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MSc International Economics and Finance
Academic year 2015-2016

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Cost-Benefit Analysis in Infrastructure Investments, the Case of Crossrail

Athens 1/2016

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Introduction

The main objective of this dissertation on Cost/Benefit Analysis (CBA hereinafter) of infrastructure investments is to evaluate and assess the financial and socio-economic impacts of one of the greatest infrastructure projects ever made in the European continent. The case is about the new urban railway network in London, UK called Crossrail, the constructing operations of which are about to be completed by December 2018-January 2019 (rail services are about to be introduced by 2017 progressively)[1]. As it is obvious, the adequate type of CBA that is going to be used during the rest of this thesis is the ex-post evaluation[2], given that construction period has been underway since mid-2009 and the new railway system has reached almost the 60% of its estimated construction and function capacity[3]. One of the most useful tools that CBA of an ongoing program provides is the concreteness of some values which have already been calculated and applied properly (e.g. investment/construction costs). In this way, given that certain values already belong to the data set and not to the estimated data, the projection of financial and socio-economic indicators can be more accurate.

In the first chapter of the thesis, a brief analysis of the CBA concept in infrastructure projects takes place through various key issues like time horizon, sources of finance, risk and wider effects of such an investment a program. Then, this literature is linked directly to the Crossrail project in the last section of the chapter.

The second chapter is dedicated to the feasibility analysis and option selection of the project. The subjects under discussion are the domestic and European legal frameworks accompanied with certain summary statistics relative to the domestic and European rail transportation, the location of the project, its time horizon, the financial planning and the implications for the environment. In the last part of the chapter, the option selection is examined by discussing the capacity of London's railway network, the route of the Crossrail and the alternative options for this route, which were on the table of negotiations.

In the third chapter, the financial analysis of the project is carried out through its crucial issues like the funding of the project, the construction costs and the estimated revenues. The scope of this chapter is to determine the financial sustainability of the Crossrail investment program by figuring out the values of core financial indicators like Net Present Value (NPV

[1] **Crossrail, London, United Kingdom**, *Railway-technology.com*, url:http://www.railway-technology.com/projects/crossrail/ and **Crossrail, Project Update, June 2015**, *Crossrail*, url: http://www.crossrail.co.uk/news/quarterly-crossrail-update/

[2] **Worsley T.**, The evolution of London's Crossrail scheme and the development of the Department of Transport's economic appraisal methods (Discussion Paper No.2011-27), *Major transport infrastructure projects and regional economic developments: Assessment and Implementation*, p.29-30, 11/2011

[3] **Crossrail, Project Update, June 2015**, *Crossrail*, url:http://www.crossrail.co.uk/news/quarterly-crossrail-update/

hereinafter) of the project, Benefit/Cost Ratio (B/C Ratio hereinafter), Internal Rate of Return (IRR hereinafter) and Payback Period. The software used for this type of evaluation is Microsoft Excel.

The most important evaluation, in the writer's opinion, is the economic one, which is put under discussion in the fourth chapter. In this part of the essay, serious economic and environmental effects of the program are considered, such as impacts on the employment/unemployment level, environmental costs/benefits, time loss/savings generated by the construction and the function of Crossrail and the impact on the private consumption, local entrepreneurship, London visits etc. Moreover, in chapter five we will try to estimate the social discount rate and any other social effects (e.g. distributional) by taking into consideration the appropriate UK and EU macroeconomic indicators. Our goal in both chapters will be to produce a positive Economic and Social NPV in combination with a sound IRR and B/C Ratio. The necessary software for the proper calculations in these chapters is Microsoft Excel, too.

In chapter six, the risk analysis of the project is the issue under consideration, in which we will track the response of our performance indicators to percentage changes of critical variables of the project (Sensitivity Analysis). Moreover, we are also going to assign probability distributions to these variables in order to perform a Monte Carlo Simulation.

In the last chapter of the dissertation, the conclusion and the final remarks of the Crossrail CBA are illustrated. Also, it is discussed the accuracy of the CBA and how useful it is going to turn out over the next years of the project's life.

Keywords: *CBA, Infrastructure Investments, Crossrail, Financial and Socio-economic Evaluation, Risk Analysis*

1. Infrastructure CBA and the case of Crossrail

Before entering into the expansion of all the financial and socio-economic issues generated and affected by the Crossrail's investment program, it would be prudent to take a first insight into the concept of the infrastructure CBA that is going to be applied to the case of Crossrail and the reasons why this is a very important field of discussion in the modern world.

Stepping into the necessity of well projected major infrastructure investment programs, reasons such as overgrowing population and labor mobility stand out as the cornerstones of the importance of CBA. Also, limited financial resources that have to be used in a more efficient way are also one of the most crucial issues that CBA tries to assess. In the same direction, market distortions and monetization of non-monetary values are subjects to the appropriate CBA in order to overcome difficult situations which arise when market data is not available or it does not provide the right information[4].

1.1 The CBA concept in infrastructure projects

In this introductory section, we are trying to illustrate the several aspects of a CBA and the variables that have to be taken into account in order to perform an unbiased CBA in an infrastructure investment program.

1.1.1 Key issues in project analysis

During the evaluation of an investment program certain issues arise, which have to be assessed in order to perform a comprehensive CBA. So, in these paragraphs we are going to analyze those factors that affect either directly or indirectly the calculation of standard financial and economic indicators of an investment (infrastructure, in our case).

Project lifetime

We open this section by determining the lifetime of the project under evaluation. The time horizon is, usually, defined in years for a long-term investment, at the end of which all assets and liabilities are liquidated and a residual value is left. It has to be mentioned, though, that the period of the operating procedures of a project can be indefinite, but a certain lifetime is taken into consideration in order to facilitate projections. The importance of the duration of the operating life procedures derives from the financial and economic appraisal of the project, because the respective indicators are sensitive to time. Indicators like NPV, IRR or B/C ratio are

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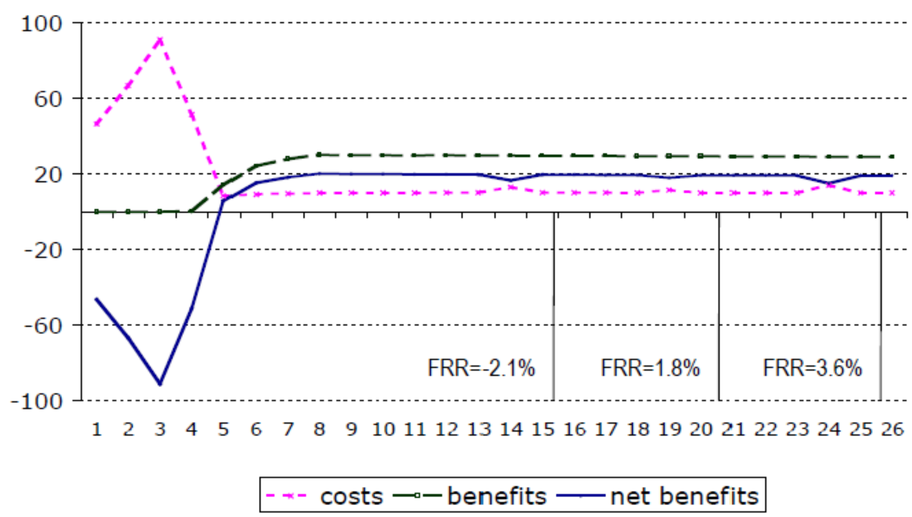
[4] **Jones H., Moura F., Domingos T.**, Transport infrastructure project evaluation using cost-benefit Analysis*, EWGT 2013 – 16th Meeting of the EURO Working Group on Transportation,* Procedia - Social and Behavioral Sciences 111 (2014) p.400–409

affected directly by the discounting period, which may determine the accept/reject areas during the decision making[5].

In the figure, the value of IRR (or FRR, Financial Rate of Return) is illustrated as the time goes by. It is clear that the longest the period, the greatest the value of FRR is, which means that the NPV of the project is equal to 0 discounted at bigger rates. It is also seen that, even with a negative discount rate, this specific project has a NPV equal to 0 until the 15th year of operations.

Figure 1.1 Different time horizon for the calculation of FRR (thousands of €) **Source: Florio M., Vignetti S. (6/2003)**



In the infrastructure sector, the operating life procedures usually last for more than 20 years and the projections for rail investments are performed in a 30-year time horizon[6]. As a result, their IRR is not very likely to be negative.

The next table contains some useful information about the project lifetime by sector.

[5] **Florio M., Vignetti S.**, Cost-Benefit Analysis of infrastructure projects in an enlarged European Union: an incentive-oriented approach, *Working Paper n.13.2003 – giugno,* p.2-10, 6/2003

[6] **Jones H., Moura F., Domingos T.**, Transport infrastructure project evaluation using cost-benefit Analysis*, EWGT 2013 – 16th Meeting of the EURO Working Group on Transportation,* Procedia - Social and Behavioral Sciences 111 (2014) p.400–409

Table 1.1 Average project lifetime by infrastructure sector Source: Jones H., Moura F., Domingos T. (2014)

Infrastructure Sector	Project Lifetime
Energy	25
Water and Environment	30
Railways	30
Roads	25
Ports and Airports	25
Telecommunications	15
Industry	10
Other Services	15

Discount rate

Another important factor to which the NPV is very sensitive is the discount rate. After either the financial or the economic analysis, the annual net cash flows generated are discounted at a fixed or a changing rate. Assuming discounting at a fixed rate[7] that tends to take greater values (comparatively to our base case, for example), the NPV is affected downwards. Looking at the NPV formula, it is easy to understand that the greater the value of the denominator, the lesser the value of the NPV is.

$$NPV = -C_0 + \sum_{i=1}^{n} \frac{NCF_i}{(1+r)^i}$$

In addition, there is also a case related to the distinction between the financial and the economic discount rate during the appraisal of an investment program. As it is going to be shown over the next chapters, especially 3, 4 and 5, there is an appropriate discount rate for each type of evaluation. For example, economic and social discount rates must include the distributional effects of the project to the economy and the next generations, respectively. So,

[7] The appropriate discount rate for the financial evaluation of an investment program is the Weighted Average Cost of Capital (WACC hereinafter). This constitutes from the sum of the percentages of funding that originates from several sources, e.g. bonds, preferred stock, retained earnings or new common stock. The interest rate of riskless bonds (e.g. government debt), which may be adjusted by some basis points upwards or downwards depending on the credibility of the corporation, is also adequate for discounting. Economic and social discount rates are usually based on formulas which include the macroeconomic rate of growth and the opportunity cost of capital on public investments (see Chapters 4 and 5).
Montague A. et al., *The Montague Review, Department of Transport*, p.24, UK 2004 and **Florio M., Vignetti S.**, Cost-Benefit Analysis of infrastructure projects in an enlarged European Union: an incentive-oriented approach, *Working Paper n.13.2003 – giugno,*p.2-10, 6/2003

it seems quite easy to understand that these specific rates are highly connected to several macroeconomic indicators and, even, to the social circumstances of a region, including employment/unemployment level, growth rate and quality of life[8].

Performance indicators

The appraisal of an infrastructure project is usually divided into financial and economic analysis. In order to track the performance of the investment, we use a number of special financial and economic indicators, the values of which are determined by the annual data that we have at our disposal. These are the investment/construction costs and operating costs, the estimated revenues, the depreciation of the capital invested, the taxation and the maintenance costs. During the economic appraisal, it is important to convert the market, usually distorted, prices into accounting ones and include wider economic and environmental effects after monetization of the respective impacts, like energy savings/consume, air pollution and changes in the annual income/GDP[9].

This data yields to the annual cash flows of the project which produce the financial and the economic NPV in the respective cases. As long as the NPV of an investment is greater than 0, the project remains sustainable. In some cases, financial NPV may not be greater than 0 but the economic NPV can be, because the project can offer more benefits than costs in a public level in the macroeconomic scale, rather than in a private[10].

Recalling the NPV formula from the last section, we can enter into the IRR concept, which may be either financial or economic. The IRR is the rate that zeros out the NPV formula. From this we can deduce that the greatest the value of the IRR, the better for the project, because at higher discount rates, the NPV can still remain greater than 0 and the project is resistant to interest rate changes[11].

$$NPV = -C_0 + \sum_{i=1}^{n} \frac{NCF_i}{(1+IRR)^i} = 0$$

[8] **Florio M., Vignetti S.**, Cost-Benefit Analysis of infrastructure projects in an enlarged European Union: an incentive-oriented approach, *Working Paper n.13.2003 –giugno,*p.2-10, 6/2003 and **Eijenraam C., Koopmans C., Tang P., Verster N.**, Evaluation of infrastructural projects; Guide for cost-benefit analysis, *Research program on the economic effects of infrastructure*, p.13-20, 4/2000

[9] **Schnabl A., Platzer G., Ecker M., Fritzsche H., Hochmuth B., Koch S., Lappöhn S., Pohl A.**, *Guidelines for cost-benefit-analysis of infrastructure projects*, Institute for Advanced Studies – Vienna, p.12-20, 3/2014

[10] **Ibid**.

[11] **Florio M., Vignetti S.**, Cost-Benefit Analysis of infrastructure projects in an enlarged European Union: an incentive-oriented approach, *Working Paper n.13.2003 – giugno,* p.2-10, 6/2003

1.1.2 Sources of finance

In the infrastructure sector, investments are usually directed to quiet large-scale projects, or sometimes mega-projects, like ports, airports, highways or railways, in our case, which makes their financing a very complicated problem. In this small section, we are trying to figure out the way that these investments are funding.

It is clear that, in projects of that magnitude, the public sector contribution might be the main source of finance, because infrastructure investments are considered to promote growth in local and regional level and increase the social welfare[12]. Such projects are also welcomed in the European Union context. For this reason, European institutions offer a variety of tools which can be used in order to co-finance infrastructure operations, such as the Structural Fund (SF hereinafter), the Cohesion Fund (CF hereinafter) and the Instrument for Structural Policies for Pre-Accession (ISPA hereinafter). These institutions usually grant funding to infrastructure projects, in contrast with the European Investment Bank (EIB hereinafter) or the Investment Fund (IF hereinafter), which are usually used for loans[13]. As a final remark, we could not have excluded from the discussion the newly introduced European Fund for Strategic Investments (EFSI hereinafter), which aims to tackle the issue of low confidence and limited risk appetite on the part of investors by using public funds to absorb some of the risks involved in infrastructure projects[14].

The above facilities may be the main sources of finance or supportive to the domestic ones. Public sector contribution usually derives from the central government (e.g. the Department for Transport in the case of Crossrail) or from regional and urban authorities. In addition, private sector is not excluded from these projects and its contribution may be important, too[15].

1.1.3 Risk Analysis

Another important factor during a CBA is the risk assessment. There are various ways in which we can perform the risk analysis of a project in order to prevent losses and avoid mistaken forecasts.

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[12] **Ammermann H.**, Study: Squaring the Circle - Improving European Infrastructure Finance, *Roland Berger Strategy Consultants*, p.5-7, 3/2015

[13] **Florio M., Vignetti S.**, Cost-Benefit Analysis of infrastructure projects in an enlarged European Union: an incentive-oriented approach, *Working Paper n.13.2003 – giugno,* p.2-10,6/2003

[14] **Ammermann H.**, Study: Squaring the Circle - Improving European Infrastructure Finance, *Roland Berger Strategy Consultants*, p.14-15, 3/2015

[15] **Ibid.** p.5-7

Risk may have to do with time horizon projections, cost and revenue forecasting and, of course, risk aversion. About time horizon, it is quite difficult to conceive when developments related with cost and revenue are going to occur, affecting, in this way, the Payback Period of the project. In addition, revenue forecasting is not accurate in the long-run and performance indicators are biased. This is a common inconvenience in the infrastructure investments because they usually last for more than two decades. Risk aversion, finally, might affect the discounting process. This happens because uncertainty usually increases as the future is further away and, at the same time, revenues decrease due to higher discounting[16].

In order to deal with risk and include in our forecasts some alternative solutions that depend on robust values, we can use sensitivity analysis to assess the volatility of critical variables and, also, assign probability distributions to these variables. During the sensitivity analysis process, we examine the percentage change downwards and upwards of a variable's value. It is important to see how the NPV and the IRR respond to the volatility of one critical variable at a time, which could be operating or investment costs, revenues etc., and determine base case, worst case and best case scenarios. Another way to perform risk analysis is the assignment of probability distributions to each of the critical variables. During this process, our variables take values which are approximate to their best estimate and we are able to generate several scenarios for NPV and IRR which depend on the probability function of our critical variables[17].

1.1.4 Wider economic effects of infrastructure projects

While studying what an adequate CBA requires, we could not have ignored the possible impact on the wider economy. A series of economic variables are affected both in the short- and the long-term periods, especially relative to economic (including environmental and growth) and employment indicators. This is the reason why land and property values are seriously taken into account and used as a measure of economic activity during the economic part of the evaluation. In relation to infrastructure investments, individuals are willing to pay a premium in order to purchase land or property in a location where several amenities (e.g. transport) are offered. So, it is rational to expect that local property prices are going to rise when an infrastructure project takes place in a specific area[18].

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[16] **Eijenraam C., Koopmans C., Tang P., Verster N.**, Evaluation of infrastructural projects; Guide for cost-benefit analysis, *Research program on the economic effects of infrastructure*, p.29-31, 4/2000

[17] **Schnabl A., Platzer G., Ecker M., Fritzsche H., Hochmuth B., Koch S., Lappöhn S., Pohl A.**, *Guidelines for cost-benefit-analysis of infrastructure projects*, Institute for Advanced Studies – Vienna, p.19-21, 3/2014

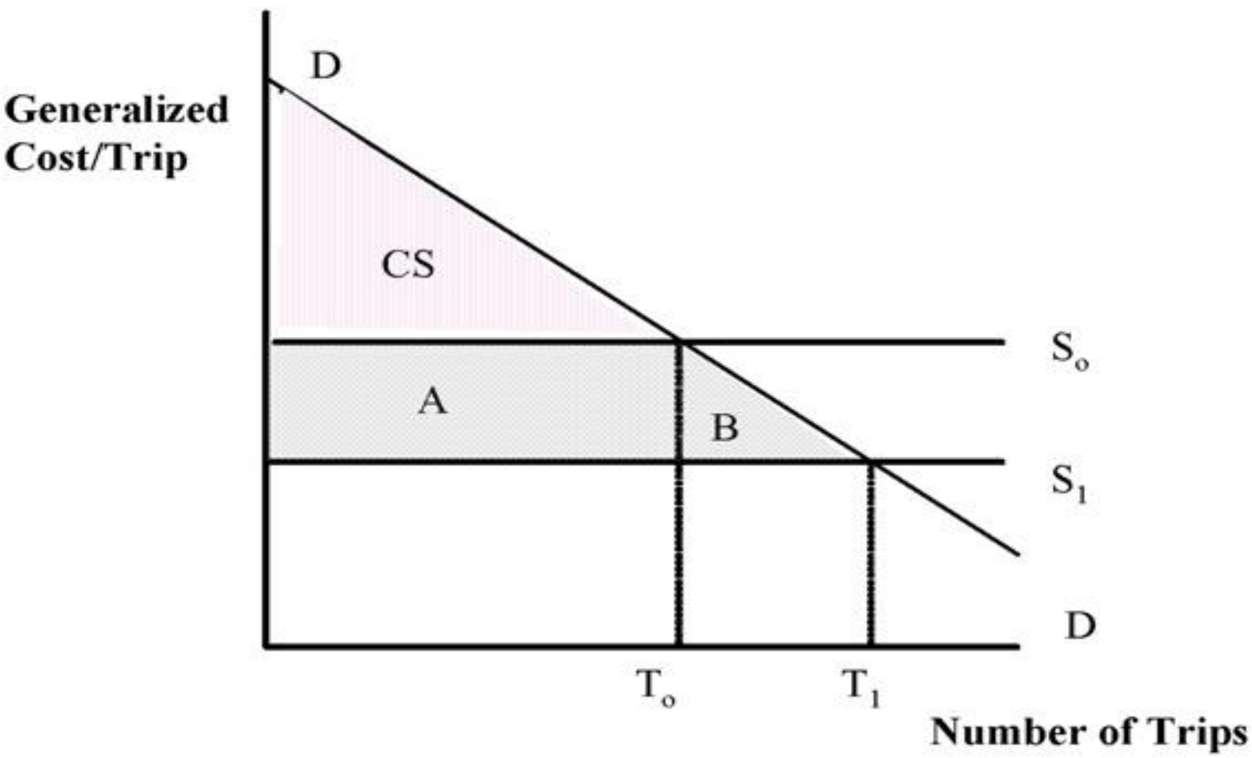
[18] **Mathur S., Smith A.**, Land value capture to fund public transportation infrastructure: Examination of joint development projects' revenue yield and stability, *Transport Policy 30 (2013)*, p.327-335, 11/2013 and **Mohammad S. I., Graham D. J., Melo P. C., Anderson R. J.**, A meta-analysis of the impact of rail projects on land and property values, *Transport Research Part A 50 (2013)*, p.158-170, 1/2013

In addition, we could also distinguish the effects of infrastructure projects between micro- and macroeconomic. Microeconomic are the ones which improve the individual firms' productivity due to transport infrastructure. It can be deduced that an expanded transport network can offer distance reduction but, also, reduced network congestion which leads to further cost savings. By taking this into account, we are able to measure the consumer surplus (the one who uses the transport network) by estimating the supply and demand curves related to the amount of trips and the general cost per trip[19].

In the next two figures, consumer surpluses are illustrated due to transport expansion in two cases. In the first case, there are no external effects and the supply curves are flat. In the second case, external effects that increase simultaneously with the number of trips, like air pollution, are included, which means that private cost is augmented and the supply curves are upward. This also implies that the consumer surplus this time is smaller. In each case, the extra benefit is calculated by the formula:

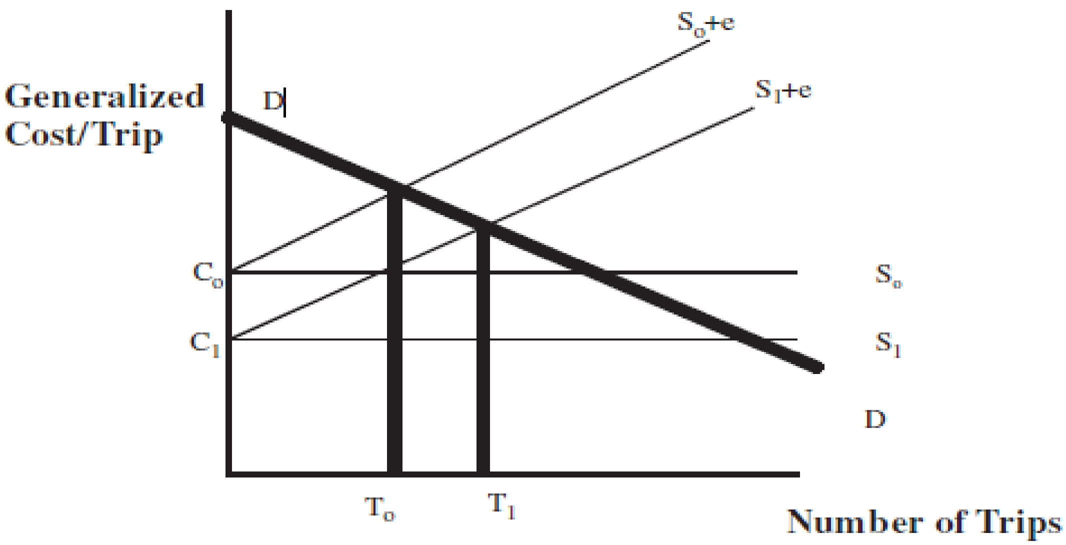
$$B = \frac{1}{2} * (S_0 - S_1) * (T_1 - T_0) \text{ and } B = \frac{1}{2} * (C_0 - C_1) * (T_1 - T_0)\text{, respectively}$$

Figure 1.2 User benefits **Source: Lakshmanan T.R. (2011)**



[19] **Lakshmanan T.R.**, The broader economic consequences of transport infrastructure investments, *Journal of Transport Geography 19 (2011)*, p.1-12, 1/2011

Figure 1.3 CBA with externalities Source: Lakshmanan T.R. (2011)



Macroeconomically, investments in transport infrastructure will tend to reduce the prices of production inputs and, also, increase efficiency. Not only costs of skilled labor and materials become lower, but increased transport capacity generates more quality of services in the long run. For example, where infrastructure is inadequate, firms' marginal cost remains at high levels. Once infrastructure investments take place, marginal costs plummet due to resource efficiency. In this way, not only cost savings are realized, but private consumption rises, too[20].

We must not disregard, though, that not all effects are connected with market values, so they have to be monetized and included in the CBA. Such effects usually have to do with air pollution, safety and uninsured risks, impacts on other modes of transport, or regional inequalities related to distributive issues[21]. In chapters 4 and 5, the economic and social evaluation of the Crossrail takes account of the above parameters.

[20] **Ibid.**
[21] **Eijenraam C., Koopmans C., Tang P., Verster N.**, Evaluation of infrastructural projects; Guide for cost-benefit analysis, *Research program on the economic effects of infrastructure*, p.13-21, 4/2000

1.1.5 Steps in CBA

As a last move before entering into the application of this literature to the Crossrail project, it would be useful to summarize its most important and widespread features in the academic world. Towards this direction, there are 9 steps that contain all the necessary action that has to be taken during the CBA[22]:

I. **Problem analysis;** the preliminary phase of an appraisal study that consists of formulating the problem, the operational aims of the project and the preconditions which the project must comply.
II. **Project definitions;** these contain the design, the construction and funding plan and the alternative solutions. In addition, a description of the base case is necessary in order to try to figure out some possible alternative solutions.
III. **Identifying the project effects;** identification, estimation and valuation of effects that are distinguished between direct, indirect and external.
IV. **Assessment of relevant exogenous developments;** sound assumptions in respect of changes in the environment of the project are created in order to track the trends in demand. These scenarios constitute a useful method to deal with uncertainty.
V. **Assessment and valuation of project effects;** effects that have to do with the construction itself (direct), wider economic effects due to the project (indirect) and externalities are assessed and valuated in monetary terms in order to proceed with the CBA.
VI. **Assessment of the project costs;** estimation of the costs involved in the implementation of the project.
VII. **Producing a cost-benefit set-up;** calculation of the profitability criteria in terms of financial analysis and evaluation of the monetized economic benefits and costs in terms of socio-economic analysis.
VIII. **Variant and risk analysis;** similar to step IV, financial and economic indicators are tested for their sensitivity to critical variables through scenario generation of percentage changes or values generated by distribution assignments.
IX. **Supplementary tasks;** tracking the performance of the project through time and perform ex-post evaluation.

[22] **Ibid.** p.43-50 and **Schnabl A., Platzer G., Ecker M., Fritzsche H., Hochmuth B., Koch S., Lappöhn S., Pohl A.**, *Guidelines for cost-benefit-analysis of infrastructure projects*, Institute for Advanced Studies – Vienna, p.4-25, 3/2014

1.2 THE CASE OF CROSSRAIL

After analyzing the most essential issues about CBA in the infrastructure sector, we may proceed with their application to the project of Crossrail. This last section of the first chapter is a necessary linkage to the Crossrail CBA. It contains general information about the project and sets the targets of its CBA.

1.2.1 General information

As mentioned in the introduction of the dissertation, Crossrail is the greatest construction project in Europe. It is located at the heart of the city of London and connects Reading and Heathrow Airport in the west with Shenfield and Abbey Woods in the east, through newly constructed tunnels under central London[23]. This route is clear in the next map and will be discussed further in the next chapter in the Option Selection section.

Map 1.1 Crossrail route **Source: Crossrail**

Operations have been underway since May 2009 and there are approximately 10,000 people working across 40 different sites. The new rail services are going to be introduced progressively by 2017, while the project is expected to reach its full capacity by 2019. These

[23] **Crossrail in numbers**, *Crossrail*, url: http://www.crossrail.co.uk/news/crossrail-in-numbers

activities are about to expand London's rail capacity by 10%, cutting journey times across the city. The route will run over 100km, of which 42km are new tunnels beneath London[24].

In addition, Crossrail is about to bring substantial changes in the greater economy of London, like increase in employment level, augmented corporate activity and impact on local property. Sustainability and environmental issues generated by Crossrail's construction are, of course, included in the economic analysis and we are going to discuss them in detail in chapter 4.

1.2.2 Targets of the Crossrail CBA

This brief analysis of the Crossrail project permits us to set the targets of the CBA as we are getting deeper into the case by studying in detail all the project data available. The investment under evaluation has to be capable of passing several tests in order to be considered sustainable in the long run.

The first one is the feasibility analysis and option selection, right in the next chapter. The goal of this process is to confirm that the Crossrail project fits both the national and the European institutional framework and examine the progress of the implementation of the investment.

The next target is to figure out the business profitability of Crossrail in chapter 3. Financial sustainability issues are going to be in the spotlight in order to determine the financial NPV of the project.

If not much attention is paid to the financial evaluation of a mainly public funded investment, economic analysis is going to determine if the Crossrail project is worth to be completed at all. So, our focus concentrates on the economic NPV which has to be positive.

The last, but not least, target is to perform a social analysis and estimate the value of the investment for different income groups, i.e. its distributional effects, and next generations. In addition, we will try to calculate a social NPV for the investment, which has to be greater than 0.

[24] **Ibid.**

2. Feasibility Analysis and Option Selection

In this chapter we are going to study in detail the feasibility status and the option selection of Crossrail. For this purpose, the first section is dedicated to the domestic and European institutional framework, the second is about the feasibility report, which includes the demand analysis and the technical aspects of the project and in the last section we examine the best option and its alternatives for this investment program.

2.1 Institutional Framework

The Crossrail project is carried out by the British public sector and the contribution plan is split between three major authorities. There are certain provisions for their action, which are described in detail in the domestic legal framework or, more specifically, in the Crossrail Act. The Crossrail Act is fully compatible with the European Union Directives concerning the rail infrastructure and past domestic Acts about rail industry.

2.1.1 Who is involved?

The three major sponsors of the Crossrail project are the Department for Transport (DfT hereinafter), Transport for London (TfL hereinafter) and Network Rail. The DfT grants the central government contribution to the project, while TfL is the local public authority that sponsors the investment. These two sponsors have formed a 50/50 joint venture called Crossrail Ltd for the purposes of the project[25].

Network Rail is also run by central government and is the owner of the existing rail infrastructure. The existing infrastructure is going to be enhanced and improved by Crossrail Ltd[26].

The sponsors aim to secure the required quality of access for Crossrail services for a duration that reflects the long term lives of the assets under construction and the benefits to be delivered by the project, retaining the flexibility to increase or otherwise vary Crossrail service levels in the future. Among other objectives, DfT and TfL preserve the flexibility to sell the central section (i.e. in the London area) in a way that delivers maximum value for money and ensures that any third party users contribute to the long term costs of the project on a non-discriminatory basis. Also, the sponsors have to provide incentives to ensure efficiency of operations and maintenance expenditure, with costs transparently identified, and include qualifications for renewals and enhancements. These extra costs that might be used for

[25] **Banister D., Thurstain-Goodwin M.**, Quantifications of the non-transport benefits resulting from rail investment, *Journal of Transport Geography 19 (2011)*, p.212-223, 1/2011

[26] **Office of Rail Regulation***, Further regulatory statement on Crossrail charging*, February 2014

operations and maintenance efficiency have to be in balance with the charges paid by the rail service operators (i.e. train operators or other companies which provide services in the general context of Crossrail)[27].

2.1.2 Legal Framework

The total benefits that the Crossrail project is about to bring in the wider economic activity of London were recognized by the Parliament in the passing of the Crossrail Act in 2008. This Act facilitates the process of the investment program and secures the commitment of the sponsors and the above objectives to the project[28].

By passing this Act, the UK Parliament promotes the development of the rail network to the greatest extent that is economically practicable, and enables providers of railway services to plan for the future with a reasonable degree of assurance. In this way, investors (including public sector investors) may be comfortable that they will have sufficient rights of access to be able to capture or deliver the benefits envisaged, in line with the sponsors' objectives described in the previous section of this chapter[29].

In addition, the central government has duties to promote competition and efficiency in the provision of railway services by ensuring access for different operators. Also, Crossrail Act avoids the introduction of too much rigidity into the allocation of network capacity where alternative uses of capacity in the future may be more beneficial[30].

2.1.3 EU Directives involvement

From the sponsors' objectives and the facilitations that the domestic framework offers, we can deduce that a cost-effective approach has been adopted. This attitude complies with the Directive 2007/58/EC[31], which is quoted by the domestic authorities as a legal basis that permits the infrastructure managers to set charges to the long-term cost of the project if these are followed by increase in efficiency or cost effectiveness of the project. This objective can be met if London's transport capacity increases by the estimated percentage (10%), journey times are cut and wider economic benefits are realized[32].

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[27] **Michael Lee**, Crossrail Regulatory Statement / Sponsor Objectives, *Office of Rail Regulation*, 11/2008
[28] **Memorandum to the Transport Select Committee**, *Post legislative assessment of the Crossrail Act 2008*, 7/2013
[29] **Michael Lee**, Crossrail Regulatory Statement / Regulatory and Policy Framework, *Office of Rail Regulation*, 11/2008
[30] **Ibid.**
[31] **DIRECTIVE 2007/58/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL** of 23 October 2007 amending Council Directive 91/440/EEC on the development of the Community's railways and Directive 2001/14/EC on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure
[32] **Michael Lee**, Crossrail Regulatory Statement / Investment Recovery Charge, *Office of Rail Regulation*, 11/2008

The other EU Directive that serves as a legal basis for the domestic acts is the Directive 2001/14/EC[33]. According to this, these charges have to be necessary in order to complete the project, otherwise the project could not have been undertaken by the domestic authorities. This statement gives TfL and DfT the flexibility to sell the central section in the future in order recover the borrowed capital that was directed to construction operations. In addition, third party train operators (non-TfL) that may produce and offer rail services in the future must pay the initial sponsors a secure amount of capital which is going to give them the opportunity to finance their debt for construction[34].

2.2 Feasibility Report

After a brief description of the project's adaption in both domestic and European institutions, in this section we will examine in a more practical way the technical aspects of the implementation. For this purpose, the demand analysis of Crossrail is the next step in the CBA process, and it is followed by the production plan, the financial scheme and the environmental implications of the investment program.

2.2.1 Demand Analysis

The construction of Crossrail is expected to raise demand for journeys to/from and within London more than the estimated rate projected by the Office of Rail Regulation (ORR hereinafter) in UK. Since 1995/96, when the Crossrail Bill was not even under consideration, London passenger journeys have risen 120%. Since that date, the number of journeys has been rising, except a slight decline during 2008/09, possibly due to the financial crisis of that period[35].

The trend described above is illustrated in the official ORR figures. It can be shown that even in a one-year period (2012/13-2013/14, which is the last of our sample) there is a notable increase in the number of London passenger journeys. In the writer's opinion, year-to-year increase in passenger journeys is an important figure as the first Crossrail services become more proximate (expected to begin progressively by 2017, as mentioned in the previous sections). Running a regression in MS Excel applying the 20-year data from the ORR (1995-2014) and taking the logarithm of the number of journeys every year (which is our dependent variable), we can see that after a one-year period increase, London passenger journeys are expected to rise by approximately 1.7%.

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[33] **DIRECTIVE 2001/14/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL** of 26 February 2001 on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification

[34] **Michael Lee**, Crossrail Regulatory Statement / Investment Recovery Charge, *Office of Rail Regulation*, 11/2008

[35] **Lyndsey Melbourne**, Regional Rail Usage Profiles (Passenger Journeys) 2013-14 Statistical Release, *Office of Rail Regulation*, 1/2015

The following charts and the regression output confirm the information described above.

Figure 2.1 London passenger journeys in thousands (to/from/within region) Source: ORR

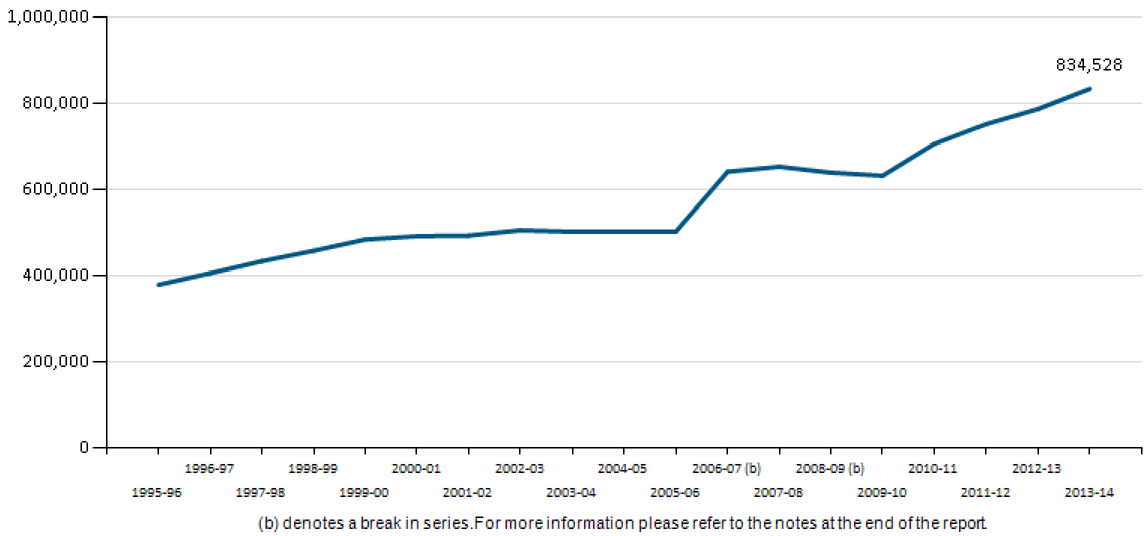
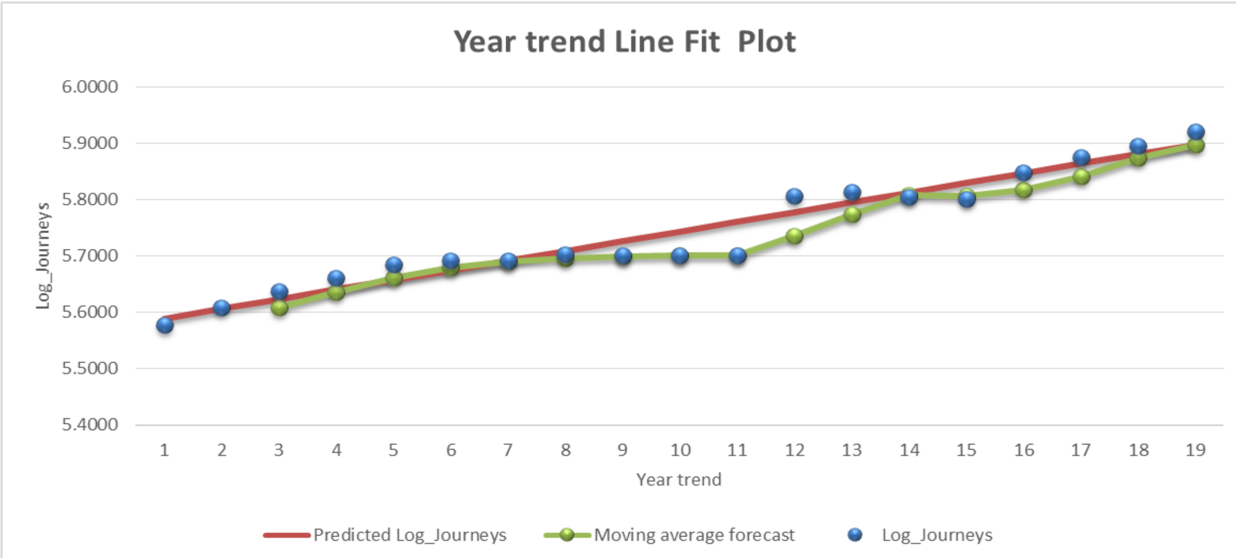


Table 2.1 Regression output, Log (journeys); Year trend Data Source: ORR

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.9694					
R Square	0.9397					
Adjusted R Square	0.9362					
Standard Error	0.0252					
Observations	19.0000					
ANOVA						
	df	SS	MS	F	Significance F	
Regression	1.0000	0.1686	0.1686	265.0763	0.0000	
Residual	17.0000	0.0108	0.0006			
Total	18.0000	0.1794				
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	5.5718	0.0120	462.5941	0.0000	5.5464	5.5972
Year trend	0.0172	0.0011	16.2812	0.0000	0.0150	0.0194

In the output, it can be seen that the independent variable coefficient (time in our case) is statistically important at a 95% confidence level with a t-Stat value of 16.2812. The next figure illustrates the line fit plot, respective to the regression and it also includes the moving average.

Figure 2.2 Regression line and Moving Average {Year trend=1, 2, ...,19} for the period 1995-2014



After stressing the importance of the growing demand for rail trips in UK, and London specifically, we are ready to consider the changes that the Crossrail project is about to cause in this sector. In a similar pattern, the number of annual and daily passengers is expected to rise sharply because of the presence of Crossrail. An ARUP study based on population (Figure 2.3) and employment forecasts (Figure 2.4) of the Greater London Authority (GLA hereinafter) shows that Central London is expected to be a destination of 250 million people annually, due to the construction of Crossrail till 2026. In addition, daily passengers are estimated at 743,000. These numbers exceed by 65 million and 195,000 the previous projections for the respective indicators[36]. In Figure 2.5[37], we illustrate these values in combination with the current transportation conditions in London.

[36] **Ove Arup & Partners Ltd**, *The impact of Crossrail on visitor numbers in Central London*, 1/2014, p.7

[37] In Figure 2.4, F stands for forecasts. The first column shows current situation, the second one is the forecast without the Crossrail project, the third is the official estimation performed in 2004 and the last is the official ARUP projection including updated inputs and assumptions
Ibid. p.24

Figure 2.3 London Population projections **Source: GLA projections**

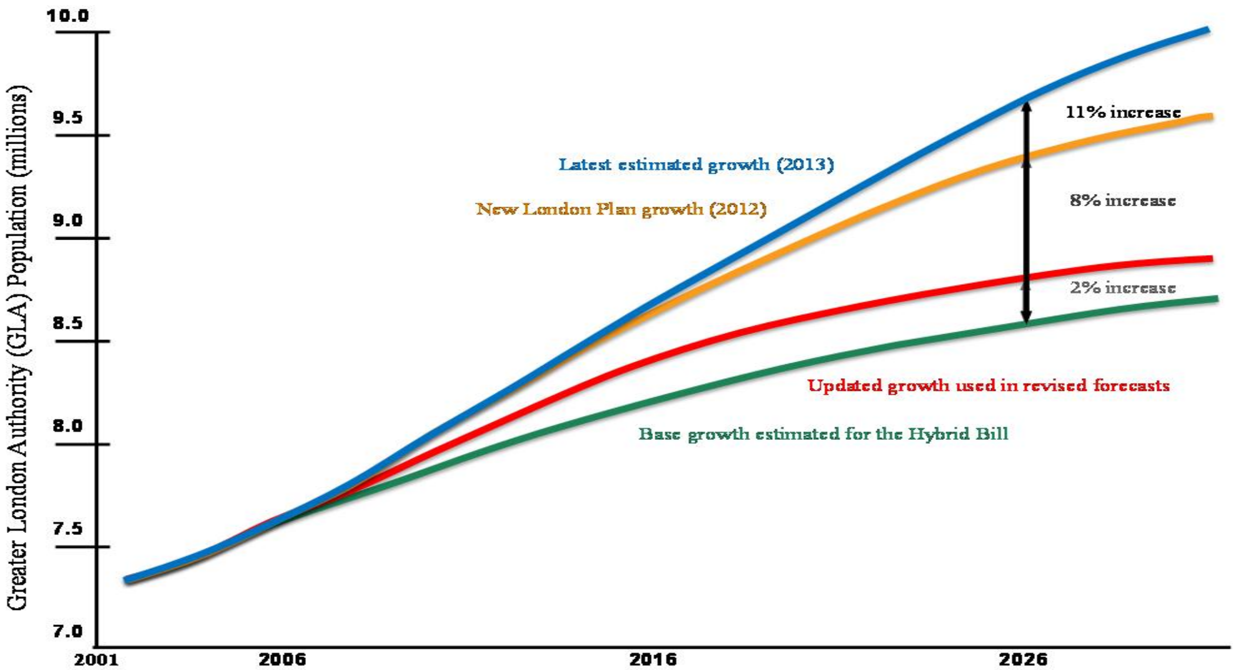


Figure 2.4 London trends and forecast for population, employment and travel demand Source: Crossrail Business Case (2011)

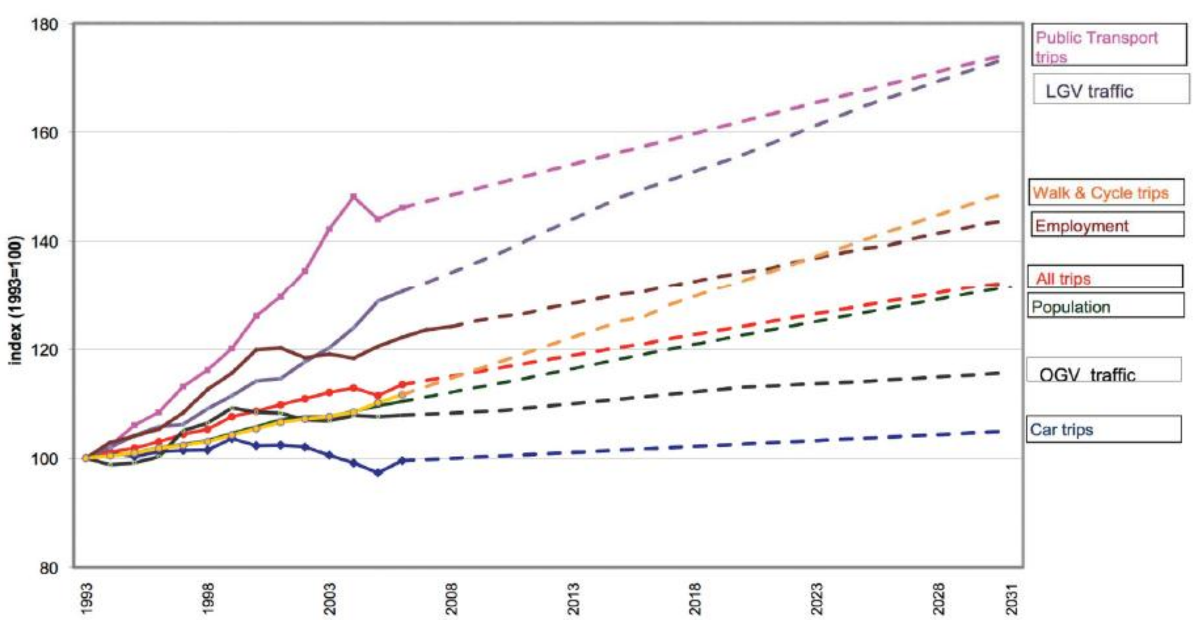
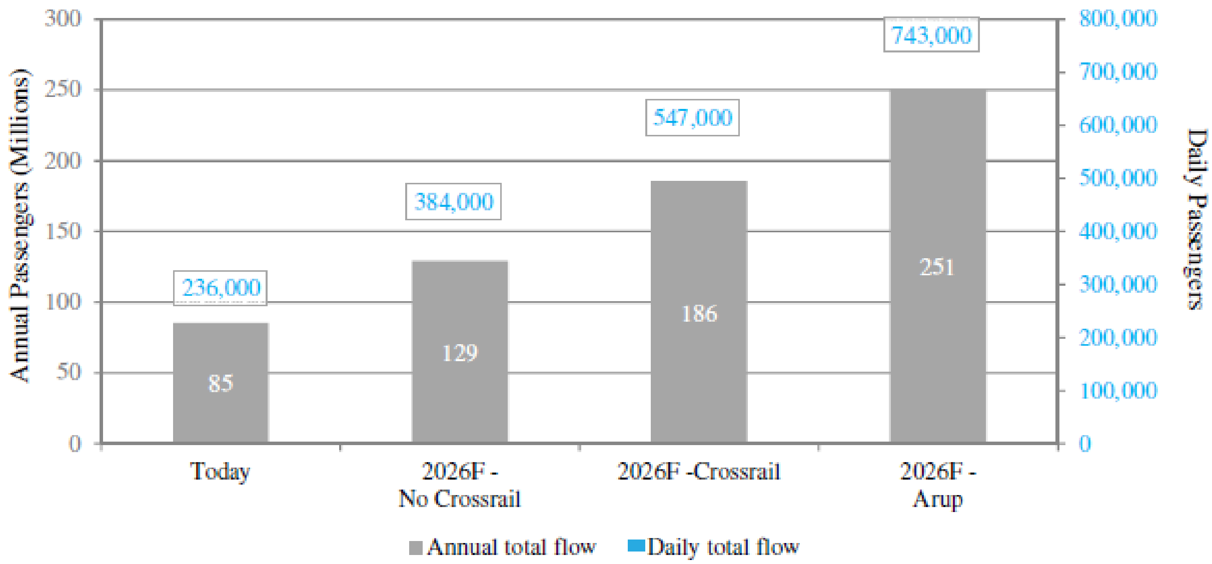


Figure 2.5 Annual and daily passenger flows Source: ARUP (2014)



The data analysis just performed is a big step towards the completion of the Crossrail project, given that rising trends in transportation to/from/within London demonstrate the necessity of such an extensive infrastructure investment.

2.2.2 Production plan and project scale

Crossrail is the biggest construction project in Europe and is one of the largest single infrastructure investments undertaken in UK. Its magnitude can be made clear through national authorities' involvement and contribution and the amount of people currently working in 40 construction sites (about 10,000). Crossrail's final route length is going to be approximately 100km when operations are over (end-2018) and there will be up to 40 stations, including 10 new stations at Paddington, Bond Street, Tottenham Court Road, Farringdon, Liverpool Street, Whitenchapel, Canary Wharf, Custom House, Woolwich and Abbey Wood[38].

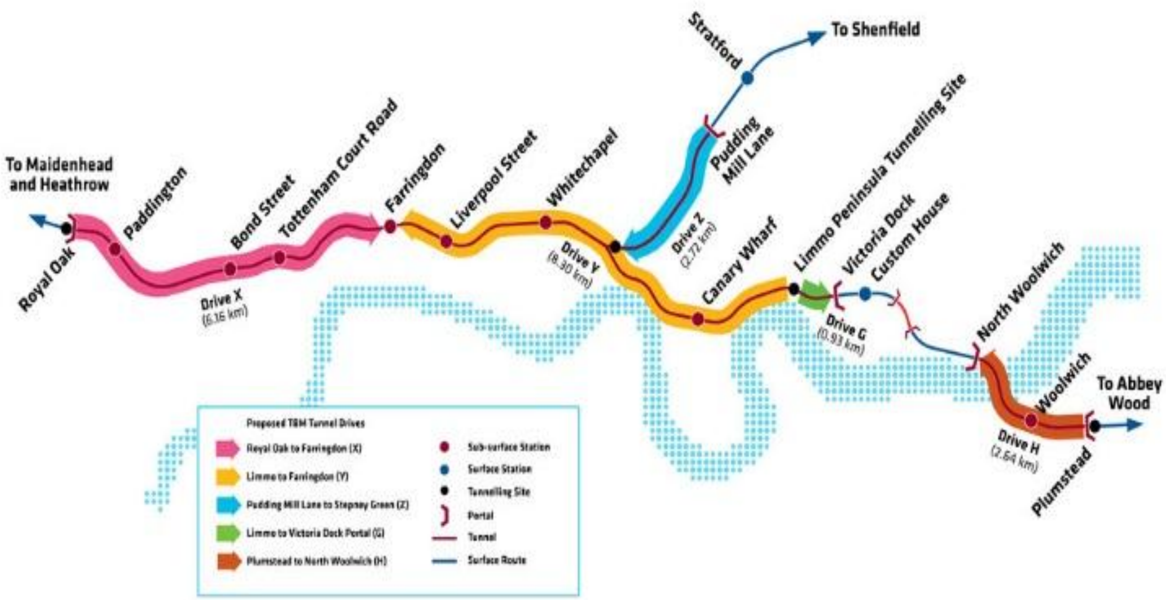
As mentioned before, Crossrail's construction operations have been underway since 2009. The first parts of the construction process were station establishment, civil engineering and network rail works. The most ambitious and exciting part of the project, though, began in the summer of 2012. The case is about tunneling, which makes Crossrail the first completely new underground line in more than 30 years. London's underground network has not

[38] **Crossrail**, *Crossrail in numbers*, url: http://www.crossrail.co.uk/news/crossrail-in-numbers

undergone such substantial changes since the original Paddington to Farringdon section opened in 1863[39].

The route (Reading and Heathrow Airport in the west to Shenfield and Abbey Woods in the east) that Crossrail links to the already existing network could not have been realized without such an extensive and newly designed tunneling infrastructure. Crossrail's tunnel sections have a length of 42km and they are 6.2 meters wide. This remarkable infrastructure achievement is located 40 meters deep in the UK capital, since its construction is over since June 2015[40].

Map 2.1 Tunneling sequence diagram **Source: Crossrail**



Station construction, civil engineering and network rail works are expected to finish until the end of 2018, while both railway systems and trains and railway depot operations began in 2014 and they are expected to be over in 2018 and 2017, respectively. In addition, public space and development around stations will be in progress as long as operating life procedures last[41].

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39 **Crossrail**, *Construction*, url: http://www.crossrail.co.uk/construction/
40 **Crossrail**, *Construction and tunneling*, url: http://www.crossrail.co.uk/construction/tunnelling/
41 **Crossrail**, *Moving Ahead*, url: http://www.crossrail.co.uk/news/quarterly-crossrail-update/ , 9/2015

2.2.3 Available technology

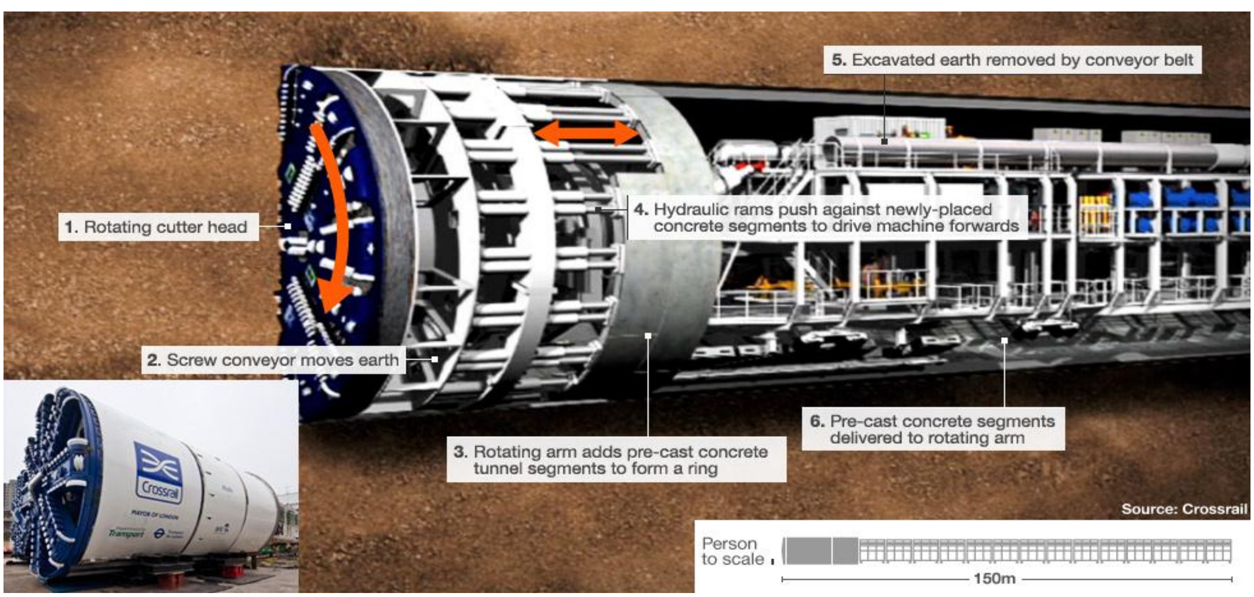
In order to complete the ambitious plan described earlier, especially during tunnel construction, use of edge technology machinery was essential. Crossrail Ltd used 8 tunnel boring machines carefully weaved through London's congested sub-terrain, snaking between the existing tube network, sewers, utilities and hidden rivers at depths of up to 40 meters[42].

Each of the 8 tunneling machines has an external diameter of 7.1 meters, weighs around 1000 tones and measures around 150 meters in length. At the front of every machine there is a cutting wheel, which is pressed against the tunnel face by hydraulic cylinders, and behind this, a series of trailers houses all the mechanical and electrical equipment. As the boring machine moves ahead, the loosened material is removed from the cutter head through a screw conveyor, which moves the material to the back of the machine and out of the tunnel[43].

The tunnel face is continuously monitored by pressure sensors that check the turning power of the cutting wheel and the screw conveyor, keeping track of the material that has been excavated. The tunnel lining created by the Crossrail's boring machines is designed to last 120 years[44].

The image below shows a tunnel boring machine and how it works.

Image 2.1 Crossrail tunnel boring machine **Source: Crossrail**



[42] **Crossrail**, *Tunneling*, url: http://www.crossrail.co.uk/construction/tunnelling/meet-our-giant-tunnelling-machines/
[43] **Ibid.**
[44] **Ibid.**

2.2.4 Financial planning

In the beginning of this chapter, we highlighted the contribution of the two major sponsors to the project, which are TfL and DfT. In this section we are going to see in detail the way they will finance Crossrail and the amount of capital that they need to spend in order to complete the investment. The initial package approved by the Labor Government in 2008 with the Crossrail Act was £15.9 billion, but the coalition government in 2011 reduced this amount to £14.8 billion (with maintenance and operation costs included)[45]. Also, it is important to mention that all values in this section are present values and they have been calculated at a 95% confidence interval.

The most complicated scheme is the one that TfL is going to use. Its total contribution to the project is expected to be around £7.7 billion, in cooperation with the local authority (i.e. GLA). The greatest part of this contribution (about £4.1 billion) will be financed by the Crossrail Business Rate Supplement (BRS hereinafter). BRS is a fiscal method based on land value finance. In UK, it has the form of a multiplier (2% in our case) that applies to all non-domestic properties with a rateable value that exceeds £55,000. This means that a business with a rateable property of £100,000 is going to pay for the BRS every year £2000 (2%*100,000). This rate has to be paid for 24 to 31 years, which is the charging period for Crossrail. So, BRS contribution to the project consists of £3.5 billion financed by GLA borrowing and £0.6 billion in direct funding (City Infrastructure Levy and Mayor contributions).The remaining amount (approximately £3 billion) is going to be financed directly by TfL through prudential borrowing from the Public Works Loan Board (PWLB hereinafter) and the EIB[46].

In Table 2.2 we illustrate the annual contribution of TfL and GLA.

The other major sponsor, DfT, has agreed to contribute £5.1 billion to the project directly. This amount will be granted to the 50/50 joint venture of DfT and TfL, Crossrail Ltd. To this amount is aggregated the capital that Network Rail is about to spend for on network works (approximately £2 billion)[47].

Before closing this section, it is essential to mention that the contributions of the major sponsors during the construction period do not sum to the final estimated cost of the project mentioned at the beginning, because the latter includes maintenance and operating costs. These numbers are about to be examined in detail in the next chapter.

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[45] **Roukouni A., Medda F.**, Evaluation of Value Capture mechanisms as a funding source for urban transport: the case of London's Crossrail, *Social and Behavioral Sciences 48 (2012)*, p.2393-2404, 6/2012

[46] **Ibid** and **Greater London Authority**, *Intention to levy a business rate supplement to finance the Greater London Authority's contribution to the Crossrail project* (Final Prospectus), 1/2010

[47] **Greater London Authority**, *Intention to levy a business rate supplement to finance the Greater London Authority's contribution to the Crossrail project* (Final Prospectus), 1/2010

Table 2.2 Planned contributions towards costs of Crossrail project by TfL during construction phase Source: GLA (2010)

Year Ended 31 March	TfL base contribution £bn	Of which financed by GLA borrowing £bn[1]
2009	0.5	
2010	0.5	
2011	0.8	0.8
2012	0.8	0.7
2013	0.8	0.7
2014	1.2	0.8
2015	1.1	0.5
2016	0.8	
2017	0.5	
2018	0.6	
Total	7.7	3.5

1. Financing and repayment of this contribution funded by the Crossrail BRS
Figures may not sum due to rounding

2.2.5 Environmental implications

It is easy to understand that an infrastructure investment program of that magnitude may result in certain environmental and ecosystem issues which have to be addressed by the appropriate legal framework. For this purpose, the authorities behind Crossrail Ltd have reached an agreement on a Construction Code which provides the necessary actions to be taken in order to manage several effects caused by construction operations[48].

In the environmental context, especially, the Environmental Management Plans (EMPs hereinafter) stand out as the fundamental action plan, in collaboration with local authorities.

[48] **Crossrail**, *Environmental Minimum Requirements (including Crossrail Construction Code)*, url: http://www.crossrail.co.uk/about-us/crossrail-act-2008/environmental-minimum-requirements-including-crossrail-construction-code

EMPs contain the appropriate range of issues that will be covered for the various locations or worksites during the Crossrail construction. The issues under consideration are the following[49]:

I. Area management plan, providing general details of implementation, including working hours, site layout and site appearance
II. Emergency plan, including pollution incident controls
III. Community liaison plan
IV. Lorry and traffic management plans
V. Green travel plan
VI. Noise and vibration management plan
VII. Dust management plan
VIII. Lighting management plan
IX. Site waste management plan
X. Ecological management plan
XI. Water management plan

EMPs are expected to guarantee the implementation of the existing legislation related to environmental policies and oblige the nominated undertaker to comply with it during the construction and operating periods[50].

Again, the monetization of these effects (like carbon emissions valuation) takes place in chapter 4 as part of the economic evaluation of Crossrail.

2.3 Option Selection

We close this chapter with the option selection for the Crossrail project. For this purpose, this section is dedicated to the final route of the new rail network and the other options that were under consideration for London's railway expansion.

Evidence from a couple of decades ago suggested that it was necessary to relieve the crowded rail network of London due to the increasing need for commuting to the capital. For this reason the central government created the Central London Rail Study (CLRS hereinafter) in order to review the alternative solutions to this problem. In general, the major options were two. The first was the construction of a completely new deep level underground and the

[49] **Crossrail**, *Construction Code* (Annex 1 to the Environmental Minimum Requirements), p.8, 7/2008
[50] **Ibid**. p.9

second was very similar to the existing Crossrail schemes, which implied a project that would enhance and use more effectively the existing rail network[51].

The evaluation of the transport benefits in each option marked the difference in favor of the Crossrail schemes. For instance, the study considered waiting time, walking around the station and journey times as baseline issues. Regarding these factors, potential passengers found walking and waiting at the station more irritating than spending more time on a train. In addition, time spent travelling in crowded conditions was evaluated, too, because the same study showed that passengers and commuters were willing to wait for a less crowded later train rather than boarding a crowded one[52].

These constraints were all satisfied by the Crossrail schemes due to reduction of the railway intersections to a minimum number, which would made potential passengers walk and wait less. Moreover, Crossrail's passenger carrying capacity was higher, according to the study, which would make the trains less crowded. Further benefits would come from the low-cost operation of these schemes and reduced traffic congestion due to switch of transport mode by the individuals[53].

[51] **Worsley T.**, The evolution of London's Crossrail scheme and the development of the Department of Transport's economic appraisal methods (Discussion Paper No.2011-27), *Major transport infrastructure projects and regional economic developments: Assessment and Implementation*, p.9-12, 11/2011
[52] **Ibid.**
[53] **Ibid.**

3. Financial Analysis

As we move on with our CBA, the next step is to perform the financial analysis of the Crossrail project. The scope of this chapter is to evaluate all costs and estimated revenues during the project lifetime in order to measure the financial performance of Crossrail as a single business case, which means that wider economic costs and benefits are excluded from this type of evaluation.

Before we continue with our analysis, it is important to set some assumptions. The first one is that our evaluation will be carried out for a 60-year period (2009-2068), which means that discounting is going to last for the same time[54]. Our benchmark rate will be 5%, which is a more realistic approach to the evaluation compared to the rate that HM Treasury Green Book proposes (3% and 3.5%)[55]. Also, given that this specific project is totally funded by the public sector and it will remain public until the provisions in relation with possible private sector involvement are enabled, as it was discussed in the beginning of the previous chapter, we will assume no taxation on the project's annual revenues. As a result, depreciation will not be an issue during financial analysis. For the same reason, financial return on capital is going to be equal to financial return on national capital. In addition, we assume that all investment costs are paid equally during the construction period, which is from 2009 to 2017. Finally, maintenance operations are assumed to begin in 2025 and occur every 10 years.

3.1 Total Investment Costs (Construction, Operation, Maintenance)

Having discussed the financial planning of Crossrail in the previous chapter, we are able to move on with the detailed expansion of the investment costs. As it was mentioned, the final amount of capital that it is required for the construction, operation and maintenance of Crossrail is £14.815 billion. This number is calculated in terms of PV and includes inflation provisions at the rate of 1%[56].

As a result, net construction expenses are approximately £11.540 billion, again in PV terms, of which[57]:

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[54] **Economic Appraisal of Crossrail**, p.2, 2005

[55] Crossrail's NPV data calculation has been carried out using a 3% rate for the first 30 years of discounting and a 3.5% for the last 30 years of the 60-year appraisal, according to the HM Treasury Green Book (**Crossrail business case update**: July 2011). In the writer's opinion, though, given that first appraisal attempts began under different macroeconomic conditions, in an updated appraisal like this one, benchmark discount rate has to be higher during financial evaluation.

[56] **Crossrail**, *Funding*, url: http://www.crossrail.co.uk/about-us/funding

[57] **Economic Appraisal of Crossrail**, p.2, 2005

- £7 billion are directed to tunnel and station construction and railway systems
- £640 million to land purchases or other property
- £1.3 billion to indirect costs and project management
- £300 million to depot costs
- £2.3 billion to on-network works

In order to generate the annual payments of these values for the 60-year discounting period and introduce them in our evaluation willing to create annual cash flows, it was used MS Excel Solver XLAM application for expanding their PV to the construction period (2009-2017) at a 5% benchmark rate. In the table below we illustrate the result of our programming, using the only constraint of equal payments annually.

Table 3.1 Crossrail construction expenditure **Data source: Economic Appraisal of Crossrail (2005)**

Period	Tunnels, stations,	Land and proper	Indirect costs and	Depot costs	On network works
2009	-£984,830,560	-£90,041,651	-£182,897,104	-£42,207,024	-£323,587,184
2010	-£984,830,560	-£90,041,651	-£182,897,104	-£42,207,024	-£323,587,184
2011	-£984,830,560	-£90,041,651	-£182,897,104	-£42,207,024	-£323,587,184
2012	-£984,830,560	-£90,041,651	-£182,897,104	-£42,207,024	-£323,587,184
2013	-£984,830,560	-£90,041,651	-£182,897,104	-£42,207,024	-£323,587,184
2014	-£984,830,560	-£90,041,651	-£182,897,104	-£42,207,024	-£323,587,184
2015	-£984,830,560	-£90,041,651	-£182,897,104	-£42,207,024	-£323,587,184
2016	-£984,830,560	-£90,041,651	-£182,897,104	-£42,207,024	-£323,587,184
2017	-£984,830,560	-£90,041,651	-£182,897,104	-£42,207,024	-£323,587,184
NPV	-£7,000,000,000	-£640,000,000	-£1,300,000,000	-£300,000,000	-£2,300,000,000

These expenses represent the best estimate made by the management team and include network works and other indirect costs, like the project management, that had been excluded, initially, due to difficulties in proper projections[58].

The main contributors are TfL through GLA (local authority), and the DfT (central government). It is important to mention though that most of the funds used for the construction (about 60% of the investment costs), originate from London taxpayers, i.e. households and businesses. The main fund transmission mechanism is the previously discussed BRS which totally contributed to the construction operations approximately £4.1 billion through TfL and GLA and represents the London businesses' grant to the project.

[58] **Montague A. et al.**, *The Montague Review, Department of Transport*, p.14, UK 2004

Finally, the total cost of on-network works has been undertaken by the third party of the sponsors, which is the Network Rail, run by the central government[59].

The same method was used for the operating and maintenance costs. After introducing the PVs in MS Excel (£1.670 billion for operation and £1.606 billion for maintenance), Solver yielded the annual payments under the constraint that these would be equal every year. It is important to recall at this moment that operating costs are expected to be paid by 2017 when operation starts, and maintenance works begin in 2025 and occur every 10 years, under our assumptions. The results of this procedure are shown in the following table.

Table 3.2 Crossrail, operation and maintenance expenditure Data Source: Crossrail Economic Appraisal (2005)

Period	Operation	Maintenance
2017	-£133,963,558	£0
2018	-£133,963,558	£0
2019	-£133,963,558	£0
2020	-£133,963,558	£0
2025	-£133,963,558	-£1,161,820,047
2030	-£133,963,558	£0
2035	-£133,963,558	-£1,161,820,047
2040	-£133,963,558	£0
2045	-£133,963,558	-£1,161,820,047
2050	-£133,963,558	£0
2055	-£133,963,558	-£1,161,820,047
2060	-£133,963,558	£0
2065	-£133,963,558	-£1,161,820,047
2068	-£133,963,558	£0
NPV	-£1,670,000,000	-£1,606,000,000

These values include the cost of operating the trains on both the main line rail network and the central section. It is assumed that track access charges would be paid to Network Rail for the use of the mainline rail network, but that there would be no payment for access to infrastructure on the central section. The operating costs include the cost of operating stations in the central area, but it is assumed there would be no additional cost for access to Network Rail stations for services that are being substituted. It is also assumed that Crossrail would only be responsible for maintenance and renewals on the central section, with those on the main network being paid through track access charges[60].

[59] **Crossrail**, *Funding*, url: http://www.crossrail.co.uk/about-us/funding
[60] **Montague A. et al.**, *The Montague Review, Department of Transport*, p.20, UK 2004

3.2 Estimated Revenues

The estimated revenues of Crossrail are strongly related to its everyday operation and the income generated by fares. It is a completely different approach to the one we have already used in the demand analysis of the project, where we estimated the expected number of journeys and passengers every year by analyzing annual data. Given that in UK, and London in our case, rail ticket prices depend on the hour of the day and the distance of the trip[61], it is very difficult to produce an accurate estimation of the annual expected revenues of Crossrail.

For these reasons, the available data in present value terms contains a weighted average of peak and off-peak hour journeys during the day. In addition, it has been calculated a weight of each journey taking account of the frequency (number of passengers) of each distance within the Crossrail route. These incorporations in the estimation process have yielded an estimate of £13.575 billion in present value terms[62]. As we did in the previous section, we plugged this number in MS Excel and, using the Solver, we managed to produce the annual payments under the only constraint that they will be equal. The results of the programming are shown in the table below.

Table 3.3 Crossrail, estimated annual revenue **Data Source: Crossrail Economic Appraisal (2005)**

Period	Revenues
2016	£0
2017	£1,088,955,271
2018	£1,088,955,271
2019	£1,088,955,271
2020	£1,088,955,271
2030	£1,088,955,271
2040	£1,088,955,271
2050	£1,088,955,271
2060	£1,088,955,271
NPV	£13,575,000,000

According to the traffic distribution projections, the one-third of this public income is expected to be generated by the new routes that the Crossrail project is about to bring, while the other two-thirds originate from the improvement of the existing rail network of London.

[61] Peak fares apply Monday to Friday (not on public holiday) 06:30-09:30 and 16:00-19:00. Off-peak fares apply at all other times

Transport for London, *Fares and Payments*, url: https://tfl.gov.uk/fares-and-payments/ticket-types/on-oyster#on-this-page-3

[62] **Economic Appraisal of Crossrail**, p.3, 2005

Despite these estimations, the demand elasticity of likely revenues of Crossrail (-0.6), according to the *Montague Review* (which was carried out for this purpose), is based on limited data about transport and takes into account the already existent fares. This approach was considered conservative and the *Review,* concluded that the appropriate elasticity to be used in the projections is 1.1, which would almost increase likely revenues by 50%. In agreement with the conclusion reached by Adrian Montague and his team, other significant projects that are in progress in London and the greater area, mainly new enhancements to the transport network, are about to maximize Crossrail's annual revenues[63].

At this point, it is important to mention that the data used in this appraisal is robust to Montague's remarks and it is based on more recent evaluation attempts. In any case, risk analysis's objective, which is going to be the subject of chapter 6 of this dissertation, will be the assessment of any important or less important deviations in the project's critical variables.

In addition, this section has examined strictly Crossrail's likely profitability, so any shifts from other transport modes to Crossrail, which will generate losses to them, are going to be evaluated in the economic and social analysis of the project.

3.3 Financial Return on Capital

After analyzing the project's total costs and revenues, it is prudent to move on with the financial return on the capital invested for the construction and operating life procedures. In other words, we are going to evaluate the financial indicators of the project, like NPV with different discount rates, BCR at our benchmark rate for all reasons explained above (see footnote 55) and IRR. Moreover, given that Crossrail is totally funded by the British public sector at this time, financial return on capital is equivalent to the financial return on national capital.

The data extracted from the official sources of Crossrail (Crossrail Ltd, GLA, DfT, TfL, ORR and ONS) have yielded the following financial indicators which we are going to consider in our analysis. For the 60-year period appraisal, NPV at our benchmark 5% rate is negative with a BCR close (slightly under) to 1. Although at this relatively high rate these two indicators do not give a totally green light for the investment, it is important to consider that, in the writer's opinion, an infrastructure project of that magnitude is more likely to bring more economic than financial benefits. In addition, we discussed above the necessity of a higher rate due to the severe European economic conditions and, for this reason, it is remarkable to see that Crossrail indicators approach the acceptance area even at this rate.

[63] **Montague A. et al.**, *The Montague Review, Department of Transport*, p.21-22, UK 2004

At lower discount rates (including the one that HM Treasury Green Book suggests, 3.5%), NPV takes positive values, which makes the investment completely viable financially, without taking into consideration wider economic benefits. This means that, even if a private institution had undertaken the investment, it would have been approved by the CBA management team. Finally, the project's financial IRR (at which NPV is equal to 0) is approximately 4.6% and the payback period has been calculated to almost 25 years[64].

In the tables below, we specify the numbers described above and in the figure we see the NPV response to different discount rates (which yields to zero at 4.6%). * denotes that inflation projections have been included.

Table 3.4 Crossrail, Financial evaluation

Time (years)	2009	2017	2021	2025	2030	2040	2050	2060	2068
Trend	1	9	13	17	22	32	42	52	60
Investment Costs*	-1,623,563,523	-1,623,563,523	0	0	0	0	0	0	0
Tunnels, stations, railway systems	-984,830,560	-984,830,560	0	0	0	0	0	0	0
Land and property	-90,041,651	-90,041,651	0	0	0	0	0	0	0
Indirect costs and project management	-182,897,104	-182,897,104	0	0	0	0	0	0	0
Depot Costs	-42,207,024	-42,207,024	0	0	0	0	0	0	0
On network works	-323,587,184	-323,587,184	0	0	0	0	0	0	0
Maintenance Costs*	0	0	0	-1,161,820,047	0	0	0	0	0
Operating Costs*	0	-133,963,558	-133,963,558	-133,963,558	-133,963,558	-133,963,558	-133,963,558	-133,963,558	-133,963,558
Estimated Revenues*	0	1,088,955,271	1,088,955,271	1,088,955,271	1,088,955,271	1,088,955,271	1,088,955,271	1,088,955,271	1,088,955,271
Depreciation	-246,666,667	-246,666,667	-246,666,667	-246,666,667	-246,666,667	-246,666,667	-246,666,667	-246,666,667	-246,666,667
EBIT	-1,870,230,190	-915,238,477	708,325,046	-453,495,001	708,325,046	708,325,046	708,325,046	708,325,046	708,325,046
Tax Rate	0	0	0	0	0	0	0	0	0
NOPAT	-1,870,230,190	-915,238,477	708,325,046	-453,495,001	708,325,046	708,325,046	708,325,046	708,325,046	708,325,046
Add Back Depreciation	246,666,667	246,666,667	246,666,667	246,666,667	246,666,667	246,666,667	246,666,667	246,666,667	246,666,667
Net Cash Flow	-1,623,563,523	-668,571,810	954,991,713	-206,828,335	954,991,713	954,991,713	954,991,713	954,991,713	954,991,713
Cumulated Net Cash Flow	-1,623,563,523	-13,657,079,994	-9,837,113,143	-7,178,966,340	-2,404,007,777	5,984,089,302	14,372,186,381	22,760,283,459	29,238,397,113

[64] The formula used for the payback period is the following:

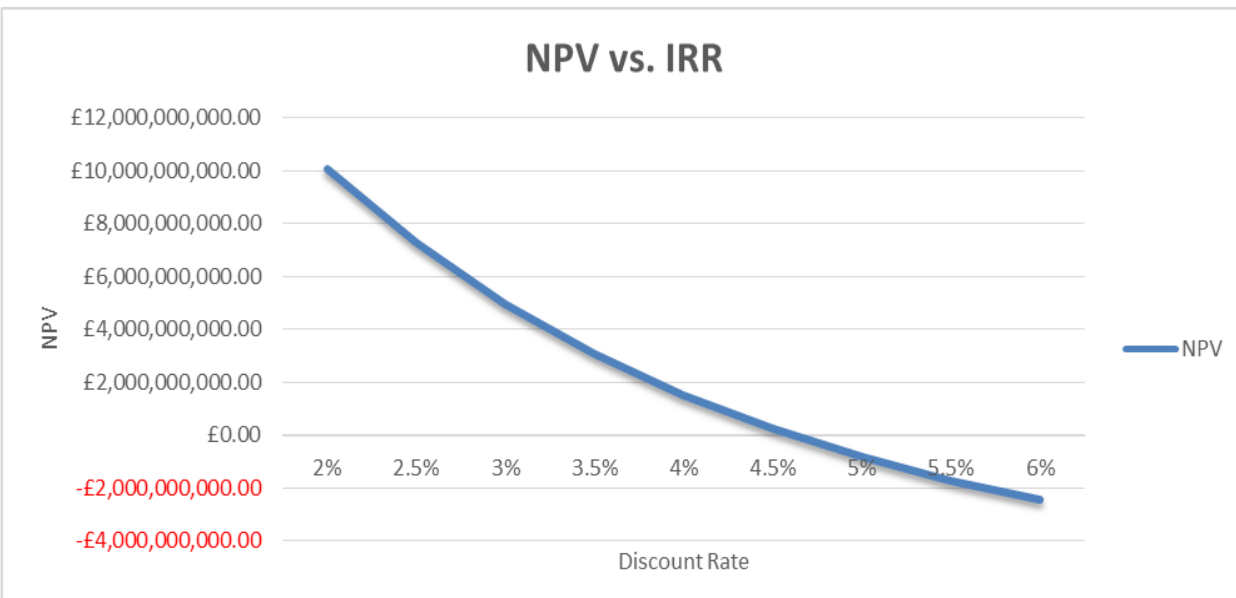
$$Payback\ Period = Years\ before\ full\ recovery + \frac{Uncovered\ cost\ at\ start\ of\ year}{Cash\ flow\ during\ year}$$

Bringham E., Houston J., *Fundamentals of Financial Management 11th edition*, p.373-375, Thomson/South-Western, 2007

Table 3.5 Crossrail, Financial indicators

Net Present Value @	2%	£10,046,051,869.01
Net Present Value @	2.5%	£7,254,514,654.36
Net Present Value @	3%	£4,964,716,011.51
Net Present Value @	3.5%	£3,080,079,363.31
Net Present Value @	4%	£1,524,070,855.72
Net Present Value @	4.5%	£235,790,621.92
Net Present Value @	5%	-£833,421,927.00
Net Present Value @	5.5%	-£1,722,610,441.48
Net Present Value @	6%	-£2,463,233,953.49
IRR	4.6026%	
BCR @ 5%	0.9422	
Payback Period	24.5173	

Figure 3.1 Crossrail, NPV response to discount rate



In table 3.4, the main scope of our calculations is to generate an annual net cash flow in order to figure out the NPV of the investment by discounting at different rates. In this case, the negative relationship between the NPV and the discount rate is obvious, as it is illustrated in figure 3.1. The negative value of NPV at certain rates above IRR has not to be regarded as financial failure of the project. On the one hand, the main objective of an infrastructure project is to contribute to the wider economy and the GDP rather than generate earnings, which may be raised by the public sector through the increased economic activity due to the project. On the other hand, the operating period may be greater than the appraisal period suggested in the literature, which may produce a positive NPV even at higher rates. Finally, the procedure of discounting at different rates serves as a stress test to the NPV indicator, since economic conditions during the 60-year appraisal are not likely to remain stable. For this reason, in the writer's opinion, it would be prudent not to stick to the benchmark rate or the one proposed by the HM Treasury Green Book.

3.4 Financial Sustainability and Sources of Finance

The subject of this section is the financial sustainability of the whole Crossrail project during its operating life. Our main issue is the value of the cumulated net cash flow, which has to be positive during the operating life of the project. If we take a look again at table 3.4 and incorporate in our analysis the rest of the operating life (the entire MS Excel file with the Crossrail Appraisal is attached at the end of the essay), we can confirm that after the payback period the cumulated net cash flow remains positive for the entire appraisal period. This means that under the current financial and economic conditions the soundness of Crossrail's financials is secured.

This scenario permits the sponsors to continue with their plan A respective to the repayment of their loans from other institutions, which were directed to the construction of Crossrail. In detail, these loans constitute the 40% of the total Crossrail investment costs, while the remaining 60% is funded by London taxpayers[65]. For instance, the TfL's "prudential borrowing" scheme mentioned in chapter 2 in the financial planning section is about to be financed by Crossrail farepayers. PWLB and EIB loans will receive their annual payments of a total of approximately £3 billion based on farepayers contributions[66].

We must not forget, though, the provisions of the private sector involvement in the project. This may happen in any case or it might be inevitable due to financial difficulties in the future. For example, in case of a negative cumulated net cash flow in any year of operation after payback period, Crossrail Ltd must find new sources of finance for the project. This would be achieved with a purchase of any percentage of Crossrail's equity by a third party (private or not). Under the provisions discussed in the beginning of chapter 2, cost effectiveness must be the objective of the purchase, thus Crossrail may repay its loans using the funds of the new party. Moreover, in case of a new private sector contributor, extra public income will be generated due to taxation on operating profits.

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[65] **Roukouni A., Medda F.**, Evaluation of Value Capture mechanisms as a funding source for urban transport: the case of London's Crossrail, *Social and Behavioral Sciences 48 (2012)*, p.2393-2404, 6/2012 and **Crossrail**, *Funding*, url: http://www.crossrail.co.uk/about-us/funding

[66] **Greater London Authority**, *Intention to levy a business rate supplement to finance the Greater London Authority's contribution to the Crossrail project* (Final Prospectus), 1/2010 and **Crossrail**, *Funding*, url: http://www.crossrail.co.uk/about-us/funding

4. Economic Analysis

This chapter is the most essential one for the whole Crossrail project and its economic sustainability, which means that we are going to estimate its economic indicators based on the available data and then evaluate its entire contribution to the economy of UK and, especially, London. For this purpose, our first goal will be to convert market prices of total costs and revenues into accounting (or shadow) ones using a conversion factor. Thus, the next step will be to incorporate in our analysis the wider economic effects of Crossrail, after monetizing them, like any impacts on the transport network, environmental consequences, and contributions to GDP through new standards of economic activity.

4.1 Conversion of Market to Accounting Prices

The procedure of price conversion is going to help us avoid any price distortions generated in the market that might have affected product prices, especially the ones used during construction period. Unlike financial analysis, economic analysis is more comprehensive by estimating all possible socio-economic costs and benefits and not only the business case of a project.

In our analysis, the Conversion Factor (CF hereinafter) and accounting prices are given by the following relationship[67]:

$$CF = \frac{Accounting\ Price}{Market\ Price} <=> Accounting\ Price = CF * Market\ Price$$

In order to get a more or less accurate version of the value of CF which is going to be used, we will adopt the definition of the Standard Conversion Factors (SCF hereinafter). SCF is based on imports and exports and their respective tax rates (higher for imports, lower for exports) and is given by the relationship[68]:

$$SCF = \frac{M + X}{(M + T_m) + (X - T_{x)}}$$

where M and X stand for imports and exports, respectively, and T for their respective tax rate.

For this purpose, the necessary data related to imports and exports was available at UK Overseas Trade Statistics, where we found that imports' and exports' values in British Pounds were £30.5 billion and £23.5 billion, respectively[69]. It is important to mention that it is a quiet

67 **Brent R. J.**, *Applied Cost-Benefit Analysis 2nd Edition*, p.109-112, Edward Elgar, 2006

68 **European Commission, Directorate of Regional Policy**, *Guide to Cost-Benefit Analysis of Investment Projects, Structural Funds, Cohesion Fund and Instrument for pre-Accession*, p.50-52, 2008

69 **UK Overseas Trade Statistics**, *August 2015 Update*

difficult process to estimate the appropriate tax rates because in each product group applies a different tax rate. For this reason, we are going to assume a 40% tax rate on imports and a 22% on exports, based on Evans' estimates for UK[70].

Using the correct data, we are ready to generate the SCF that is going to be applied from now on in our analysis:

$$SCF = \frac{30.5 + 23.5}{(30.5 + 12.2) + (23.5 - 5.17)} = 0.885$$

This number means that we will continue with the 88.5% of the value of each annual payment used in the financial analysis, because the additional 11.5% is explained by market forces and does not reflect the real value of the payments (costs and revenues). In detail, the accounting price of the annual payment of the construction costs from 2009 till 2017 will be:

$$1{,}623{,}563{,}523 * 0.885 = £1{,}436{,}853{,}718$$

while that of the estimated revenues will be:

$$1{,}088{,}955{,}271 * 0.885 = £963{,}725{,}414$$

These new values, among others that we are going to discuss in this chapter, have been introduced in the economic and social evaluation of Crossrail and they can be examined in detail in the Crossrail Appraisal file which is attached at the end of the essay.

4.2 Impacts on London Transport Network

It is quiet easy to understand until now that a mega-project like Crossrail could not have left unaffected London's transport network. The existence of the new rail not only is capable of bringing more people daily and annually to London, but it can also reduce the journeys' duration and make the whole rail network more effective. In this section, we aggregate to the economic analysis the quantified effects of these parameters, according to the literature about Crossrail.

4.2.1 Route duration and time savings

The most significant change that Crossrail is about to bring in this sector is the new direct connection between the National Rail networks running in to Paddington and Liverpool Street (see Maps 1.1 and 2.1). The benefit from this is not just in terms of passengers willing to travel across London. Crossrail is going to allow direct access to and from the new stations

[70] **Evans D.**, The elasticity of Marginal Utility of Consumption: Estimates for 20 OECD Countries, *Fiscal Studies 26 (2)*, p.197-224, 2005

across the center of London, with passengers no longer having to change at the termini of the existing National Rail routes. These improved connections are about to reduce journey times between locations served by Crossrail by a significant amount. In addition, we must not disregard the fact that these benefits are going to spill over the rest transport system of London, especially the railways that are connected to Crossrail[71].

Some examples of journey time reduction are shown in the table below.

Table 4.1 Crossrail, impacts on example journey times **Source: Crossrail Business Case Update (2011)**

Example Journey	2010 existing journey time	Crossrail journey time
Slough to Tottenham Court Road	55mins	32mins
Ilford to Bond Street	35mins	25mins
Heathrow to Liverpool Street	55mins	32mins
City/Liverpool Street to Abbey Wood	40mins	18mins
Paddington to Canary Wharf	30mins	16mins

It is worth mentioning that time savings are the largest single element of the economic benefits. As we discussed, these accrue as a result of faster journey times on rail and road (due to Crossrail connections and relieved congestion[72]), the reduced need to interchange, and changes in walk and wait times for all transport users. The monetization of time savings for both leisure and business trips has yielded a PV of £12.832 billion[73]. This number is a sum of leisure and business trips time savings and not a single value because of the different value of time between these parameters[74].

Like in the previous chapter, we inserted this value into MS Excel Solver in order to figure out the annual benefit for the 60-year appraisal period, using our benchmark discount rate of 5%. Benefits start by 2017, when Crossrail services are about to begin. Using the data from the *Economic Appraisal of Crossrail* we derive a benefit of £696,706,979 annually, which we have introduced into the Crossrail Appraisal spreadsheet for the purposes of the economic evaluation.

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71 **Crossrail Business Case Update**: Summary Report, p.5-6, 7/2011
72 **Ibid.** p.3
73 £7.685 billion for leisure and £4.847 billion for business trips
Economic Appraisal of Crossrail, p.3, 2005
74 **Ibid.** p.2

Table 4.2 Crossrail, Time savings   Data source: Economic Appraisal of Crossrail (2005)

Period	Time savings
2016	0
2017	696706979.8
2018	696706979.8
2028	696706979.8
2038	696706979.8
2048	696706979.8
2058	696706979.8
2068	696706979.8
NPV	£12,832,000,000.0000

4.2.2 Impact on congestion and other means of transport

Earlier, in the demand analysis section, it was stressed the importance of a big infrastructure investment like this one due to the growing population in UK, and especially the City of London, and the projections related to increased employment until 2026. These factors have created the need for a renovated railway system, giving birth to the realization of Crossrail. Two of the most important features of the project is the expected congestion relief and reduced crowding. As it was stated before, Crossrail is about to increase London's rail capacity by 10% and this translates into 20% to 60% reduced congestion to all central stations and different rail lines[75].

This congestion relief has a present value of £2.889 billion in British pounds terms, according to the *Economic Appraisal of Crossrail* conducted by TfL and the DfT. We followed our usual procedure in order to solve for the annual benefit of the reduced crowding in the Crossrail stations using the MS Excel Solver, which is up to £156,856,800 annually for the 60-year operating life of the project, starting from 2017. In the table below we illustrate the result that Solver yielded.

[75] **Crossrail Business Case Update**: Summary Report, p.4, 7/2011

Table 4.3 Crossrail, Congestion benefits Data source: Economic Appraisal of Crossrail (2005)

Period	Congestion
2016	0
2017	156856800.6
2018	156856800.6
2028	156856800.6
2038	156856800.6
2048	156856800.6
2058	156856800.6
2068	156856800.6
NPV	£2,889,000,000.0000

In the previous chapter, we estimated the annual revenues of Crossrail and we let for this chapter its probable impact on other means' of transport revenues. It is obvious that the crowding relief in trains and stations among London's rail network due to Crossrail's construction is about to redistribute the revenues pie for public transport operators.

Crossrail's £13.575 billion revenues derive from mode shift to rail, changed trip patterns resulting from user benefits provided by Crossrail and commercial opportunities on Crossrail trains within Crossrail stations. Moreover, network capacity and time savings increase the catchment of central London by making it more attractive and accessible as a destination. This comes at a cost to other modes of transport in terms of lost revenues with a present value of £7.426 billion. For instance, 56% of total Crossrail's revenues derive from other operators during the appraisal period, like National Rail (30%), LUL (21%), bus (3%) and DLR (2%). Under this constraint, in our economic analysis we subtract the transfers from other modes from Crossrail's revenues in order to find the net transport revenues that the new project is going to generate[76].

Using the same method in order to find the annual losses this time, Solver has yielded a value of £595,696,637. The table presents this annual result for selective years of operation.

[76] **Economic Appraisal of Crossrail**, p.3, 2005

Table 4.4 Crossrail, shifts from other modes	Data source: Economic Appraisal of Crossrail (2005)

Period	Shifts
2016	0
2017	-595696637
2018	-595696637
2028	-595696637
2038	-595696637
2048	-595696637
2058	-595696637
2068	-595696637
NPV	-£7,426,000,000.0000

4.3 Environmental Consequences

Another important aspect of the Crossrail project and an essential feature of the economic analysis is the climate change issue. In this section, we consider the pollution that is created or avoided due to the project during constructing and operating periods, and this is going to happen by evaluating the carbon dioxide emissions in tones, annually.

According to a Crossrail Ltd study, 33% of total carbon dioxide emissions in London originates from transports emissions. In detail, of the 36,852,641 tones of CO_2 per annum, 12,165,070 derive from transport, of which 8,988,228 tones are localized in London Authorities and 3,176,842 in other Authorities along the Crossrail route. This data serves as a baseline starting from 2000 and it is evident that transport accounts for a significant proportion of the CO_2 emissions in London. In areas outside London, but within the study area because of the Crossrail route, the influence of transport on CO_2 is even more pronounced[77]. The table below presents in numbers the situation just described.

Table 4.5 Baseline carbon dioxide emissions (tones per annum)	Source: Crossrail Environmental Statement

Area	Transport emissions	Total emissions	% of emissions due to transport
London Authorities only	8,988,228	29,552,688	30%
Other Authorities along the route	3,176,842	7,299,953	44%
All areas along the route	**12,165,070**	**36,852,641**	**33%**

[77] **Environmental Resources management**, *Crossrail Environmental Statement Volume 2*, Route wide and central route section impacts, prepared for the Department of Transport, chapter 7, p.20

Now, it is important to concretize this information and stick to the numbers that have to do with Crossrail, specifically. For this purpose, it is essential to distinguish the total emissions generated between construction phase emissions and emissions during operation. About construction phase, emissions have been assessed on a route-wide basis through summing emissions calculated for each construction site during the respective years. Moreover, it is important to mention that, during the event, the nominated undertaker will ensure the appropriate mitigation of any environmental phenomena, i.e. CO_2 emissions. For example, mitigation measure may demand the use of mains electricity on worksites instead of generators and the use of barges or trains rather than heavy goods vehicles to transport excavated material and waste, where circumstances allow. Finally, there is also left a margin for extra real savings related to air pollution during construction because management plans are developed over time. Under these provisions, the estimation of air pollution in the constructing period is 80,600 tones of carbon dioxide, annually[78].

In order to monetize this environmental effect, we are going to use the appropriate data from the Global Environmental Exchange by multiplying this number by the correct price of the European Emission Allowances for the period 2013-2020, which is €8.04 per tone of CO_2[79]. Using the current exchange rate (S=£0.72), this price translates into £5.76. Also, a 1% inflation rate will be assumed for the 60-year appraisal period[80]. In the following table, we illustrate the losses during construction in terms of British Pounds. It is mentioned, though, that 2017 is excluded from the table because operation starts gradually in that year and the net losses differ from the rest of the period.

Table 4.6 Crossrail, Air pollution losses during construction **Data source: Crossrail Environmental Statement and EEX**

Period	Emissions (tones)	Price per tone	Losses
2009	80,660	-5.7600	-464,602
2010	80,660	-5.8176	-469,248
2011	80,660	-5.8758	-473,940
2012	80,660	-5.9345	-478,679
2013	80,660	-5.9939	-483,466
2014	80,660	-6.0538	-488,301
2015	80,660	-6.1144	-493,184
2016	80,660	-6.1755	-498,116

[78] **Ibid.**
[79] **EEX**, *Market Data*, European Emissions Allowances, Global Environmental Exchange, url: https://www.eex.com/en/market-data/emission-allowances/spot-market/european-emission-allowances#!/2015/08/31
[80] Unlike the other variables used in financial and economic evaluation (investment and operating costs, revenues, maintenance etc.), this price does not include inflation provisions, so this procedure has been done manually in MS Excel.

The emissions assessment also includes the estimation of the net emissions during the operation of Crossrail, considering the forecasts for reduction in air pollution due to modal shift from road to rail. In particular, the energy required to operate Crossrail originates from the national grid and has a value of 61,442 of tones CO_2 per annum[81]. In addition, the projected reduction in emissions due to modal shift from road to rail is -62,756 tones of carbon dioxide, annually. By summing the two variables, we derive the net annual operational emissions of CO_2, which is -1,314 in terms of losses or 1,314 in terms of savings[82]. The table below illustrates the annual result in British Pounds for selected years during appraisal period, including 2017, when there are losses because construction is still in process. The monetization procedure is done, again, by using the inflated price of the European Emission Allowances.

Table 4.7 Crossrail, Air pollution savings/losses during operation **Data source: Crossrail Environmental Statement and EEX**

Period	Emissions (tones)	Price per tone	Losses/Savings
2017	79,346	-6.2373	-494,901
2025	-1,314	-6.7541	8,875
2035	-1,314	-7.4607	9,803
2045	-1,314	-8.2412	10,829
2055	-1,314	-9.1034	11,962
2065	-1,314	-10.0559	13,213
2068	-1,314	-10.3606	13,614

These calculations have been used in order to estimate the Economic NPV, IRR and B/C Ratio of the project, which are the main goals of this chapter and they are summarized right in the last section.

4.4 Economic Activity and Contributions to GDP

As we approach the end of this chapter, we could not have disregarded the impact of such a mega-project on wider economic activity and GDP. In particular, the sectors that have been included in the economic evaluation and affect directly the GDP are the increase in labor force participation, move to more productive jobs, pure agglomeration and imperfect competition. All these variables are subject to the employment growth scenarios[83].

As we examine employment growth over the next years of Crossrail operation, we may recall the population and employment forecasts which were evaluated in the demand analysis section in the respective figures. Now, it is time to concretize what fraction of those projections

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[81] This number is a forecast of the Department of Trade and Industry
Environmental Resources management, *Crossrail Environmental Statement Volume 2*, Route wide and central route section impacts, prepared for the Department of Transport, chapter 7, p.21
[82] **Ibid.**
[83] **Colin/Buchanan**, *The Economic Benefits of Crossrail* (prepared in association with Volterra), p.12, 10/2007

is enabled by Crossrail's operation. The base case scenario, according to a Colin/Buchanan research, is that the Crossrail-enabled jobs will reach the 14,000 by 2016, 26,000 by 2026 and 40,000 by 2036, with a margin of extra increase of job openings if high employment growth scenarios come true. In terms of labor force increase, the contribution of new jobs to the GDP is £872 million in present value terms for the 60-year appraisal period. In addition, an extra contribution to the GDP of Britain derives from the move to more productive jobs, which has a PV of £10.428 billion[84]. In other words, this last variable measures the net benefit of the worker's move to a job with higher salary and the additional output created due to this change. For example, if people move within UK, only the additional output is included in the appraisal, while if they originate from another country, the whole output is taken into account. To sum up this paragraph, we should keep in mind the contribution to GDP of labor increase and move to more productive jobs in present value terms and mention that 17% of the new job openings are due to Crossrail, while the respective percentage regarding the move to more productive jobs is 22%[85].

Another variable under consideration in this section is pure agglomeration. Agglomeration is the name given to the growth of productivity of existing workers as the density of employment around them increases. The right way to perform an analysis with this kind of data is to find an elasticity which measures the percentage change in productivity generated by a percentage change in density of employment[86]. According to the latest estimation by Colin/Buchanan, the elasticity used for the projections of the agglomeration benefits is 0.125 and the agglomeration net benefits have a PV of £5.967 billion under the base case scenario for the discounting period of the project. Finally, our last incorporation in the economic analysis is the benefit that imperfect competition creates because of the increased business activity due to the existence of Crossrail. This number has a present value of £485 million[87].

The last step of this section is the familiar process in this dissertation of solving for the annual payments of these present values during the 60-year discounting period using a 5% benchmark rate, with the constraint of equality among payments during appraisal period. The results of the process are illustrated in the following table for selected years.

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[84] **Ibid.** p.13
[85] **Ibid.** p.18-19
[86] **Wooldridge J. M.**, *Introductory Econometrics: a modern approach 4th edition*, p.46, South-Western, 2009
[87] **Colin/Buchanan**, *The Economic Benefits of Crossrail* (prepared in association with Volterra), p.13 and p.26, 10/2007

Table 4.8 Crossrail, Contributions to GDP Data Source: Colin/Buchanan (2007)

Period	Labor increase	More productive jobs	Agglomeration	Imperfect competition
2016	0	0	0	0
2017	69,949,834	836,510,170	478,659,013	38,905,584
2018	69,949,834	836,510,170	478,659,013	38,905,584
2028	69,949,834	836,510,170	478,659,013	38,905,584
2038	69,949,834	836,510,170	478,659,013	38,905,584
2048	69,949,834	836,510,170	478,659,013	38,905,584
2058	69,949,834	836,510,170	478,659,013	38,905,584
2068	69,949,834	836,510,170	478,659,013	38,905,584
NPV	£872,000,000	£10,428,000,000	£5,967,000,000	£485,000,000

4.5 Estimation of Economic Indicators

Every section of this chapter so far has been a step towards incorporating the wider economic and environmental effects of Crossrail in the appraisal. Our first attempt was to solve for the accounting prices of the costs and revenues of the financial analysis by estimating a SCF in order to avoid market distortions in the economic analysis. Afterwards, it was essential to include the factors which characterize the economic evaluation. These values helped us derive the economic net cash flows and produce the economic NPV at different discount rates, calculate economic IRR and find B/C Ratio.

In the following table and figure, it is evident (as projected in chapter 3) that Crossrail's economic NPV is more robust. This happens because of the economic welfare that a project like this creates, rather than the financial one. We see that even with a discount rate of 12%, economic NPV is still positive (IRR=12.5870%). In our 5% benchmark rate, economic NPV is £19.895 billion and B/C Ratio exceeds 2 by approximately half a tenth. At this point of the evaluation, we have reached a sound and updated B/C Ratio by including the most important impacts of Crossrail on the wider economy (transport, environment, businesses). This ratio is almost at the middle of the Crossrail Ltd base case and best case scenario (1.8-2.4)[88], and it has been produced by discounting at 5% and not at 3% or 3.5%, according to HM Treasury Green Book. This confirms our statement and our references along this passage, that the business case of such a project may be borderline (NPV around 0 at benchmark rates), but the economic one is definitely positive, promoting growth and more sustainable development.

[88] **Economic Appraisal of Crossrail**, p.4, 2005

Table 4.9 Crossrail, Economic indicators

Economic NPV @	5%	£19,895,838,516
Economic NPV @	7%	£10,176,528,587
Economic NPV @	9%	£4,771,500,135
Economic NPV @	11%	£1,603,237,027
Economic NPV @	13%	-£326,715,500
Economic NPV @	15%	-£1,531,675,349
Economic NPV @	17%	-£2,292,277,977
Economic NPV @	19%	-£2,770,454,816
Economic IRR		12.5870%
BCR		2.0463

Figure 4.1 Crossrail, Economic NPV response to discount rate

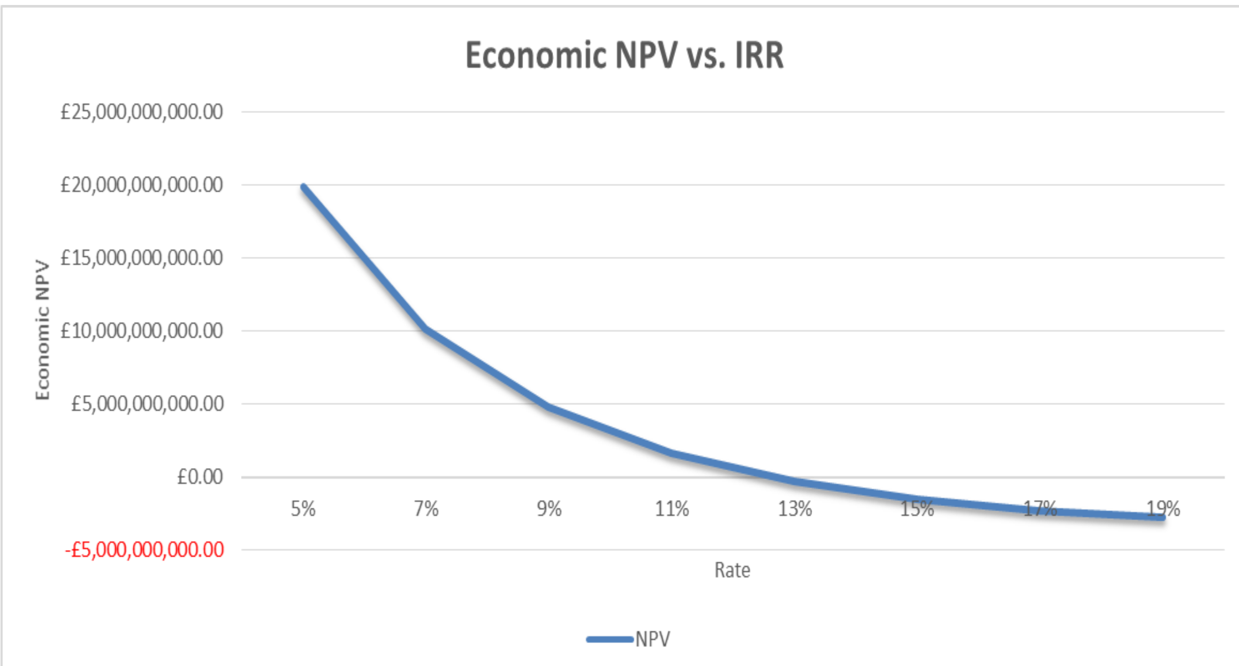

Table 4.10 Crossrail, Economic evaluation

Time (years)	CF	2009	2017	2025	2030	2040	2050	2060	2068
Trend		1	9	17	22	32	42	52	60
Investment Costs* (converted)	0.885	**-1,436,853,718**	**-1,436,853,718**	**0**	**0**	**0**	**0**	**0**	**0**
Tunnels, stations, railway systems		-984,830,560	-984,830,560	0	0	0	0	0	0
Land and property		-90,041,651	-90,041,651	0	0	0	0	0	0
Indirect costs and project management		-182,897,104	-182,897,104	0	0	0	0	0	0
Depot Costs		-42,207,024	-42,207,024	0	0	0	0	0	0
On network works		-323,587,184	-323,587,184	0	0	0	0	0	0
Maintenance Costs*		0	0	-1,161,820,047	0	0	0	0	0
Operating Costs*		0	-133,963,558	-133,963,558	-133,963,558	-133,963,558	-133,963,558	-133,963,558	-133,963,558
Estimated Revenues (converted)	0.885	0	963,725,415	963,725,415	963,725,415	963,725,415	963,725,415	963,725,415	963,725,415
Estimated Revenues*		0	1,088,955,271	1,088,955,271	1,088,955,271	1,088,955,271	1,088,955,271	1,088,955,271	1,088,955,271
Shift from other transport mode		0	-595,696,637	-595,696,637	-595,696,637	-595,696,637	-595,696,637	-595,696,637	-595,696,637
Time savings (Business and leisure)		0	696,706,980	696,706,980	696,706,980	696,706,980	696,706,980	696,706,980	696,706,980
Ambience and crowding		0	156,856,801	156,856,801	156,856,801	156,856,801	156,856,801	156,856,801	156,856,801
Carbon Emmissions during contstruction (tones)		80,660	80,660	0	0	0	0	0	0
Carbon Emmissions during operation (tones)		0	61,442	61,442	61,442	61,442	61,442	61,442	61,442
Reduction in Emmissions due to modal shift from road to rail (tones)		0	-62,756	-62,756	-62,756	-62,756	-62,756	-62,756	-62,756
Price per tone (with 1% inflation)		-5.7600	-6	-7	-7	-8	-9	-10	-10
Total Carbon Emmission Savings/Losses		-464,602	-494,901	8,875	9,328	10,303	11,381	12,572	13,614
Contributions to GDP		**0**	**1,424,024,602**	**1,424,024,602**	**1,424,024,602**	**1,424,024,602**	**1,424,024,602**	**1,424,024,602**	**1,424,024,602**
Increase in labor force participation		0	69,949,834	69,949,834	69,949,834	69,949,834	69,949,834	69,949,834	69,949,834
Move to more productive jobs		0	836,510,170	836,510,170	836,510,170	836,510,170	836,510,170	836,510,170	836,510,170
Pure Agglomeration		0	478,659,013	478,659,013	478,659,013	478,659,013	478,659,013	478,659,013	478,659,013
Imperfect Competition		0	38,905,584	38,905,584	38,905,584	38,905,584	38,905,584	38,905,584	38,905,584
Net Cash Flows		-1,437,318,319	1,074,304,983	1,349,842,429	2,511,662,929	2,511,663,905	2,511,664,983	2,511,666,174	2,511,667,216
Cumulated Net Cash Flows		-1,437,501,418	-10,424,557,393	8,506,919,961	21,065,233,694	45,020,048,229	68,974,873,075	92,929,709,312	111,861,223,290

5. Social Analysis

Our last type of evaluation will be the social one and, for this purpose, this short chapter is going to be supplementary to the economic analysis just performed. The reason that this part of the essay contains some different points from the previous lays in the attempt of estimating a social discount rate for the economic cash flows in order to find the Social NPV (SNPV hereinafter) of the Crossrail project. Moreover, we will try to find the intra- and inter-generational distribution of its benefits by extracting and managing the appropriate income and consumption data available at the Office of National Statistics.

5.1 Social Discount Rate and Social NPV

The method that is going to be used for the estimation of the social discount rate (SDR hereinafter) is based on the Social Time Preference Rate (or most commonly known as Consumption Rate of Interest) by Squire and van der Tak. Their model suggests that the SDR is equal to[89]:

$$i = eg + p$$

where e is the elasticity of marginal utility of consumption (or in other words the percentage response of consumption marginal utility to income's percentage deviations), g is the rate of consumption growth and p is the pure time preference.

According to the Pure Time Preference Theory, this last variable depicts the individuals' likelihood to consume in the present rather than in the future, given that present goods usually worth more than future goods of similar kind and quality. For this reason, the greater the value of pure time preference, the greater the aversion to consume in the present[90]. This theory helps us assume that pure time preference is equal to the market interest rate used by commercial banks for deposits up to one year. Thus, we can facilitate our calculations using the available data.

For the calculation of the SDR, we will use an elasticity of 1.25 estimated by Evans in his paper about elasticity of marginal utility of consumption estimates for 20 OECD countries, including UK, which is our case. This value (1.25) is an average of a low and a high estimate (1.1 and 1.4, respectively) according to his research paper[91]. Afterwards, we extracted the UK's

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[89] **Brent R. J.**, *Applied Cost-Benefit Analysis 2nd Edition*, p.366-370, Edward Elgar, 2006

[90] **Herbener J. M.**, *The Pure Time-Preference Theory of Interest (edited by Jeffrey M. Herbener)*, p.11-59, Ludwig von Mises Institute, 2011

[91] **Evans D.**, The elasticity of Marginal Utility of Consumption: Estimates for 20 OECD Countries, *Fiscal Studies 26 (2)*, p.197-224, 2005

annual per capita consumption growth from the World Bank Database (1.4%)[92] and, as a final step, the Statistical Data Warehouse of the European Central Bank was our source for the pure time preference rate for UK, based on the literature described previously (0.875%), which is also an average of the rate offered to households (1.25%) and the rate offered to businesses (0.5%)[93]. Using this data, the estimation of the SDR is:

$$SDR = 1.25 * 1.4 + 0.875 = 2.6250\%$$

Discounting the economic net cash flows (which are shown in the table for selected years) at this rate for the 60-year appraisal period, we generate a social NPV of £43,786,475,327, which is pretty much a rational estimation if the magnitude of the project is taken into account.

Table 5.1 Crossrail, Economic net cash flows and SNPV

Time (years)	Economic Net Cash Flows
2009	-1,437,318,319
2016	-1,437,351,834
2025	1,349,842,429
2030	2,511,662,929
2040	2,511,663,905
2050	2,511,664,983
2060	2,511,666,174
2068	2,511,667,216
Social NPV	£43,786,475,328

92 **The World Bank**, *Data / Household final consumption expenditure per capita growth (annual %)*, url: http://data.worldbank.org/indicator/NE.CON.PRVT.PC.KD.ZG/countries/GB?display=graph

93 **ECB Statistical Data Warehouse**, *Bank Interest Rate Statistics / Deposits*, url: http://sdw.ecb.europa.eu/browseChart.do?DATASET=0&REF_AREA=160&node=9484269&SERIES_KEY=124.MIR.M.GB.B.L22.F.R.A.2240.GBP.N&SERIES_KEY=124.MIR.M.GB.B.L22.F.R.A.2250.GBP.N

5.2 Distribution of Benefits

The main objective of this section is to determine the distribution of benefits to different income groups in the present (intra-temporal distribution) and over the next generations (inter-temporal). In other words, we will try to find the distribution weights of Crossrail for each income group, which means that the welfare enabled by the project varies, depending on the salary of each group[94]. In order to calculate these weights, we are going to use several macroeconomic indicators like marginal propensity to consume (MPC hereinafter), per capita weekly income and rate of return on public investments. The specified data has been extracted from Bank of England, Office for National Statistics and ECB working papers, respectively.

5.2.1 Intra-temporal distribution weights

According to the CBA theory, the intra-temporal distribution weights are given by the relationship[95]:

$$d_i = (\frac{\bar{C}}{C_i})^e$$

where d_i is the distribution weight for income group i, $\bar{C}$ is the average consumption per capita, C_i is the consumption of income group i, and e is the elasticity of marginal utility with respect to consumption which we introduced in the previous section.

In our case, we will assume the existence of three income groups, a low-income with a salary of £200 per week ($G_1 = 200$), an average-income with a salary of £535 per week ($G_2 = 535$) according to ONS, and a high-income group of £870 weekly ($G_3 = 870$)[96]. It is evident, though, that under normal circumstances workers do not spend all their salary, so in order to derive the consumption per group and the average consumption we have to use the MPC of each group. A Bank of England research suggests that the low-wage group has a MPC of 0.78, the average 0.7 and the high-wage 0.67. This number defines the percentage of the weekly, in our case, income which is directed to consumption[97].

Using this data, we are able to calculate the average consumption and the consumption per group in order to move on with the estimation of the intra-temporal distribution weights. The results are the following:

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[94] **Brent R. J.**, *Applied Cost-Benefit Analysis 2nd Edition*, p.323-358, Edward Elgar, 2006

[95] **Ibid.**

[96] **Office for National Statistics**, *Sustainable Development Indicators*, 7/2015

[97] **Bunn P., Le Roux J., Johnson R., McLeay M.**, *Influences on household spending: evidence from the 2012 NMG Consulting survey*, Bank of England, Quarterly Bulletin, Q4/2012

$$C_1 = 200 * 0.78 = 156$$

$$C_2 = \bar{C} = 535 * 0.7 = 374.5$$

$$C_3 = 870 * 0.67 = 649.9$$

Keeping these values in mind and recalling the elasticity of marginal utility with respect to consumption used in the previous section (1.25), we may now calculate the weights of each group, which are:

$$d_1 = (\frac{374.5}{156})^{1.25} = 2.9882$$

$$d_2 = (\frac{374.5}{374.5})^{1.25} = 1$$

$$d_3 = (\frac{374.5}{649.9})^{1.25} = 0.5021$$

Stepping into the interpretation of these weights, it is highly observable that welfare enabled by Crossrail is more important to the low-wage group at this specific point of time because the benefits directed to it have almost the triple worth, while for the high–income group, the project's benefits are less significant and their worth to it is down to approximately half. The average group yields a weight of 1, which means that the benefits that enjoys due to Crossrail construction and operation are equal to their original value.

5.2.2 Inter-temporal distribution weights

The last goal of this chapter is to figure out the value that this investment program is going to have for the income groups we discussed previously, but among different generations over the next years of operation. In order to derive the complete distributional weight for every group i for the next generations (ω_i), it is necessary to find the value of public income (v) given by the equation:

$$v = \frac{(q - sq)}{(r - sq) * \beta}$$

where q is the rate of return on public capital, s and r are the MPC and SDR, respectively, used in the previous section and β is the SCF that was used in chapter 4 in order to convert market prices into accounting ones. If $v > 1$, then a unit of public income is valued more than a unit of consumption[98].

The new variable in this relationship is the rate of return on public capital, or in other words, the average return on public investments. According to a research paper of ECB written by Afonso and St. Aubyn, the value of this variable for UK is 2.28%[99]. In addition, we are going to use the MPC of the average-income group in this formula not only for convenience, but because it is more representative for the majority of the British population. Based on the data used so far, our estimate for the value of public income is:

$$v = \frac{2.28 - 0.7 * 2.28}{(2.625 - 0.7 * 2.28) * 0.885} = 0.7511$$

which means that a unit of public income is equal to 75.11% of a unit of consumption. As a last step, we solve for the complete weights of our income groups using the following formula:

$$\omega_i = \frac{d_i}{v}$$

For the low-wage, average-wage and high-wage groups, the inter-generational distribution weights are, respectively:

$$\omega_1 = \frac{2.9882}{0.7511} = 3.9784$$

$$\omega_2 = \frac{1}{0.7511} = 1.3314$$

$$\omega_3 = \frac{0.5021}{0.7511} = 0.6684$$

It is evident that for the low-income group the inter-generational distribution of benefits is worth almost 4 times their original value, while the high-income group finds the Crossrail project less useful inter-temporally, yielding a weight of almost 0.7. For the average-income group, the benefits of Crossrail are equal to 1.3314 times their original value.

As a conclusion to this chapter, we may highlight the findings of our estimates in the last section, which suggest that this specific infrastructure investment is likely to be more important to the low and average-income population or, in other words, the majority of the British capital.

[98] **Xepapadeas A.**, Social Cost-Benefit Analysis, Intra-generational and Inter-generational Distribution, *Cost-Benefit Analysis of Investment Projects*, Lectures 2015

[99] **Afonso A., St. Aubyn M.**, *Macroeconomic rates of return of private and public investment: crowding-in and crowding-out effects*, ECB Eurosystem Working Paper Series No. 864, 2/2008

Similarly, the low weights of the high-income residents explain their ability to move comfortably from/within/to London without the existence of Crossrail.

6. Risk Analysis

As a last step of the evaluation of Crossrail, our analysis concentrates on the risk during the construction and operating life of the project. For this purpose, the appropriate tools for the risk evaluation will be the Sensitivity Analysis and the Monte Carlo Simulation. Both methods yield an estimate of the NPV changes when certain variables deviate from their base case estimation over time. Their difference lies in the fact that during Monte Carlo Simulation the key procedure is to assign distributions to the critical variables, which take random values around their best estimate, while in Sensitivity Analysis each changing variable by a certain percentage is examined alone.

6.1 Sensitivity Analysis

6.1.1 Determination of critical variables

The process of Sensitivity Analysis is conducted by varying one variable at a time and determining its effect on financial indicators[100]. At this condition, the main objective in this section is to figure out the NPV and IRR response to the critical variables. This implies that the first scope of this section is to determine which variables are the critical ones during the evaluation of Crossrail. According to the European Commission Guide to Cost-Benefit Analysis of Investment Projects, a variable can be considered critical when a 1% deviation can lead to a 1% or more change in the NPV, or, in other words, when the elasticity of the NPV with respect to each variable is equal to or greater than unity[101].

In order to determine the critical variables of the investment program, it is necessary to recall Crossrail's NPV at the 5% benchmark rate from chapter 3, which is -£833,421,927[102]. Keeping this in mind, we may now calculate the NPV and IRR response to the variables' annual changes in the financial analysis, which are the investment costs, the operating and maintenance costs, the estimated revenues and the discount rate[103]. The results of this sensitivity test are summarized in the table below.

[100] **European Commission, Directorate of Regional Policy**, *Guide to Cost-Benefit Analysis of Investment Projects, Structural Funds, Cohesion Fund and Instrument for pre-Accession*, p.60-62, 2008 and **Schnabl A., Platzer G., Ecker M., Fritzsche H., Hochmuth B., Koch S., Lappöhn S., Pohl A.**, *Guidelines for cost-benefit-analysis of infrastructure projects*, Institute for Advanced Studies – Vienna, p.19-21, 3/2014

[101] **European Commission, Directorate of Regional Policy**, *Guide to Cost-Benefit Analysis of Investment Projects, Structural Funds, Cohesion Fund and Instrument for pre-Accession*, p.60-62, 2008

[102] About Crossrail's negative financial NPV see chapter 1 section 1.1.2 and chapter 3 section 3.3

[103] Changes in maintenance costs occur every 10 years and discount rate deviations remain fixed for the whole 60-year appraisal period

Table 6.1 Crossrail, determination of critical variables (financial analysis)

Determination	NPV	%Δ NPV	IRR	%Δ IRR
Investment +1% p.a.	-£948,821,927	-13.8465%	4.5509%	-1.1235%
Investment -1% p.a.	-£718,021,927	13.8465%	4.6550%	1.1401%
Operation +1% p.a.	-£850,121,927	-2.0038%	4.5944%	-0.1769%
Operation -1% p.a.	-£816,721,927	2.0038%	4.6107%	0.1767%
Maintenance +1%	-£845,406,146	-1.4380%	4.5966%	-0.1287%
Maintenance -1%	-£821,437,708	1.4380%	4.6085%	0.1285%
Revenues +1% p.a.	-£697,671,927	16.2883%	4.6685%	1.4319%
Revenues -1% p.a.	-£969,171,927	-16.2883%	4.5362%	-1.4423%
Rate +1%	-£929,869,179	-11.5724%	4.6026%	0.0000%
Rate-1%	-£735,180,643	11.7877%	4.6026%	0.0000%

In the table, all variables of the project seem to have considerable impact on its NPV. By taking a glance at the % NPV change, the ones which prevail are the investment costs, the estimated revenues and the discount rate. Moreover, IRR is resistant to the discount rate changes given that the annual net cash flows are not affected. The remaining two variables, i.e. operating and maintenance costs, appear to have minor effects on the NPV and the IRR related to the rest. It is evident that these variables play quite an important role in the financial analysis of Crossrail and their stand-alone risk is very considerable during the financial evaluation.

The same variables are expected to affect equivalently the project's viability in the economic analysis, too, but the existence of the SCF, which was used previously in order to convert the market prices into accounting ones, in combination with the environmental implications and Crossrail's expected contributions to the GDP of Britain focus our attention on these variables in the Sensitivity Analysis of the economic evaluation. For this reason, the same sensitivity test was performed in order to figure out the variables to which economic NPV and economic IRR are sensitive. At this point we may recall again the benchmark values which are £19,895,871,577.41 and 12.5870%, respectively, at a 5% discount rate.

In the table that follows, we note the reduced impact of the variables which are more critical to the financial analysis of the project on the ENPV and the EIRR, except the discount rate. ENPV's elasticity with respect to the discount rate still remains at the "critical variable area" with a value of 1.6% approximately, as it can be seen in the %Δ ENPV column. Not surprisingly enough, the other variables taken into consideration in the economic analysis do not seem to have a great impact on the core economic indicators, except the contributions of the project to the GDP of UK, which affects the ENPV by almost a percentage unit. In the first place, it is evident that this happens because during the economic evaluation many extra variables have been taken into account and each one affects the investment program's viability by a small amount, which is very important, though, in order to yield the current and by far positive ENPV.

Table 6.2 Crossrail, Determination of critical variables (economic analysis)

Determination	ENPV	%Δ ENPV	EIRR	%Δ EIRR
Investment +1% p.a.	£19,793,709,516	-0.5133%	12.4975%	-0.7114%
Investment -1% p.a.	£19,997,967,516	0.5133%	12.6779%	0.7218%
Operation +1% p.a.	£19,879,138,516	-0.0839%	12.5821%	-0.0394%
Operation -1% p.a.	£19,912,538,516	0.0839%	12.5920%	0.0394%
Maintenance +1%	£19,883,854,296	-0.0602%	12.5843%	-0.0213%
Maintenance -1%	£19,907,822,735	0.0602%	12.5897%	0.0213%
Revenues +1% p.a.	£20,015,977,266	0.6038%	12.6226%	0.2829%
Revenues -1% p.a.	£19,775,699,766	-0.6038%	12.5513%	-0.2835%
Rate +1%	£19,571,475,444	-1.6303%	12.5870%	0.0000%
Rate-1%	£20,225,500,643	1.6569%	12.5870%	0.0000%
GDP contr. +1%	£20,073,358,516	0.8922%	12.6396%	0.4178%
GDP contr. -1%	£19,718,318,516	-0.8922%	12.5343%	-0.4191%
CO2 constr. +1%	£19,895,804,251	-0.0002%	12.5870%	-0.0002%
CO2 constr. -1%	£19,895,872,780	0.0002%	12.5870%	0.0002%
CO2 oper. +1%	£19,895,782,275	-0.0003%	12.5870%	-0.0001%
CO2 oper. -1%	£19,895,894,757	0.0003%	12.5870%	0.0001%
CO2 reduc. +1%	£19,895,895,960	0.0003%	12.5870%	0.0001%
CO2 reduc. -1%	£19,895,781,072	-0.0003%	12.5870%	-0.0001%
CO2 price +1%	£19,895,805,454	-0.0002%	12.5870%	-0.0002%
CO2 price -1%	£19,895,871,577	0.0002%	12.5870%	0.0002%

Another conclusion which can be met after this kind of sensitivity test is that the economic indicators do not fluctuate that much by changing the values of the variables. It is remarkable that the ENPV remains positive and almost unaffected, while the EIRR does not exceed the range of 12.5%-12.7%. Therefore, the variables to be used in the sensitivity analysis are the discount rate and the total contributions to the GDP, given that the ENPV's elasticity with respect to them exceeds and it is close to unity, respectively.

6.1.2 Sensitivity analysis of financial indicators

Previously, it was proved the sensitivity of the financial NPV to the variables which take part in the financial analysis. Now it is time illustrate the results yielded in MS Excel by changing the value of the critical variables (one at a time) from -30% to +30% with a 5% step between each calculation. In the next table, it is proved with more precision the conclusion met before regarding the elasticity of the NPV with respect to certain variables. It is clear that discount rate, revenues per annum and investment costs per annum changes affect more the financial NPV by turning it positive after a certain rate of deviation. For instance, a 10% plummet of the discount rate or the annual investment costs makes our initially negative NPV positive, while a 10% increase in the annual revenues has exactly the same impact. The other two variables do not affect that much the NPV and leave its sign unaffected during this process.

Table 6.3 Financial NPV with respect to critical variables' changes

NPV	Rate	Revenues p.a.	Operation p.a.	Investment p.a.	Maintenance
-30%	£3,080,079,363	-4,905,921,927	-332,421,927	£2,628,578,073	-£473,895,349
-25%	£2,265,125,185	-4,227,171,927	-415,921,927	£2,051,578,073	-£533,816,445
-20%	£1,524,070,856	-3,548,421,927	-499,421,927	£1,474,578,073	-£593,737,542
-15%	£849,758,847	-2,869,671,927	-582,921,927	£897,578,073	-£653,658,638
-10%	£235,790,622	-2,190,921,927	-666,421,927	£320,578,073	-£713,579,734
-5%	-£323,559,808	-1,512,171,927	-749,921,927	-£256,421,927	-£773,500,831
0%	-£833,421,927	-833,421,927	-833,421,927	-£833,421,927	-£833,421,927
5%	-£1,298,395,674	-154,671,927	-916,921,927	-£1,410,421,927	-£893,343,023
10%	-£1,722,610,441	524,078,073	-1,000,421,927	-£1,987,421,927	-£1,827,639,234
15%	-£2,109,777,105	1,202,828,073	-1,083,921,927	-£2,564,421,927	-£1,013,185,216
20%	-£2,463,233,953	1,881,578,073	-1,167,421,927	-£3,141,421,927	-£1,073,106,312
25%	-£2,785,987,259	2,560,328,073	-1,250,921,927	-£3,718,421,927	-£1,133,027,409
30%	-£3,080,747,146	3,239,078,073	-1,334,421,927	-£4,295,421,927	-£1,192,948,505

The same procedure was followed in order to figure out the response of the financial IRR and the results were pretty much the same. The variables that affect the NPV more seem to have similar impact on the IRR, except the discount rate, of course, because its deviations do not affect the annual net cash flows. In the table below, the range of the IRR, when annual revenues and investment costs vary, is between 2.3%-6.4% and 3.3%-6.6%, respectively. Annual operating and maintenance costs (which occur every 10 years from 2025 and on) changes keep the IRR range between 4.3%-4.8% and 4.4%-4.7%, respectively.

Table 6.4 Financial IRR with respect to critical variables' changes

IRR	Rate	Revenues p.a.	Operation p.a.	Investment p.a.	Maintenance
-30%	4.6026%	2.3303%	4.8435%	6.6301%	4.7774%
-25%	4.6026%	2.7601%	4.8038%	6.2096%	4.7486%
-20%	4.6026%	3.1650%	4.7639%	5.8291%	4.7197%
-15%	4.6026%	3.5490%	4.7238%	5.4826%	4.6907%
-10%	4.6026%	3.9151%	4.6836%	5.1653%	4.6614%
-5%	4.6026%	4.2656%	4.6432%	4.8730%	4.6321%
0%	4.6026%	4.6026%	4.6026%	4.6026%	4.6026%
5%	4.6026%	4.9275%	4.5618%	4.3513%	4.5729%
10%	4.6026%	5.2417%	4.5208%	4.1169%	4.5431%
15%	4.6026%	5.5462%	4.4797%	3.8976%	4.5131%
20%	4.6026%	5.8419%	4.4384%	3.6916%	4.4829%
25%	4.6026%	6.1297%	4.3968%	3.4976%	4.4526%
30%	4.6026%	6.4101%	4.3551%	3.3145%	4.4221%

As a last step of the sensitivity analysis of the financial indicators, it is prudent to illustrate the spider diagrams of the NPV and the IRR which contain the percentage changes of all the critical variables. The ones with the sharpest slope have the greatest impact on both our financial indicators, while the remaining variables with the smooth slope compared to the others affect moderately the financial indicators. The IRR schedule with respect to discount rate deviations is flat, as described before.

Figure 6.1 Sensitivity Analysis, NPV spidergram

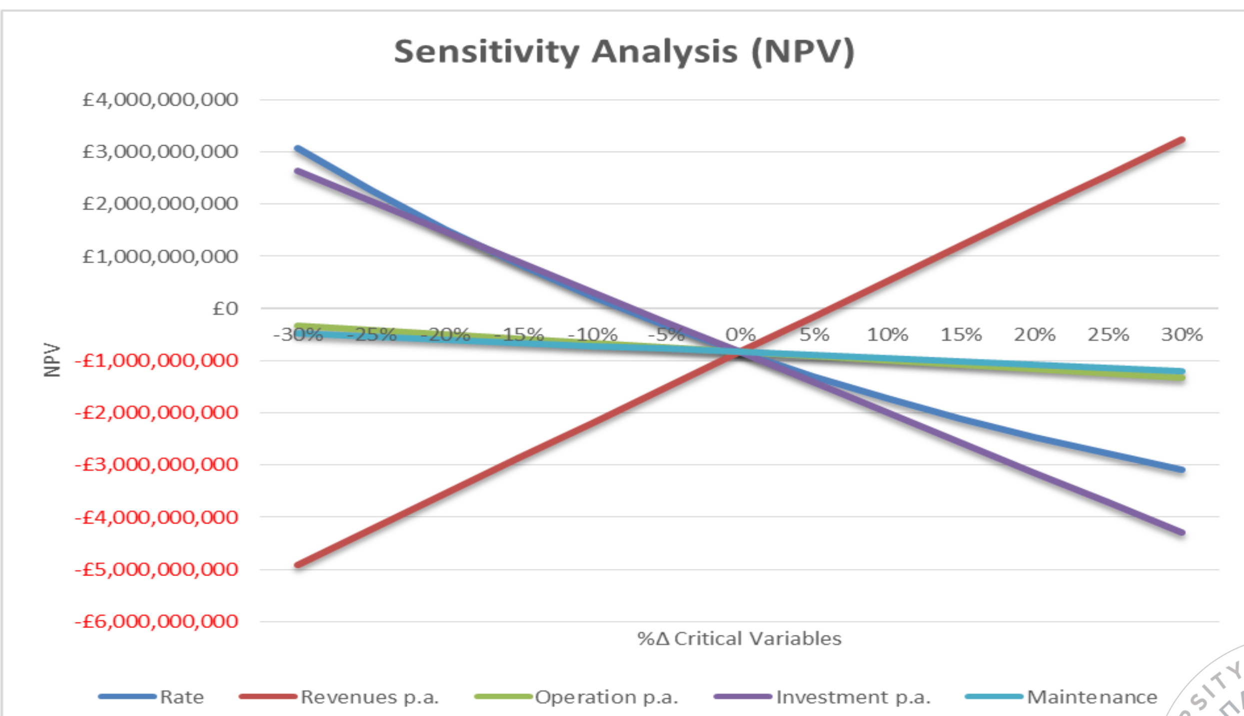
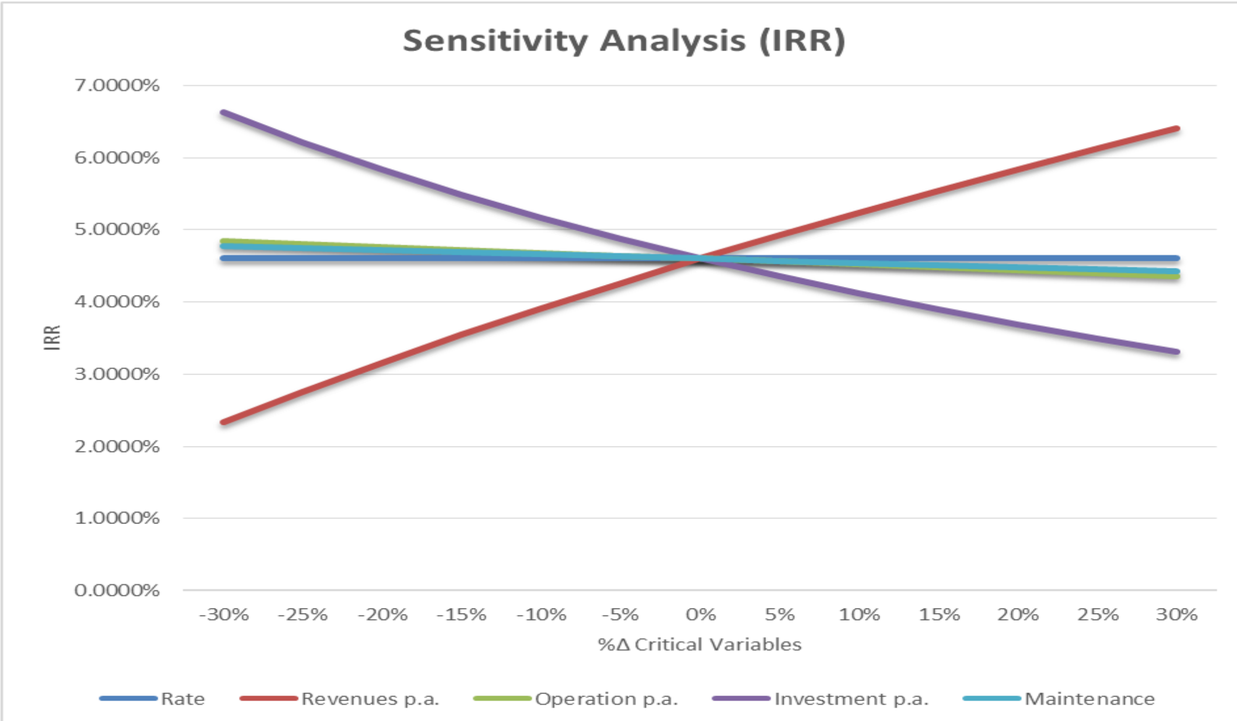


Figure 6.2 Sensitivity Analysis, IRR spidergram



6.1.3 Sensitivity analysis of economic indicators

Following the same path in this section by varying the critical variables within a range of ±30% from their base case value, we approach different ENPV and EIRR as the discount rate and the total contributions of the project to the GDP deviate from their best estimate. As it is obvious in the following tables, Crossrail has a robust economic viability given that ENPV never turns negative, while EIRR variations due to the stand-alone risk of the project's contribution to the GDP of Britain occur at higher levels related to the FRR changes discussed above.

Table 6.5 Economic NPV with respect to critical variables' changes

ENPV	Rate	Contributions to GDP p.a.
-30%	£32,627,109,606	£14,570,238,516
-25%	£30,028,121,331	£15,457,838,516
-20%	£27,645,406,922	£16,345,438,516
-15%	£25,458,329,079	£17,233,038,516
-10%	£23,448,434,499	£18,120,638,516
-5%	£21,599,204,985	£19,008,238,516
0%	£19,895,838,516	£19,895,838,516
5%	£18,325,056,518	£20,783,438,516
10%	£16,874,934,068	£21,671,038,516
15%	£15,534,750,163	£22,558,638,516
20%	£14,294,855,582	£23,446,238,516
25%	£13,146,556,173	£24,333,838,516
30%	£12,082,009,679	£25,221,438,516

Table 6.6 Economic IRR with respect to critical variables' changes

IRR	Rate	Contributions to GDP p.a.
-30%	12.5870%	10.9221%
-25%	12.5870%	11.2122%
-20%	12.5870%	11.4970%
-15%	12.5870%	11.7767%
-10%	12.5870%	12.0514%
-5%	12.5870%	12.3215%
0%	12.5870%	12.5870%
5%	12.5870%	12.8482%
10%	12.5870%	13.1053%
15%	12.5870%	13.3583%
20%	12.5870%	13.6074%
25%	12.5870%	13.8528%
30%	12.5870%	14.0946%

The tables above prove Crossrail's robust economic indicators, while in the following spidergrams it can be confirmed this statement although the slope of the ENPV with respect to the critical variables' variations is not smooth and generates significant changes which never result in a negative ENPV, though. The EIRR schedule formed by the deviations from the expected GDP contributions of the project is almost flat.

Figure 6.3 Sensitivity Analysis, ENPV spidergram

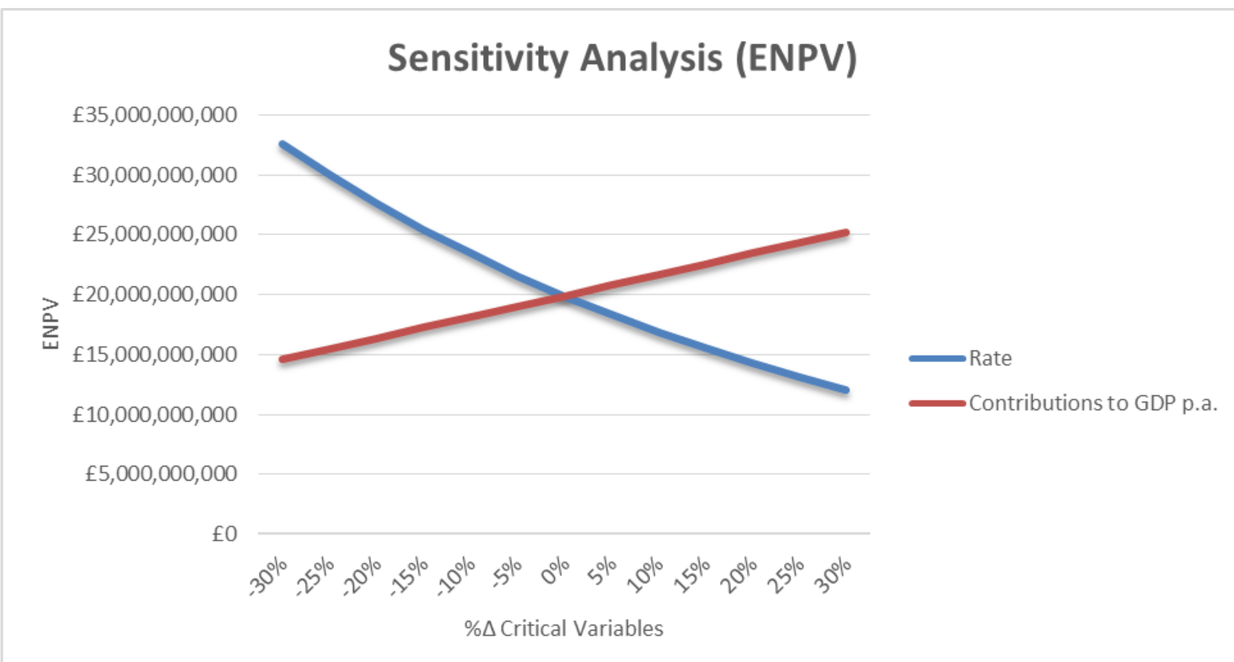
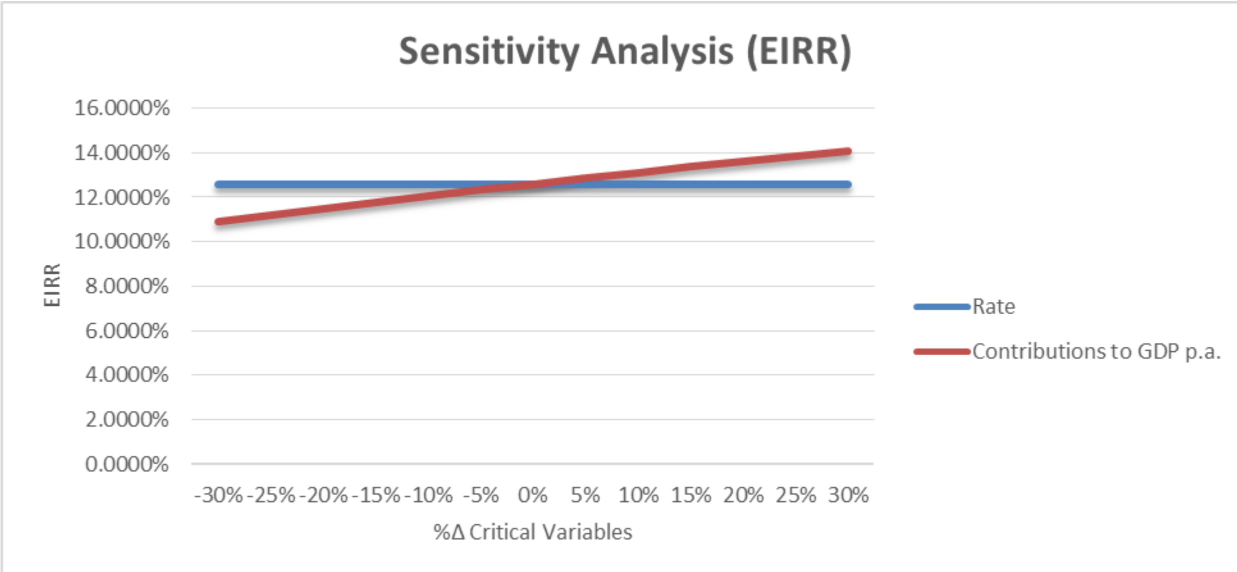


Figure 6.4 Sensitivity Analysis, EIRR spidergram



6.2 Monte Carlo Simulation

The other method which was used for the purposes of the risk analysis is the Monte Carlo Simulation. This process allows the assignment of certain probability distributions to the critical variables of the investment program and helps us calculate the NPV by taking into account different scenarios of every variable each time. This approach permits the inclusion of the variability of the critical variables and the probability of occurrence of events, unlike sensitivity analysis. Each of the critical variables is assigned a probability distribution defined in a precise range of values around the best estimate, used as the base case, in order to calculate the expected values of financial and economic indicators[104].

By assigning the correct distribution to each of our critical variables, it is more likely to achieve an accurate risk analysis. In the case of Crossrail, in which investment costs, estimated revenue and contributions to GDP have been proved critical, it is rational to assume a normal (Gaussian) distribution because of the small and independent changes that are expected to occur in each variable every year[105]. In order to build a histogram formed by NPV estimates around the base case, we created 1000 scenarios for every variable each year with the same probability of occurrence (p=0.001) and we plugged into the NORMINV function of MS Excel the best estimate of each variable as the mean and a portion of this mean (around 20%) as a standard deviation, combined with a random probability. In every sheet which contains the

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[104] **Schnabl A., Platzer G., Ecker M., Fritzsche H., Hochmuth B., Koch S., Lappöhn S., Pohl A.**, *Guidelines for cost-benefit-analysis of infrastructure projects*, Institute for Advanced Studies – Vienna, p.20, 3/2014

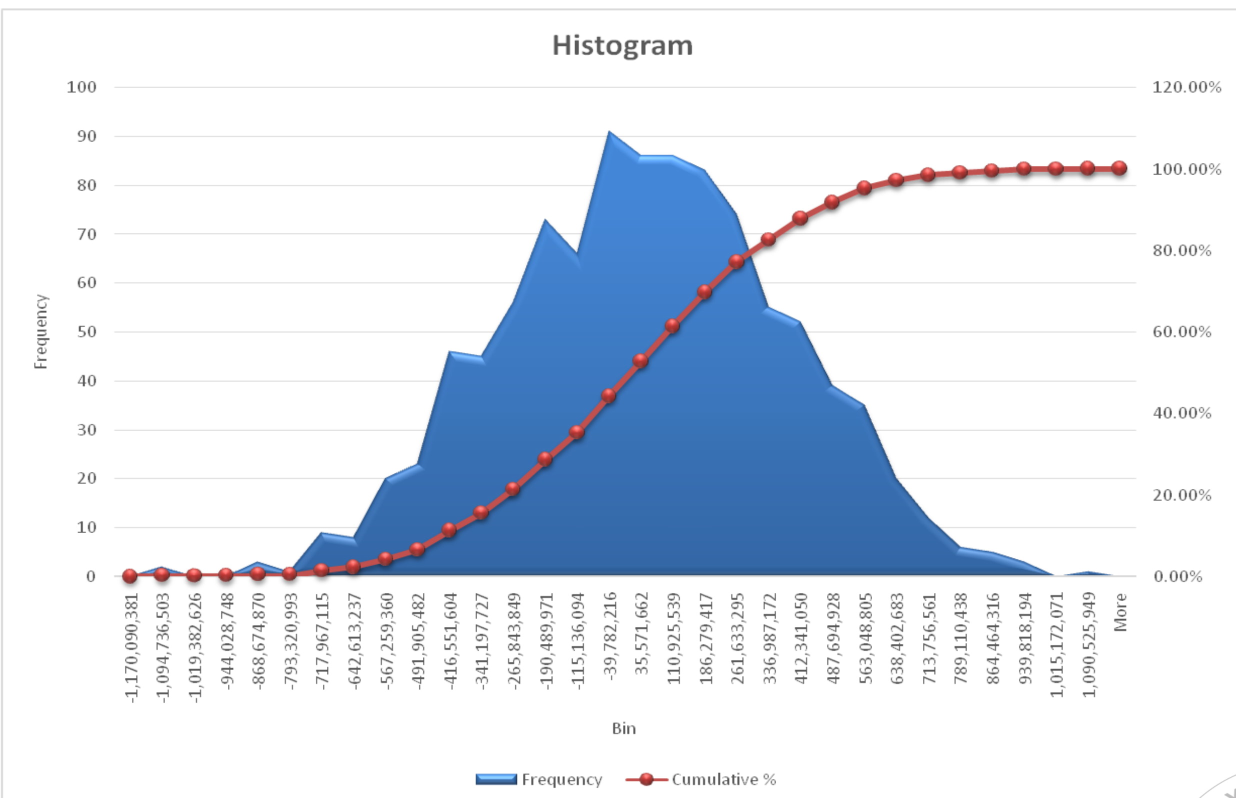
[105] **European Commission, Directorate of Regional Policy**, *Guide to Cost-Benefit Analysis of Investment Projects, Structural Funds, Cohesion Fund and Instrument for pre-Accession*, p.236-237, 2008

scenarios described above in the Crossrail Appraisal file attached at the end of the dissertation, it can be executed a Monte Carlo Simulation in real time by pressing F9. In addition, during the Monte Carlo of the financial analysis' variables (investment costs and estimated revenues) it has been used the IRR as a discount rate for convenience (4.6%), because it is close to the 5% benchmark that has been applied and gives a clearer picture of the responsiveness of FNPV from negative to positive and vice versa, depending on the random deviations from the base case of the critical variables. The ENPV which originates from the simulation applied on contributions to GDP is discounted at the familiar 5% benchmark rate.

6.2.1 Investment costs Monte Carlo

During the construction period of Crossrail, it was assumed an annual £150 million standard deviation around the mean (£-1,623,563,523) for every scenario generated. The results are illustrated in the distribution figure below, where it can be confirmed the variation of the NPV with respect to the investment costs' random values. Keeping in mind that discounting is at IRR where NPV is equal to 0, the estimates are almost halved into positive and negative. This can lead to the conclusion, though, that even slight changes in the investment capital are capable of bringing significant ones in the NPV.

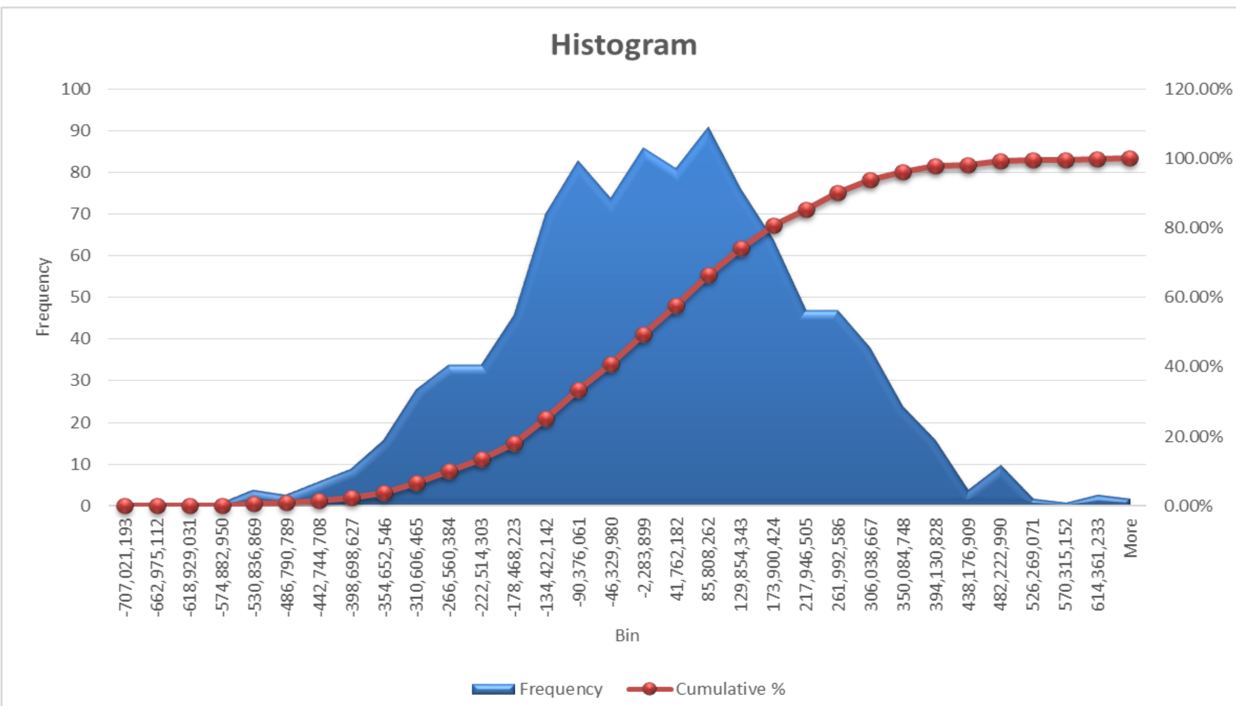
Figure 6.5 FNPV Monte Carlo Simulation (Investment costs)



6.2.2 Estimated revenues Monte Carlo

Equivalently, the random values of the estimated revenues have almost the same impact on the FNPV of Crossrail. Discounting at IRR, we can prove that the random values of the estimated revenues during the operating life of the project have quiet an important effect on the most important financial indicator. Using a mean of £954,991,713, it has been assigned a standard deviation of £100 million in order to achieve the estimates of the FNPV for each one of the 1,000 scenarios that have been created, while, for convenience, the years in which maintenance occurs have been excluded from the Monte Carlo. The results are summarized in the figure below and they are similar to the previous ones regarding the Monte Carlo of the investment costs. Most of the estimates are located around 0 because of discounting at the IRR, but random deviations from the best estimate of the expected revenues have a great impact on the FNPV, stretching it to negative or positive, either.

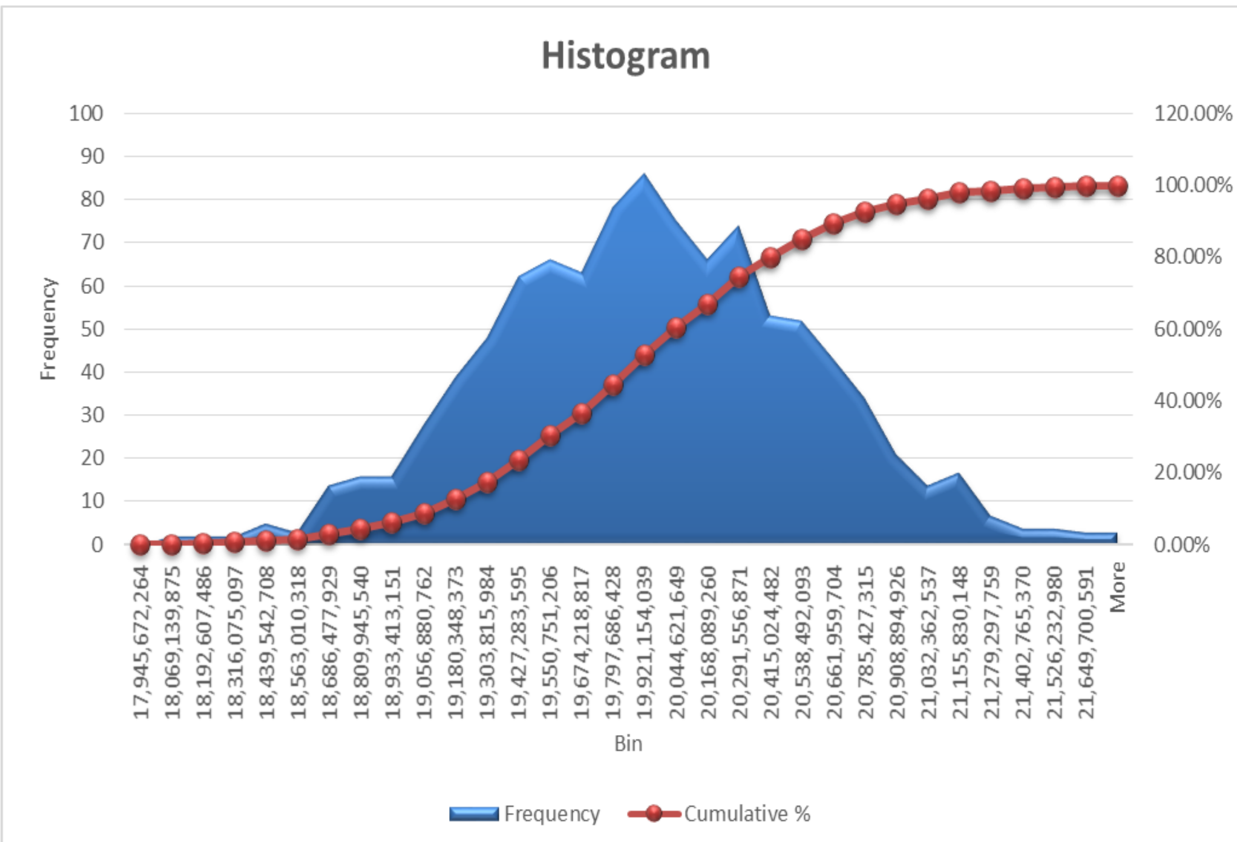
Figure 6.6 FNPV Monte Carlo Simulation (Expected revenues)



6.2.3 Contributions to GDP Monte Carlo

Our last attempt in this section is to perform a Monte Carlo Simulation for the ENPV as well using the total contributions of Crossrail to the GDP of Britain as a critical variable. This time it has been used a standard deviation of £300 million for the estimated economic net cash flow of each year, regarding the variation of the expected contributions to the GDP which have a mean of £1,424,024,602. Discounting at the benchmark rate of 5% which has been used so far, it can be confirmed the robustness of the economic viability of Crossrail. Although there is a range of about £4 billion between the least and the greatest value that the simulation generated, it is important that the ENPV of the project never turns negative. Therefore, all variables that have been included in the economic evaluation and affect the performance of Crossrail in a macro-level, are significant enough in order to sustain any possible changes in the total of its contributions to the GDP.

Figure 6.7 ENPV Monte Carlo Simulation (Contributions to GDP)



7. Remarks and Conclusions

The scope of this dissertation was to evaluate the financial and economic sustainability of one of the greatest infrastructure investment programs in the European continent. After reviewing the most important features of the literature which is linked to the CBA of infrastructure investments, it was followed a detailed report of the project's feasibility in the institutional framework of UK and EU and the demand analysis of the project as well. In that section it was highlighted the necessity of a project with Crossrail's magnitude based on the forecasts related to growing population and employment trends.

Afterwards, the financial evaluation of the project with the most recent data extracted by the official sources resulted in a slightly negative FNPV (taking into account the magnitude of the project and the provisions for economic growth rather than financial wealth, given the nature of the public sector infrastructure investments) and a borderline BCR, discounting at a 5% benchmark rate.

The results met in that part of the essay were not an obstacle for the viability of Crossrail. By including the appropriate variables related to the environmental implications and the expected economic growth due to the project, it was proved the significance of the investment in the macro-level of the economy of Britain, reaching a by far positive ENPV and a BCR close to 2, discounting the economic net cash flows at the same benchmark rate (5%).

Equivalently, the SNPV (the product of discounting the economic net cash flows at the estimated SDR) as well as the other social indicators which include the intra- and inter-temporal distribution of benefits stressed the importance of such an investment program for the future generations, especially for the low and the average income groups of the population.

Finally, the results met in the risk analysis chapter revealed a financial sensitivity of the project, given that its indicators were volatile due to changes in critical variables in both methods used. On the contrary, its economic indicators' robustness was undisputable after performing the Sensitivity Analysis and the Monte Carlo Simulation.

The CBA route followed so far has reached its terminal station by determining the absolute acceptance of Crossrail as an upcoming transportation reality in London's rail network.

Crossrail Appraisal.xlsx
Crossrail expanded indicator values.xlsx

8. References

Afonso A., St. Aubyn M., *Macroeconomic rates of return of private and public investment: crowding-in and crowding-out effects*, ECB Eurosystem Working Paper Series No. 864, 2/2008

Ammermann H., *Study: Squaring the Circle - Improving European Infrastructure Finance*, Roland Berger Strategy Consultants, 3/2015

Banister D., Thurstain-Goodwin M., Quantifications of the non-transport benefits resulting from rail investment, *Journal of Transport Geography 19 (2011)*, 1/2011

Brent R. J., *Applied Cost-Benefit Analysis 2nd Edition*, Edward Elgar, 2006

Bringham E., Houston J., *Fundamentals of Financial Management 11th edition*, Thomson/South-Western, 2007

Bunn P., Le Roux J., Johnson R., McLeay M., *Influences on household spending: evidence from the 2012 NMG Consulting survey*, Bank of England, Quarterly Bulletin, Q4/2012

Colin/Buchanan, *The Economic Benefits of Crossrail (prepared in association with Volterra)*, 10/2007

Crossrail business case update: July 2011

Crossrail, *Construction Code* (Annex 1 to the Environmental Minimum Requirements), 7/2008

Railway-technology.com, url: http://www.railway-technology.com/

Crossrail, url: http://www.crossrail.co.uk

DIRECTIVE 2001/14/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 February 2001 on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification

DIRECTIVE 2007/58/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2007 amending Council Directive 91/440/EEC on the development of the Community's railways

ECB Statistical Data Warehouse, url: http://sdw.ecb.europa.eu/

Economic Appraisal of Crossrail, 2005

EEX, url: https://www.eex.com/en/

Eijenraam C., Koopmans C., Tang P., Verster N., Evaluation of infrastructural projects; Guide for cost-benefit analysis, *Research program on the economic effects of infrastructure*, 4/2000

Environmental Resources management, *Crossrail Environmental Statement Volume 2, Route wide and central route section impacts*, prepared for the Department of Transport

European Commission, Directorate of Regional Policy, *Guide to Cost-Benefit Analysis of Investment Projects, Structural Funds, Cohesion Fund and Instrument for pre-Accession*, 2008

Evans D., The elasticity of Marginal Utility of Consumption: Estimates for 20 OECD Countries, *Fiscal Studies 26 (2)*, 2005

Florio M., Vignetti S., *Cost-Benefit Analysis of infrastructure projects in an enlarged European Union: an incentive-oriented approach,* Working Paper n.13.2003 – giugno, 6/2003

Greater London Authority, *Intention to levy a business rate supplement to finance the Greater London Authority's contribution to the Crossrail project* (Final Prospectus), 1/2010

Herbener J. M., *The Pure Time-Preference Theory of Interest (edited by Jeffrey M. Herbener)*, Ludwig von Mises Institute, 2011

Jones H., Moura F., Domingos T., Transport infrastructure project evaluation using cost-benefit Analysis, EWGT 2013 – *16th Meeting of the EURO Working Group on Transportation*, Procedia - Social and Behavioral Sciences 111 (2014)

Lakshmanan T.R., The broader economic consequences of transport infrastructure investments, *Journal of Transport Geography 19 (2011)*, 1/2011

Melbourne L., *Regional Rail Usage Profiles (Passenger Journeys) 2013-14 Statistical Release*, Office of Rail Regulation, 1/2015

Mathur S., Smith A., Land value capture to fund public transportation infrastructure: Examination of joint development projects' revenue yield and stability, *Transport Policy 30 (2013)*, 11/2013

Mohammad S. I., Graham D. J., Melo P. C., Anderson R. J., A meta-analysis of the impact of rail projects on land and property values, *Transport Research Part A 50 (2013)*, 1/2013

Memorandum to the Transport Select Committee, *Post legislative assessment of the Crossrail Act 2008*, 7/2013

Michael Lee, *Crossrail Regulatory Statement / Investment Recovery Charge*, Office of Rail Regulation, 11/2008

Montague A. et al., *The Montague Review*, Department of Transport, UK 2004

Office for National Statistics, Sustainable Development Indicators, 7/2015

Office of Rail Regulation, *Further regulatory statement on Crossrail charging*, February 2014

Ove Arup & Partners Ltd, *The impact of Crossrail on visitor numbers in Central London*, 1/2014,

Roukouni A., Medda F., Evaluation of Value Capture mechanisms as a funding source for urban transport: the case of London's Crossrail, *Social and Behavioral Sciences 48 (2012)*, 6/2012

Schnabl A., Platzer G., Ecker M., Fritzsche H., Hochmuth B., Koch S., Lappöhn S., Pohl A., *Guidelines for cost-benefit-analysis of infrastructure projects, Institute for Advanced Studies* – Vienna, 3/2014

The World Bank, url: http://data.worldbank.org/

Transport for London, url: https://tfl.gov.uk/

UK Overseas Trade Statistics, August 2015 Update

Wooldridge J. M., *Introductory Econometrics: a modern approach 4th edition*, South-Western, 2009

Worsley T., The evolution of London's Crossrail scheme and the development of the Department of Transport's economic appraisal methods (Discussion Paper No.2011-27), *Major transport infrastructure projects and regional economic developments: Assessment and Implementation*, 11/2011

Xepapadeas A., Social Cost-Benefit Analysis, Intra-generational and Inter-generational Distribution, *Cost-Benefit Analysis of Investment Projects*, Lectures 2015