared close to being

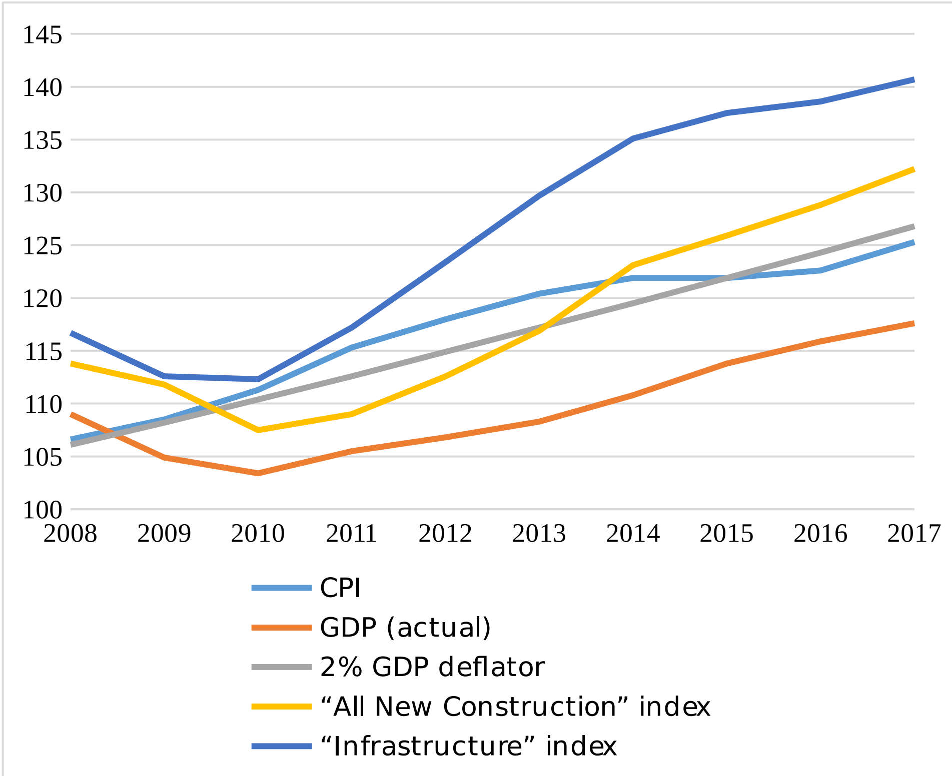

Figure 1 UK Price Changes 2008/09 to 20017/18, as measured by various indices (2005=100).

exceeded. Expenditure expressed in real terms, in 2005 prices, is shown in Table 2.

When expressed in real terms Crossrail's financial situation was much less challenging. Using the 2% GDP deflator, cumulative expenditure would have reached 71.2% of the budget while using the infrastructure index to adjust nominal expenditure 65.3% of the budget would have been spent, which was far from problematic.

As the Crossrail example illustrates, the budget for a transport infrastructure project is subject to inflation risk, which is the risk that price changes in actual inputs are different to price changes in the basket of goods and services tracked by the particular inflation index used to adjust the project's nominal expenditure to express this in real terms. Figure 1 showed that for the period 2005 to 2017/18 the largest price change was in the Infrastructure Index, and the greatest difference between the indices selected was between the Infrastructure Index and GDP. The significance of this latter point for transport infrastructure projects is that broadly speaking funding for transport infrastructure is generally from taxpayers, via the finance ministry where changes to tax revenue, and therefore available funding, tends to follow GDP. Changes in the cost of inputs to an infrastructure tends to track the Infrastructure Index, which can be seen to deviate significantly from GDP therefore creating a financial disparity. As the Crossrail project illustrates, this inflation risk can account for a significant percentage of a project's budget and many hundreds of millions of pounds.

How inflation shopping can be used to allocate inflation risk

Having identified inflation risk as a significant issue, inflation shopping provides the means to allocate where inflation risk is held. A way to determine this allocation is by using the 'five case' business model guidance from the UK's finance ministry, which "provides a universal thinking framework that if understood and applied correctly accommodates the widely varied features of any investment or spending proposal." (HM Treasury,

Table 1 Crossrail expenditure, variously adjusted (British Pounds, billions)

1

Index:	Expenditure[2]		Indices									
			"CPI"		GDP (actual)		GDP (2%)		"All New Construction" index		"Infrastructure" index	
Base year:	**Nominal £bn**		**£bn (2005)**		**£bn (2005)**		**£bn (2005)**		**£bn (2005)**		**£bn (2005)**	
	In Year	**Total**	**In year**	**Total**	**In year**	**Total**	**In year**	**Total**	**In year**	**Total**	**In year**	**Total**
2008/09	0.20	0.20	0.19	0.19	0.18	0.18	0.19	0.19	0.18	0.18	0.17	0.17
2009/10	[3] 0.96	1.16	0.88	1.07	0.92	1.10	0.89	1.08	0.86	1.03	0.85	1.02
2010/11	0.72	1.88	0.65	1.72	0.70	1.79	0.65	1.73	0.67	1.70	0.64	1.67
2011/12	1.04	2.93	0.90	2.62	0.99	2.78	0.92	2.65	0.95	2.66	0.89	2.55
2012/13	1.51	4.43	1.28	3.90	1.41	4.19	1.31	3.97	1.34	4.00	1.22	3.78
2013/14	1.58	6.01	1.31	5.21	1.46	5.65	1.35	5.31	1.35	5.35	1.22	4.99
2014/15	1.58	7.65	1.30	6.51	1.43	7.08	1.32	6.64	1.28	6.63	1.17	6.16
2015/16	1.60	9.25	1.31	7.82	1.41	8.49	1.31	7.95	1.27	7.91	1.16	7.33
2016/17	1.64	10.89	1.34	9.16	1.42	9.90	1.32	9.27	1.27	9.18	1.18	8.51
2017/18	1.62	**12.51**	1.29	**10.45**	1.38	**11.28**	1.28	**10.55**	1.23	**10.40**	1.15	**9.66**

[1] Crossrail (Elizabeth Line) Briefing Paper. House of Commons Library. pg23.

Table 2 Crossrail expenditure, variously adjusted, against £14.8bn (2005) funding envelope

Index:	Nominal Expenditure	Indices				
		CPI	GDP (actual)	GDP deflator (2%)	"All New Construction" index	"Infrastructure" index
Base year:	In year	2005	2005	2005	2005	2005
2017/18 total	£12.51bn	£10.45 bn	£11.28 bn	£10.55 bn	£10.40 bn	£9.66 bn
% of funding agreement	84.5%	70.6%	76.2%	71.2%	70.3%	65.3%

2018). The five case business model consists of the strategic case that sets out the rationale for the investment, which is accompanied by four other cases for change which are more directly related to risk management:

- Economic case, including establishing what are the risks and their costs, and how are they best managed
- Commercial case, including establishing who will manage which risks
- Financial case, which covers affordability, taking into account all financial costs
- Management case, which includes management of resources required for delivery, arrangements for managing budgets and managing the project's risk register and plans for risk management.

The financial case sets out how the project will be funded, which in Crossrail's case is a mix of the taxpayer via national government, local businesses via local government sources, and borrowing against future revenues. Taxpayer revenues tend to change in line with GDP, income via local businesses is a mix of business rates which change in line with CPI and the London Mayor's Infrastructure Levy which changes in line with a construction index and future revenue is regulated to change in line with CPI.

The economic case sets out the project's budget, which is then managed under the terms set out in the management case. The management team therefore need to determine how their project's budget will be converted from nominal costs to real costs, in a set base year, over its duration. The management team also needs to agree the project's commercial case which includes the terms for letting contracts with organisations in their supply chain and establishing where inflation risk is allocated.

The main options for where to allocate inflation risk are: (i) the funder, in this case the combination of London's Mayor and HM Treasury, the UK's finance ministry; (ii) the project's delivery agency / management team, in this case Crossrail Ltd., and; (iii) the contractors / suppliers who provide the inputs to the project. Allocation of inflation risk is achieved through inflation shopping, ie, selecting the basis for price changes, in (a) the financial case, where for simplicity government revenue is assumed to track GDP; (b) the economic case, specifically the project's budget. Several options exist on how to accommodate price changes, including: allowing no price changes; to approximate long term GDP changes by using the 2% GDP deflator; to use a sector specific index, or; to allow the free flow of actual price changes at market rates, and; (c) the Commercial case, where contract pricing with suppliers is agreed. These contractual terms include provision for pricing on a firm, fixed or 'time and materials' basis. Firm pricing is a total, all inclusive price that will not change, so the contractor holds the inflation risk. It is common for a contractor to consider inflation risk when agreeing a firm price, so a firm price typically includes the supplier's expectation for changes in input prices over the contract duration. Fixed pricing is a total, all inclusive price that can change using an agreed mechanism so allows parties to allocate inflation risk by agreeing which index to use to adjust prices over the duration of the contract. This choice of inflation index is therefore critical in determining where inflation risk is held. A 'time and materials' contract flows

Table 3 Various Options for Inflation Shopping to Allocate Inflation Risk between Principal Parties

	Basis for price changes				
	A	**B**	**C**	**D**	**E**
Financial case: project funding, eg, Taxpayer via finance ministry	GDP (actual)	GDP (actual)	GDP (actual)	GDP (actual)	GDP (actual)
Economic case: project budget, owned by management team	Firm budget, no changes	Fixed budget plus 2% (GDP deflator) increase	Fixed budget plus 2% (GDP deflator) increase	Fixed budget plus sector specific index increase	Variable budget based on time and materials
Commercial case: Agreed contract pricing with suppliers	Firm price contract, no changes	Fixed price plus 2% (GDP deflator) increase	Fixed budget plus sector specific index increase	Fixed budget plus sector specific index increase	Variable pricing based on time and materials
Allocation of inflation risk	Suppliers hold all inflation risk	Suppliers hold inflation risk above 2% on inputs	Management team holds inflation risk on inputs above 2%	Funder holds most inflation risk.	Funder holds all inflation risk.

materials and subcontracted services costs directly to the client.

A range of choices exist for how to assemble the various options by which changes to a project's funding, budget and contract pricing is accommodated within the five case business model. A selection of principal options are presented in Table 3.

Option A does not transfer price changes that occur in project inputs during the project's delivery. This means the suppliers hold all the inflation risk. As the funder's income is likely to vary with GDP, which typically rises, the effect is that suppliers subsidise the project's cost, although it is likely that suppliers will have costed the inflation risk and priced accordingly at the outset, adding an allowance for contingency.

Option B links the project budget to an approximation for GDP, the 2% GDP deflator, with a 'back to back' agreement to increase supplier pricing by 2% per annum. This means suppliers hold inflation risk on price changes above 2% on their inputs, which as shown in Figure 1, appeared to be the case throughout much of the time Crossrail was delivered. The funder bears inflation risk where actual GDP differs from 2%, which was the case in the UK over this period.

Option C links the project budget to an approximation for GDP, the 2% GDP deflator, and supplier pricing changes in line with an approximation for changes in their input costs, the Infrastructure Index. Here suppliers hold no inflation risk, unless their inputs differ significantly from those tracked by the Infrastructure Index. Price changes pass to the management team, who hold the inflation risk on price changes to inputs above 2%, which was the case in the UK over this period. Like with option B, the funder has to bear inflation risk where actual GDP differs from 2%, which was the case over this period.

Options D and E are variations on a 'back to back' arrangement where changes in suppliers' input prices are transferred via the management team to the funder, who holds all / the vast majority of the inflation risk

Conclusion

Returning to the research question posed at the start of this paper, 'What effect does the choice between alternative inflation indices have on a project's delivery cost performance?' The work presented in this paper shows there is strong support in the literature and from industrial practice for assessing transport infrastructure project cost performance on a real basis by adjusting nominal spend to a base year. The choice of inflation index is however less defined, though the consensus is that this choice should be appropriate for the sector and match the profile of inputs to the project.

Using the data from Crossrail for illustrative purposes, this analysis demonstrates how the choice of index used to adjust a multi-year transport infrastructure project's cost to a constant year / real basis has a substantial effect. This includes dramatically shaping the conclusion that is drawn about a transport infrastructure project's financial 'success', ie, whether its outturn cost was on or below its forecasted cost.

This work also illustrates there are a variety of options for inflation shopping that results in or allows for inflation risk to be allocated between parties.

Overall this work demonstrates that 'inflation shopping' when making the choice of index has a sizable effect on ex-post cost evaluation of a transport infrastructure project. This highlights the importance of making the decision on which index to choose in an objective, open and accountable manner such as being based on an independent assessment of the options, free from conflicts of interest. It is also highly recommended that the specific index used to make the adjustment is clearly stated when presenting cost performance data.

Further Work

From the research presented in this paper it is clear there are a variety of options on which inflation index could be selected, and therefore the potential for 'inflation shopping' is very real so the basis on which the choice of inflation index is made in practice warrants investigation.

While this research has focused on ex-post evaluation, there is the need to 'look back to look forward' when ex-ante forecasting the budget for a transport infrastructure project in order to adjust forecasts for systematic errors of judgement (biases). This requires taking an 'outside view' based on the delivery performance of a reference class of similar projects, where creating a reference class requires ex-post analysis of previous projects (Kahneman and Tversky, 1977; Lovallo and Kahneman, 2003). Adjusting the outturn cost so it can be compared relative to the forecasted cost requires the use of an inflation index where, as this paper demonstrates, the choice of inflation index has a material effect on project cost evaluation and therefore the conclusions drawn.

The effect of the choice of adjustment index therefore has serious implications for researchers. This has a significant impact on the important task of ex-post analysis when evaluating whether a project has been 'successful' as measured in terms of its outturn / actual cost relative to its budgeted cost. This finding has a significant implication for researchers and others that seek to determine the performance of a 'reference class' of projects. As demonstrated here, an apparently innocuous and small difference that results from using one index rather than another has a significant effect on the result, particularly as this error increases with both project duration and when various projects all have their data normalised to a single, common base year. In this latter case the base year chosen could be 20 or more years from the nominal year which means even small errors will make a material difference. It is therefore recommended that further work is undertaken to understand how inflation has been considered when undertaking reference class forecasting and in large-scale empirical studies of project cost performance, and what effect the choice of inflation index had on the conclusions these studies draw on reference class and population level project cost performance.

It would be more than ironic to find that efforts that seek to address one set of biases (optimism, etc) have been skewed by another systematic error.

Development and use of a customised, dynamic inflation index

The importance of accurately assessing project performance data is robustly made by Merrow and Yarossi (1990) who, "believe that little progress can be expected in the state of our knowledge of projects without systematic and very detailed data collection … Otherwise the results are not meaningful." (Merrow and Yarossi, 1990, p. 6.2). One implication is that even a sector specific index based on an approximately representative basket of goods and services may not support the degree of systematic and detailed data collection Merrow and Yarossi advocate when adjusting nominal costs incurred in different years across the duration of projects. The profile of inputs on a particular transport infrastructure project will be specific to it and may deviate significantly from even a sector specific index that tracks an approximately representative set of inputs, which means that price changes should be tracked against a price index made up of a suitably weighted basket of these inputs, i.e. it needs to be tailored. A customised index of this nature could employ specific indices for major groups of inputs, ie, particular commodities; specialist labour; rents; etc., with these inputs weighted according to actual spend, while using an overall sector index for residual spend.

It is also the case that a transport infrastructure project transitions through lifecycle phases, each with very different inputs, from design, where the inputs are mostly professional services, through to build where this could begin mostly as a ‘civil engineering’ project then morph into a ‘construction project’ before becoming a ‘mechanical/electrical engineering’ project and then finally an ‘IT project’ before being finally commissioned into service. The spend profile will substantially alter from one phase to the next which means that not only is it necessary to create a customised index for the project, but this index should be amended periodically to reflect the prevailing spend profile. Given this would be non-standard, attention will be required to ensure the basis for the index and its data sources are peer-reviewed and externally validated to verify its suitability and integrity.

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Appendix A. Indices and data sources

Consumer Prices Index (CPI) time series is sourced from the UK Office for National Statistics, Series ID: D7BT

Actual **Gross Domestic Product (GDP**) time series is sourced from the UK Office for National Statistics, Series ID: IHYQ

Nominal GDP at 2% time series was calculated using a simplified annual compound interest formula: Actual= Principal * (1+ inflation rate) with 2005=100 and inflation at 2% across the term.

"All New Construction" and "Infrastructure" indices were sourced from the UK government Department for Business, Innovation and Skills" (BIS), replaced by the Department for Business, Energy and Industrial Strategy in 2016, and the UK Office for National Statistics (ONS). BIS produced the "BIS quarterly construction price and cost indices" up to September 2014 with responsibility passing to the ONS in April 2015. ONS has produced its "Construction output price index" since 2012, including a "Output Price Index for New Construction" which includes the sub-indices "All New Construction" and "Infrastructure" used here.

ONS advice was followed to create a longer running time series across the duration required by linking the BIS series and ONS series, and also linking the ONS (2005=100) series and ONS (2015=100) series.

Appendix B. Description of approach used to adjust nominal expenditure to real expenditure

The table below expands Table 1. Crossrail expenditure, variously adjusted (British Pounds, billions), to include inflation index data. This shows the adjustment factor for each year of each time series, where for each 2005=100.

To adjust nominal expenditure to the 2005 base year using an index requires taking each year's nominal expenditure and adjusting by the relevant index factor for that year to calculate the adjusted expenditure for that year, ie, real expenditure= nominal expenditure (in year) * (base year index factor / in year index factor).

This calculation is illustrated using a worked example to adjust nominal expenditure in 2009 to real expenditure (base year=2005) using the infrastructure index.

Real expenditure (base year=2005)= nominal expenditure in 2009 * (2005 infrastructure index factor / 2009 infrastructure index factor)

= £0.96bn * (100/112.6)

= £0.85bn

Crossrail (Elizabeth Line) Briefing Paper. House of Commons Library. pg20

Crossrail (Elizabeth Line) Briefing Paper. House of Commons Library. pg23.

	Nominal expenditure		Adjust for CPI inflation			Adjust for GDP (actual)			Adjust for GDP (2%)			Adjust for "all new construction" inflation			Adjust for "infrastructure" inflation		
	£bn			£bn (2005)			£bn (2005)			£bn (2005)			£bn (2005)			£bn (2005)	
	In Year	**Total**	**CPI index**	**In year**	**Total**	**GDP index**	**In year**	**Total**	**GDP index**	**In year**	**Total**	**ALL CON index**	**In year**	**Total**	**Infra index**	**In year**	**Total**
2008	0.20	0.20	106.6	0.19	0.19	109.0	0.18	0.18	106.1	0.19	0.19	113.8	0.18	0.18	116.7	0.17	0.17
2009	0.96	1.16	108.5	0.88	1.07	104.9	0.92	1.10	108.2	0.89	1.08	111.8	0.86	1.03	112.6	0.85	1.02
2010	0.72	1.88	111.3	0.65	1.72	103.4	0.70	1.79	110.4	0.65	1.73	107.5	0.67	1.70	112.3	0.64	1.67
2011	1.04	2.93	115.3	0.90	2.62	105.5	0.99	2.78	112.6	0.92	2.65	109.0	0.95	2.66	117.2	0.89	2.55
2012	1.51	4.43	118.0	1.28	3.90	106.8	1.41	4.19	114.9	1.31	3.97	112.6	1.34	4.00	123.4	1.22	3.78
2013	1.58	6.01	120.4	1.31	5.21	108.3	1.46	5.65	117.2	1.35	5.31	116.9	1.35	5.35	129.7	1.22	4.99
2014	1.58	7.65	121.9	1.30	6.51	110.8	1.43	7.08	119.5	1.32	6.64	123.1	1.28	6.63	135.1	1.17	6.16
2015	1.60	9.25	121.9	1.31	7.82	113.8	1.41	8.49	121.9	1.31	7.95	125.9	1.27	7.91	137.5	1.16	7.33
2016	1.64	10.89	122.6	1.34	9.16	115.9	1.42	9.90	124.3	1.32	9.27	128.8	1.27	9.18	138.6	1.18	8.51
2017	1.62	**12.51**	125.3	1.29	**10.45**	117.6	1.38	**11.28**	126.8	1.28	**10.55**	132.2	1.23	**10.40**	140.7	1.15	**9.66**