Icelandic Journal of Engineering
Verktækni - Tímarit Verkfræðingafélags Íslands

**https://doi.org/10.33112/ije.29.2**

# Megaprojects and their potential impacts on innovation and technological progress

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Greinin barst 1. febrúar 2023.
Samþykkt til birtingar 22. desember 2023.
Birt á vef 30. desember 2023.

## Ágrip
Risaverkefni (e. Megaprojects) eru mjög flókin vegna tæknilegra, efnahagslegra, fagurfræðilegra og pólitískra þátta og eiga sér jafnan öfluga talsmenn en einnig harða andstæðinga. Í hagfræðiritum er ríkjandi viðfangsefni greining á mistökum og áhrifum þeirra á kostnað og framkvæmdatíma. Fjöldi tilvika og tölfræðilegra greininga hafa sýnt fram á að þessi mistök eru ekki handahófskennd heldur tengjast frekar dæmigerðum ferlum við skipulagningu og framkvæmd risaverkefna. Ekki er hægt að nota þessi dæmigerðu mistök sem algild rök gegn risaframkvæmdum almennt. Það eru mörg dæmi um risaverkefni sem hafa reynst hagkvæm, jafnvel eftir erfiðleika á upphafsstigum verkefnisins. Risaverkefni geta stuðlað að nýsköpun og tækniframförum. Þetta er hægt að greina á örkvarða með ítarlegri virknigreiningu og umfangsmeiri kvarða með því að búa til líkan af innbyggðum vaxtaráhrifum. Hægt er að nota kerfishreyfingu (e. system dynamics) og samþætt matslíkön til að bera kennsl á möguleika risaverkefna til að undirbyggja tækniframfarir. Þar sem risaverkefni, sem hugsanlega fela í sér möguleika á tækniframförum, krefjast langtíma- og að hluta til spámennsku greiningar varðandi kostnað og ávinning er nauðsynlegt að framkvæma vandaðar áhættugreiningar til að forðast fjárhagslegt tap vegna takmarkaðra verkefnaáætlana og hlutdrægni sem á rætur í óhóflegri bjartsýni.

**Lykilorð:** *Einkenni risaverkefna, áætlanagerð, tækniframfarir, áhrifamælingar, kerfisvirkni, samþætt mat, áhættugreining.*

## Abstract
Megaprojects show high complexity due to technological, economic, aesthetic, and political characteristics, and find strong promoters as well as strong opponents. In economic literature the analysis of failures and their impacts on cost and time overruns is dominating. Many examples, case studies and statistical analyses underline that these failures are not distributed randomly but rather are linked to typical processes involved in the organization, planning, procurement, and implementation of megaprojects. However, these typical failures cannot be used as a

general argument against the planning of megaprojects. There are also several examples existing for large projects which have turned out economically successful, even after difficult start-up phases. Megaprojects may foster innovation and technical progress in economic sectors. This can be identified and analyzed on the micro-scale by detailed activity analysis and in the macro-scale by modeling endogenous growth impacts. System dynamics and integrated assessment models can be used for identifying the potential of megaprojects for fostering technological change. As megaprojects promising potentials for technological change require long-term and partly speculative projections of costs and benefits it is necessary to carry out careful risk analyses for avoiding investment failures caused by immature project plans and optimism biases.

**Key words:** *Megaprojects' characteristics, planning failures, success factors, potential of technological change, impact measurement, system dynamics, integrated assessment, risk analysis.*

## 1 Introduction

Megaprojects are large and in general complex investments for achieving substantial progress in areas of high public interest, such as culture, health care, energy production, city planning, or transportation. The term "mega" *firstly* refers to the unusually high expenditures while "unusually" is defined differently depending on the competence of the planning authority. On the national scale for economically advanced and large countries a financial volume of 1 bill. US$ and more appears to be a good definition for categorizing megaprojects (see Flyvbjerg, 2014). A *second* common feature of megaprojects is their complexity, which includes challenges for their planning and construction, sector-internal interactions with other projects or areas, and sector-external interactions with other areas of the economy. Furthermore, the interactions are working over a long time-horizon, including manifold feedback mechanisms which may be reinforcing or dampening certain impacts. A *third* common feature is the presumed uniqueness of the project for promoters and decision makers. Flyvbjerg (2014) has summarized the associated expectations by "four sublimes":

- Technological: unique technology, new challenges for planners, engineers and Constructors.
- Economic: stimulation of regional (or even national) technical progress and economic activity.
- Aesthetic: new symbol of attractiveness for a region or city, improved image of a region or city stimulating tourism.
- Political: support for political careers, linking the names of political promoters to a symbol of regional/national progress.

The "sublimes" are partly emotional and hard to capture by analytical methods as they are only partly based on rationalized expectations. The above three common features of megaprojects provide a challenge for economic and social evaluation. This is because the measurement of impacts cannot be based on "classical" tools of forecasting and simulation. *Conventional cost-benefit analysis* starts from the assumption that a project is widely independent from other projects or from public decision making in other areas. It will be difficult to rank the priority of a megaproject within a list of smaller projects. If the ranking is done, for instance, by using the benefit over cost ratio then a megaproject is disadvantaged a priori by its high investment costs. Finally, the "classical" performance criteria used by statistical analyses in the literature like overruns of costs and time are important as first rough indicators but cannot give the full picture for a comprehensive evaluation.

Several megaprojects which came out extremely negative with respect to "conventional" performance. criteria have shown that they were highly beneficial in the long run because of their *wide range of impacts*, going far beyond the conventional cost-benefit (CBA) evaluation horizon. Prominent examples are the Suez- and Panama canals or the opera houses in Sydney and Hamburg. This gives the motivation to study not only reasons for failure, which is the predominant direction of research on megaprojects in the literature[1], but also reasons for success and their identification. One reason for success can be that a megaproject induces new economic activity, innovation, and technological change in the long run. As this is not included in conventional cost-benefit analyses it is necessary to apply extended assessment methods based on long-term impact scenarios for checking the economic viability of big investments. Furthermore, it will be useful accompanying the scenario forecasts and the planning process by a careful risk analysis which helps avoiding failures caused by immature plans and appraisal optimism.

We start the discussion in section 2 with an *overview* of megaprojects with respect to their nature, characteristics, and exposure to risk. On this base the *reasons for failures* can be analyzed and the drivers for *long-term success* identified in section 3. In section 4 we will focus on the "economic sublime" which refers to the expectations of promoters with respect to regional or even national impacts on economic growth. This can be studied on the micro-economic scale investigating the change of production technology in sectors directly affected and on the macro-economic scale by checking the contribution to *endogenous macro-economic growth*. Section 5 will discuss the needs for an extended economic assessment which will focus *on integrated assessment methods*. An important success factor consists in permanent risk analysis and management which is an issue accompanying all steps of planning, implementation, and operation. Section 6 will present the conclusions.

## 2 Megaprojects: Their nature and exposure to risk

The project of a *bridge over the strait of Messina*, combining the mainland of Italy with Sicily Island, gives a good example for the nature of megaprojects. The bridge is planned to link Villa San Giovanni (close to Reggio di Calabria, Italian mainland) and Messina (port city of Sicily). The maritime strait of Messina has a width of min. 3km and a water depth of min. 72 m. The strait is known because of strong winds and maritime currents. The project has a very long history, starting with the Roman Empire when the military forces planned to construct a bridge made from coupled barges and barrels for organizing the logistic military supply between Calabria and Sicily Island during the Punic Wars (264-146 B.C.). The project failed like many projects which were developed after. The project was revived in the early 1960ies. A public company "Stretto di Messina S.p.A." was established in 1983 and prepared the first detailed plans which were the base of charging the Eurolink consortium in 2005 with the construction of the bridge which was planned to start in 2007. The following historical development is characterized by a "*Yoyo game*" between protagonists and adversaries of the project: canceling of plans in 2006, promotions for revival in 2008, canceling and winding up of the consortium in 2013, rediscovered in 2020 again as a project for stimulating Italian economy after the Covid-19 depression (finance suggested through Covid-stimulus payments allocated by the EU Commission to Italy, altogether 209 bill. EUR).

[1] See the literature discussed in Rothengatter (2019).

*Table 1: Key characteristics of the Messina bridge*[2]

| Key characteristics | |
|---|---|
| **Design** | **Suspension bridge** |
| **Total length** | **3,666 m** |
| **Longest span** | **3,300 m** |
| **Height** | **382.6 m** |
| **Vertical clearance** | **65 m** |
| **Width** | **60.4 m** |
| **Lanes for road** | **4** |
| **Tracks for rail (lower floor)** | **2** |
| **Cost estimation** | **7-8 bill. EUR** |

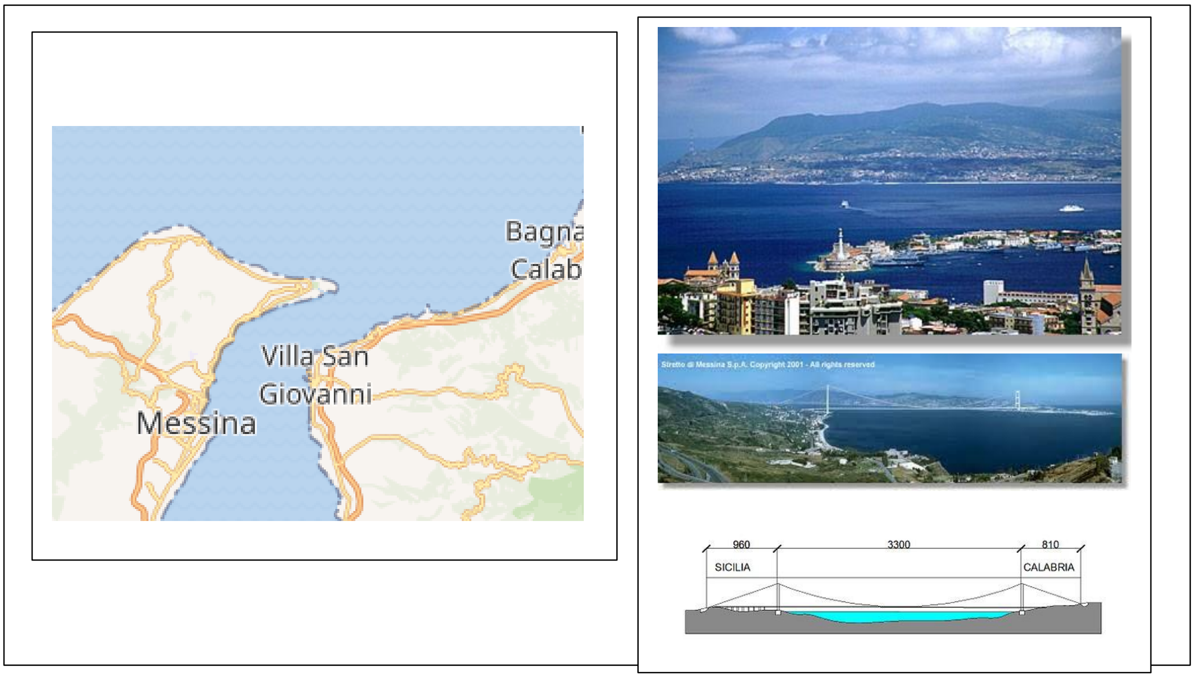



*Figure 1: Bridge over the Strait of Messina.*
*Source**:** https://ejatlas.org/conflict/the-bridge-over-the-strait-of-messina.*

The characteristics underline the unique character of the bridge: By far the longest span and the highest pylons, to be built in a region with high risk of earthquake, strong winds and strong maritime currents. All four sublimes can be studied in detail, particularly the *political sublime* during the time of frequently changing governments in Italy, when the “Berlusconi government” was strongly in favor and the “Prodi government” strongly against. The rumor was spread that the Calabrian Ndrangeta[3] was the biggest supporter because they could control the supply of materials for construction.[4]

[2] See https://ejatlas.org/conflict/the-bridge-over-the-strait-of-messina
[3] This is the Calabrian Mafia organization.
[4] There is a rich literature existing on the history and the phases of political procurement. An overview can be found in Wikipedia: Strait of Messina Bridge.
A recent publication is contributed by B.L. Nadeau (2023).

The main argument in favor of the bridge was that it would *stimulate economic growth* in the southern part of Italy, in Calabria and in Sicily, regions of high rates of unemployment and structural gaps. Under the Berlusconi government economists from the southern Italian region were charged with preparing a cost-benefit analysis (CBA), resulting in a highly positive economic evaluation. Under the Prodi government[5] economists from Northern Italy and from other parts of Europe found that the results of the economic evaluation were extremely unrealistic. For instance, the traffic forecast for the bridge was estimated about 3 times of the traffic forecast of the Oresund bridge in Denmark.[6]

This was hard to explain because the regions connected by the Messina bridge have a much lower population compared with the Oresund regions (Messina: 237.000, Reggio di Calabria 183.000 inhabitants; Copenhagen: 603.000, Malmö 300.000 inhabitants and a much higher population in the surrounding agglomeration areas). The high forecast for the traffic development on the Messina bridge could also not be explained by tourism because the accessibility of most touristic areas of Sicily from Northern Italy and other European is much better by airplane compared with train or car. The team of economists hired by the Prodi government concluded that other measures of *regional economic support* would be more effective compared to constructing a bridge. The risk that the bridge investment would end in an economic disaster was evaluated high and a cancelling of the project was recommended.

## 3 Failures and success stories

Many large projects have been analyzed in the literature and most of them were classified as failures. Bent Flyvbjerg (2014) summarized his findings on megaprojects with the persiflage of four overs: "*over cost, over time, over and over again*". The following table exhibits some selected megaprojects which were evaluated failures following this criterion.[7]

*Table 2: Selected megaprojects with high cost or time overruns.*

| **Prject/*management*** | **Start/ open.** | **Const. cost[8]** | **Cost over run %** | **Essentials characteristics and problems** |
|---|---|---|---|---|
| **Suez-Canal /Egypt/ *private*** | 1803/ 1858/ 1869 | 426 mill. ffrs | 230-1,900 | Based on a vision (F. de Lesseps); no clear plan for engineering and management in early phase; private concessions, design elements, approvals and technologies developed during construction. under political conflicts (FR/UK/TR). |
| **Panama Canal /Panama/ *private*** | 1876/ 1889/ 1905-1914 | 352 mill. US$ | 200-260 | 2nd canal project of de Lesseps; interruption because of bankruptcy; difficult geological and climate conditions (28,000 workers died); revival and continuation by US |

[5] Romano Prodi was Prime Minister of Italy from 1996 to 1998 and from 2006 to 2008.
[6] This was the finding of a study group (including the author) which was charged by the Prodi-government in 2008. Report unpublished. See also: https://www.visitcopenhagen.com/copenhagen/planning/oresund-bridge-gdk711853.
[7] See Rothengatter (2019)
[8] Cost in currencies given by planning authorities, relating to time of opening. Cost overrun interval: Actual costs versus estimated costs at time of project start (first figure) – at time of political decision (second figure).

| | | | | |
|---|---|---|---|---|
| | | | | government; more careful planning in the 2nd phase. |
| **Boston Big Dig /USA/ *public*** | 1991/ 2003 | 15.5 bill. US$ | 170-450 | Central Road Artery Project; planned by Mass. Turnpike Auth.; 58% financed by Federal State; evolution of complex sub-projects; rent seeking of big construction firms; massive changes of plans during construction; geological problems. |
| **Channel Tunnel /UK-France/ *private*** | 1987/ 1994 | 15.0 bill. £ | 80-100 | Delayed construction and approval partly caused by changes of national safety regulations; additional financial costs; over-optimistic revenue expectations; several debt restructurings; HSR connection to London delayed (2003/07). |
| **Berlin Airport /Germany/ *public*** | 2006/ 2020 | 6.0 bill. € | 200-250 | Massive planning failures; problems with innovative elements (e.g.: exhaust flue); more than 400 major changes of plans; management failures with coordination of construction work; missing information and documentation. |

*Source: Rothengatter (2019) – Higher estimates including financial costs.*

Some examples in the above list have turned out indeed as planning disasters after detailed analysis, such as the Boston Big Dig or the Berlin Airport project. In other cases, the first negative evaluation should be revised. The most prominent example of this category is the *Suez-canal*.[9] The cost overrun of 1,900% exhibited in several literature pieces[10] uses low initial cost estimations when first ideas were developed around the year 1800 under the regime of Napoleon I (30 mill. ffrs). After the foundation of the Suez Canal company in 1858 the total costs of construction were estimated 162 mill. ffrs plus 26 mill. cost for interest payments, which makes 188 mill. ffrs. In the year of opening 1869 the total costs turned out to be 426 mill. ffrs. which makes 1,420 % cost overrun compared with the first estimation, while the cost overrun compared with the estimation at the start of construction reduces to 230%. The often-quoted figure of 1,900% includes investments for early extensions and maintenance work after opening, amounting to additional 62 mill. ffrs. Severe political and technical problems characterize the history of the Suez-canal. At that time the U.K. government strongly torpedoed the project, while the supporting Ottoman empire and the Egypt kingdom being unreliable and close to bankruptcy. On the technical side it was necessary developing *innovative excavation technologies* and efficient supply chains. Therefore, comparing the cost overruns for such a complex historical project with more recent undertakings one learns to recognize the performance of engineers as well the courage of initiators and risk takers at that time of history. Today the Suez Canal is the busiest canal of the World (18,800 vessels in 2020) and contributes 8% of the state budget of Egypt.

Other large transportation projects can be classified as successful using the classical criteria of evaluation.

[9] There is a rich documentation on the history of the Suez-canal. See e.g.: Hicks (2012).
[10] For example, in the publications of Flyvbjerg.

*Table 3: Selected large transportation projects with low cost and time overruns.*

| **Project/*management*** | **Start/ Opening** | **Constr. Cost** | **Cost Overrun %** | **Essential characteristics and success factors** |
|---|---|---|---|---|
| **Athens Airp. /Greece/ *PPP*** | 1996/ 2001 | 2.1 bill. € | 0 | New airport of category 2 (up to 25 mill. paxe), 20 km East of Athens; PPP under lead of construction company; 45% private share; 55% state finance, supported by EU; 51 months of construction time; development project for old airport area. |
| **Oresund Fixed Link /Den.-Swed./ *public*** | 1995/ 2000 | 4.1 bill. € | 32-70 | Combined bridge, tunnel, artificial island; road and rail; Oresund Bro Consortiet formed 1992; contracts with 3 construction consortia; cost escalation through safety and environmental requirements; pay-back period 35 years (completely user financed). |
| **Viaduc de Millau /France/ *private*** | 2001/ 2004 | 0.4 bill. € | 13 | Cable-stayed bridge over Tarn Canyon; one of the tallest bridges of the world with mast height of 343 m; length 2,460 m; planned by M. Virlogeux, designed by star-architect N. Foster; toll finance; innovative construction techniques; tourist attraction. |
| **HSR Tours-Bordeaux /France/ *PPP*** | 2011-2017 | 7.8 bill. € | 0 | Missing HSR link of 340 km between Paris and Bordeaux; PPP with 49% private capital, to be refinanced by rail track charges; concession for 50 years; EU co-finance; travel time P-B (530 km) reduced from 3'15 h to 2 h; first positive impacts on housing market in Bordeaux. |

*Source: Rothengatter (2019)*

The above lists demonstrate that a general characterization of megaproject by the" four overs" is not justified. Furthermore, megaprojects may exceed costs budgets originally planned and may need more time. Despite such problems they may provide substantially positive benefits to society in the long run.

The main reason for failures is not the size of a megaproject but rather the way it is planned, procured, managed, and politically decided and controlled:

(1) In many cases the *planning phase* is not detailed enough and does not lead to a mature project. Important aspects are left open and shifted to decisions in the construction phase. This can include:

- P*erformance indicators* (e.g.: in the case of Berlin-airport it was not clear whether separate terminals should be designed for low-cost carriers or the A 380 aircraft).
- *Technical specifications* (e.g.: in the case of the Channel Tunnel the requirements of fire police were not harmonized on the French and UK side).
- The flight approach paths in the case of several airport projects which in a late phase of implementation lead to *conflicts with citizens* and environmental groups.
- The rail operation programs in the case of large railway investments.

*many involved organizations* requiring heterogenous performance specification railway stations for which the conflicts arising are shifted to the later stage of project realization (e.g.: Stuttgart 21 project involving a high-speed link, regional and urban rail investments, an underground main station, and a station at the airport),
- Insufficient topographical and underground analysis (e.g.: in the case of the Big Dig underground road project in Boston).

(2) The procurement phase does not lead to a capable project organization with efficient *project management and effective control*.

- Regional authorities which have *little experience* with large projects decide on the governance and management. The result is often establishing project companies according to political criteria and controlling them by local/urban politicians. Particularly big urban transport projects are prone to such procurement failures.
- The project company may be exposed to *strong political pressure*. This may lead to many changes of construction components during the construction phase. The architect of the Berlin airport reported about 400 major changes which had been decided by political organizations during the construction phase.
- *Local authorities* are often not happy with hiring international consultancies because they are afraid of high costs and the risk of rent seeking.

(3) Due to the strong political influence the project managers focus more on the political backing rather than on following management practices.

- *Change management* is missing. This includes contractual arrangements that the political body deciding on changes will have to pay for the follow-up costs.
- *Risk management* is lacking. Risk management is necessary throughout the whole process from the first plans up to the operation of a project (Rothengatter, 2017).
- *Advanced tools* of architecture are often not applied. This concerns particularly the application of building information modeling (BIM) which would allow for checking the functioning of all components and the impacts of changing performance requirements.
- *Experiences* which have been gained worldwide with similar projects are not used because of the presumed uniqueness of the megaproject.

(4) The importance of <u>permanent information and mediation</u> is often underestimated. Support from the affected population, the public and media is needed, otherwise it can happen – as in the case of the Stuttgart 21 project – that unexpected violent conflicts arise when the construction work is started. A good example of effective public relations work is the construction of the rail main station at Vienna which included a merger of two existing stations and a re-structuring of the city quarter (cost volume about 1 billion EUR, low increase of costs compared with plans at the time of approval).

## 4 Potential impacts on innovation and technological progress

### 4.1 Micro-economic impact analysis

The historical examples of the big canal projects show that *leap-frog changes of technology*, for instance for transportation systems, require big investments in technical components for which not all functions and costs of provision are known. This would also hold for instance for the revolutionary Hyperloop transport technology which is promoted by industrial groups. Such an investment would imply high risks as it is uncertain whether essential performance criteria can be fulfilled. E.g., if safety requirements for passengers in the vacuum tubes cannot be fulfilled the project will die. Other projects can provide options for technological progress which are less radical and consist of an intelligent combination of known advanced technologies. This can be illustrated by the example of an innovative *transshipment hub* for rail freight transport. This can be composed of the following technological components[11]:

- Automated lift and movement of containers and other loading units.
- Automated ground movement of loading units between rail tracks and storage area.
- Automated sorting of loading units by type of goods and destinations.
- Automated processing of trains in the hub without marshalling operations.
- Paperless organization of the registration and reporting tasks as well as the payments.

Similar micro-economic impact analyses can be prepared for large airport investments as for instance the Athens airport project (see Table 3). Micro-economic approaches are promising if the main impacts are concentrated within geographical units, industrial sectors, or societal groups. In such cases the interdependencies and scopes of feedback processes are low and conventional methods of cost-benefit analysis can be applied. As soon as substantial secondary impacts are expected following the investment the micro-analysis should be extended by regional and macro-economic assessment (see section 4.3). For example, the move of the Munich airport in Germany to a new location in the region Erdinger Moos, about 30 km distant from the city, stimulated a big economic upturn in the region while it reduced congestion and over-concentration of activities in the central city area.

## 4.2 Cost-benefit analysis (CBA)

CBA is explained in many textbooks, guidelines and project reports and will not be described here again. Important characteristics are:

- Partial approach, i.e., it is assumed that it is sufficient to analyze only the sector for which a project is planned (e.g.: transport) while all other sectors are in full employment equilibrium.
- Rationality and perfect foresight of agents.
- Equal marginal utility of money for all social groups, i.e., no distributional problems.
- Environmental and safety impacts either monetized and included in the CBA or treated separately.

Under the above assumptions the benefits are dominated by *savings for operating and time costs.* As the CBA approach is widely standardized it has gained wide acceptance and its outcomes serve as a dominating criterion of project evaluation (see e.g.: the Guide to Cost-Benefit Analysis of the EU Commission (2014) or country evaluation methods as presented in the Quinet report (2013)).

[11] Example: Megahub of Lehrte in Germany. Mentioned as an important megaproject of the German Federal Transport Masterplan in: *Deutschlandtakt: Bewertung Infrastrukturmaßnahmen für den 3. Gutachterentwurf.* (PDF) In: *downloads.ctfassets.net.* Intraplan Consult, TTS TRIMODE Transport Solutions. August 17, 2021, p 2.

## 4.2 Macro- and regional economic impact analysis

Different approaches for assessing megaprojects, ensembles of projects or policy strategies have been presented in Rothengatter (2017 and 2019):

- Computed general equilibrium and spatial general equilibrium models (CGE, SCGE).
- Macro-econometric models.
- Macro- and regional economic simulation models.
- Systems dynamics.

Megaprojects may aim at stimulating technological change and innovations. If this is a focal goal, then the assessment method will have to integrate a module which is able to model the potential for such impacts. P. Romer (1990)[12] has developed a macro-economic growth model which has substantially extended the economic growth theory and prepared the base for integrating endogenous growth factors into macroeconomic assessment of large projects. Box 1 presents a brief illustration of his idea.

Two basic equations of the Romer model illustrate the endogenous impact of research and development (R&D) on economic growth:

(1) $Y = f(A, H_Y, L, X)$ production sector

(2) $\dot{A} = \frac{dA}{dt} = \delta * H_A * A$ R&D sector

Y: real product
$H_Y$: human capital in production
L: low qualified labor input
$\delta$: productivity growth parameter
A: total factor productivity
$H_A$: high qualified human capital in R&D
X: output of intermediate sector (capital)

The R&D sector develops blueprints for new technologies and sells them to the intermediate sector (here not modeled). Increasing technological knowledge drives the total factor productivity A.

*Box 1: Endogenous growth generated by the human capital in R&D*
*Source: Romer (1990).*

This idea can be transferred to other *investments into social capital*. In the long run such changes in social capital may stimulate technological change and productivity much more than the short and medium run effects of cost reductions for used resources and invested time.

A paper prepared for the Asian Development Bank even investigates the influence of high-speed rail investments on patent rights and the knowledge economy (see Bhatt and Kato, 2021[13]). The paper analyses the impact of high-speed rail (HSR) investments on the *patent right application*s per capita (see Figure 2). The latter is used as an indicator of the potential of innovation and technological change. The results of statistical analysis for 14 countries support the hypothesis that

[12] Paul Romer was honored with the Alfred Nobel Memorial Prize for Economics in 2018.
[13] Further publications sponsored by the Asian Development Bank Institute are available. They address in the first instance highspeed investments in Japan, India, or Indonesia.

investment in modern mobility technology has an influence on the knowledge economy. This would be in line with P. Romer's theory of endogenous growth.

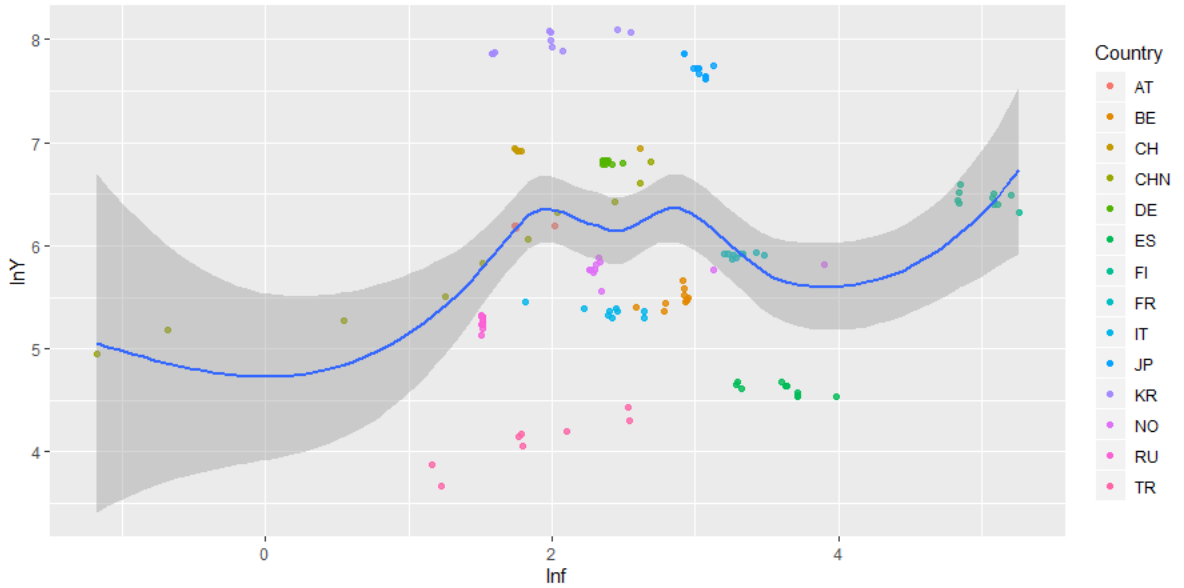



*Figure 2: Scatter plot of patent applications per capita (Y) versus investments in high-speed rail per capita (f) in 14 countries from 2007-2016.*

*Source: Bhatt and Kato (2021)*[14]

This positive expectation with respect to the impacts of modern transport technology on economic productivity was also supported by a study on the economic impacts of the HSR project between Stuttgart and Ulm in Germany, which included a new underground railway station and several substantial investments for regional and urban public transport as well as for rail freight service. The regional impact analysis studied the influence of the project on 10 industrial growth sectors which were identified by combined cross section/time series analysis.[15] Also the Austrian evaluation method for transportation projects is based on a regional impact analysis, highly differentiated by industrial sectors, and including a variable for technological change (see WIFO and IHS, 2021).

## 5 Applied measurement of wider economic impacts

### 5.1 Extended CBA

The most widely applied method of economic assessment for large projects is cost-benefit analysis (CBA). CBA is based on welfare theory and assumes a full employment equilibrium in all sectors except for the sector under analysis (partial economics approach), perfect foresight and a *homo oeconomicus* behavior of all economic agents. Under these not very realistic assumptions consumer's and producer's surpluses give the measures for economic impacts if society accepts that impacts on income redistribution don't play any role (marginal utilities of income are assumed to be equal for all social groups). From this follows that there is no influence of large projects on the

[14] See also Miwa et al. (2022)

[15] Unfortunately, this positive result of regional economic analysis had to be reconsidered later when it turned out that the costs of the project had been underestimated (assumption in the assessment study: 5.3 bill. EUR, present estimation: 14 bill. EUR). Therefore, the project has developed to become a blueprint for planning and procurement failures made with megaprojects.

capital stock and its development by technological change. But it may be the aim of investments into large projects and their combinations (e.g.: they should form a network in the case of HSR) to foster technological development and increase productivity.

One possibility for overcoming this weakness of conventional CBA is to extend CBA by *wider economic impacts (*WEI). The WEI model of the UK Department for Transport (DfT) gives an example of this approach (based on the work of Graham (2006)). This has been summarized by Legaspi et al. (2015) in an assessment study for public transportation projects in Australian cities. Table 1 shows in the first column the types of benefits, in the second column the welfare economic benefits according to the conventional CBA approach, in the fourth column the wider economic impacts leading to GDP changes, and in the third column the overlaps between conventional CBA and wider economic impact analysis.

*Table 4: Typology of Wider Economic Impacts*

| **Benefit and Impact types** | **Welfare Economic Benefits (WEB)** | **Overlapping of WEB and GI** | **GDP Impacts (GI)** |
|---|---|---|---|
| **Conventional economic appraisal** | | | |
| VOC savings | ✓ | | |
| VTTS: Leisure | ✓ | | |
| VTTS: Commuting | ✓ | | |
| VTTS: Business | ✓ | WB3, GI6 | |
| Accident cost savings (safety) | ✓ | | |
| Environmental impacts reduction | ✓ | | |
| **Wider Economic Benefits** | | | |
| **WB1**: Agglomeration economies | ✓ | GI4 | |
| **WB2**: Increased competition | ✓ | GI5 | |
| **WB3**: Increased output in imperfectly competitive markets | ✓ | GI6 | |
| **WB4**: Welfare benefits arising from improved labour supply | ✓ | GI1, GI2 & GI3 | |
| **Wider Economic Benefits and GDP Impacts** | | | |
| **GI1**: More people choose to work | | WB4 | ✓ |
| **GI2**: Some people choose to work longer hours | | WB4 | ✓ |
| **GI3**: Move to higher productive jobs | | WB4 | ✓ |
| **GI4**: Agglomeration economies | | WB1 | ✓ |
| **GI5**: Imperfect competition | | WB2, WB3 | ✓ |
| **GI6**: Business time savings and reliability | | VTTS Business | ✓ |

*Source: Legaspi et al., 2015*

The quantification of agglomeration economies as a component of WEI is performed by an elasticity approach:

$$WB1 = \sum_{i,j}\left[\left(\varepsilon_{i,j} \times \frac{\Delta ED_j}{ED_j}\right) \times GDP_{i,j} \times E_{i,j}\right]$$

i: industries j: locations ED: effective employment density
ε: elasticity of productivity with respect to effective employment density
GDP: output per employed person E: number of jobs

The heart of the method consists in estimating the elasticities of productivity with respect to effective employment (employment weighted by an accessibility index). Until now the results for the elasticity estimations for different industries show a high variance and a low level of confidence. The method, furthermore, is reduced to the estimation of agglomeration impacts. This approach was applied for the assessment of the HS 2 high-speed rail project in the UK (see appendix).

## 5.2 Integrated assessment methods

Integrated assessment methods may combine:

- Wider economic impacts
- Environmental and energy impacts
- Technological change
- Spatial and distributional impacts.

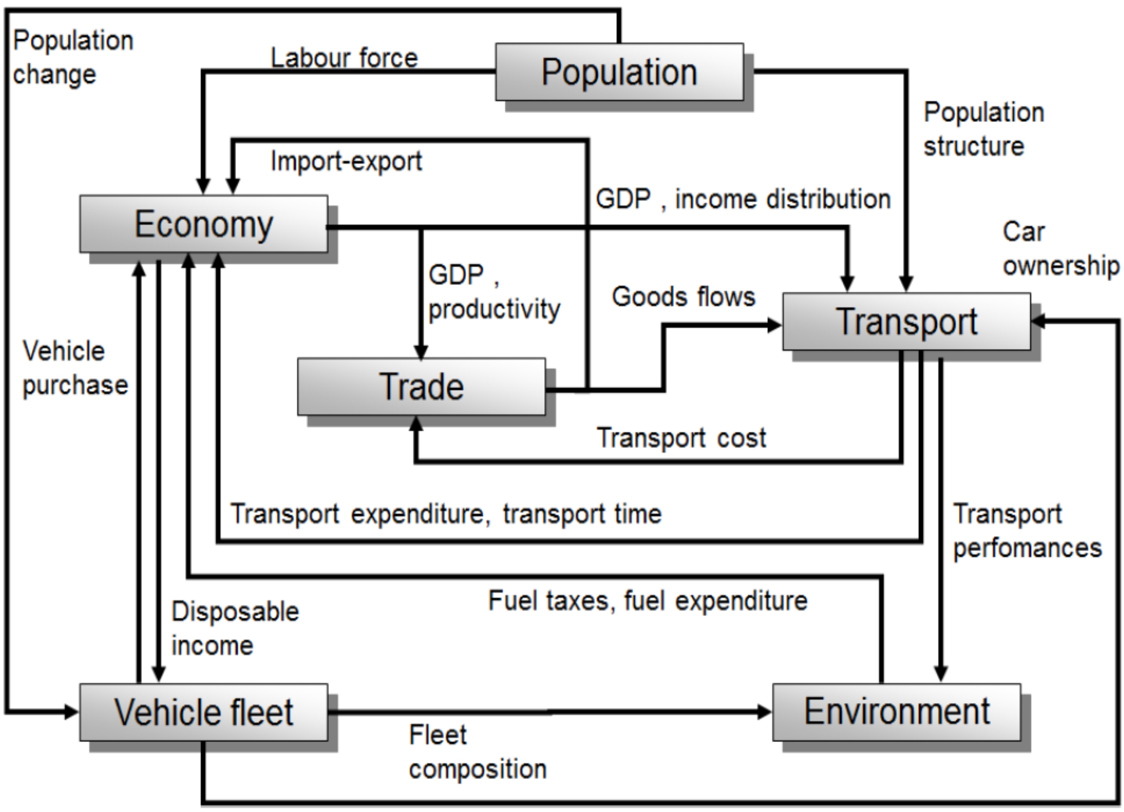
Methodological approaches include:

- Computed and spatial computed equilibrium models
- Macro- and regional economic models
- System dynamics
- Combined sector simulation models.

A discussion of these approaches can be found in Rothengatter (2017). Here only some aggregate figures for such approaches are given. Figure 3 presents the structure of a *system dynamics model* (SDM) for the area of EU+Norway and Switzerland. SDM is particularly appropriate for dynamic feedback analysis and long-term forecasting for network investment strategies. Large investments into the transport infrastructure may induce changes of productivity in later periods as shown in the stylized output profiles of Figure 4. The Figure shows the stylized profiles of short-term economic impacts (income effects through multiplier/accelerator processes), of changes of generalized costs (time and operation cost reductions in a medium-term perspective), and of productivity change (endogenous growth impacts in the long run). The productivity impacts may arise in late periods of the project life and are hard to predict. Because of the high uncertainty of the magnitude of such impacts it is recommendable to apply alternative scenarios for quantifying a corridor for the expected productivity development induced by the investment.

The European Commission applies the SDM ASTRA for the WEI-assessment of transport policy programs (see Figure 3). ASTRA is combined with several sector models such as network models for passenger and freight transport or geographical models for land use changes.

System dynamics, simulation models, and integrated modeling of transport, economy, environment, energy, and technology are appropriate instruments for generating quantitative images of potential impacts of megaprojects on long-term changes including technological progress.




*Source: TRT - Fraunhofer-ISI*

29 countries, 25 industrial sectors, more than 200 tsd. dynamic equations

*Figure 3: ASTRA model version for integrated assessment of transport investments*
*Source: http://www.trt.it/en/tools/astra/*

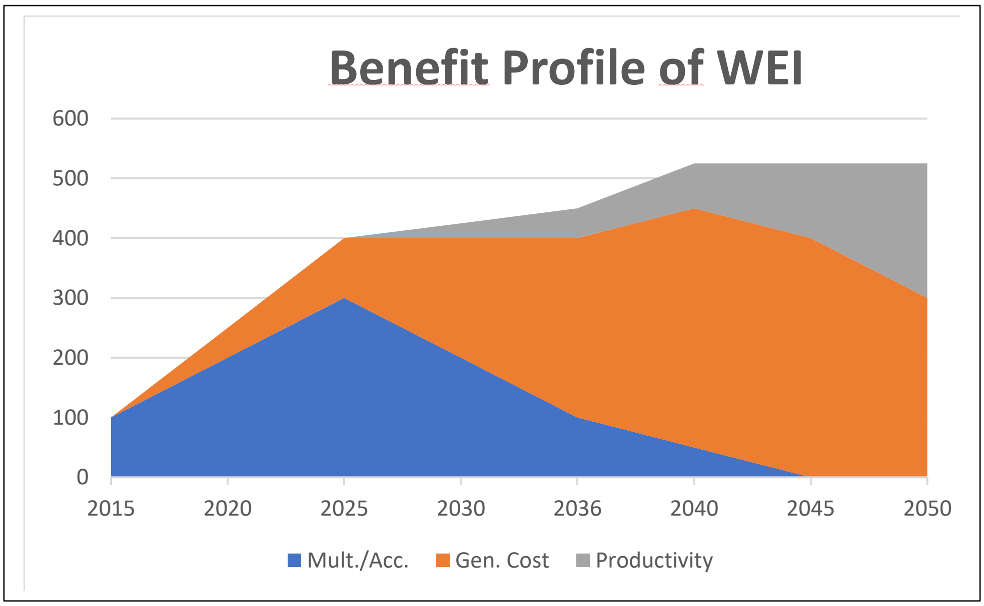


*Figure 4: Benefit profile for wider economic impacts including productivity change.*

*Source: The author.*

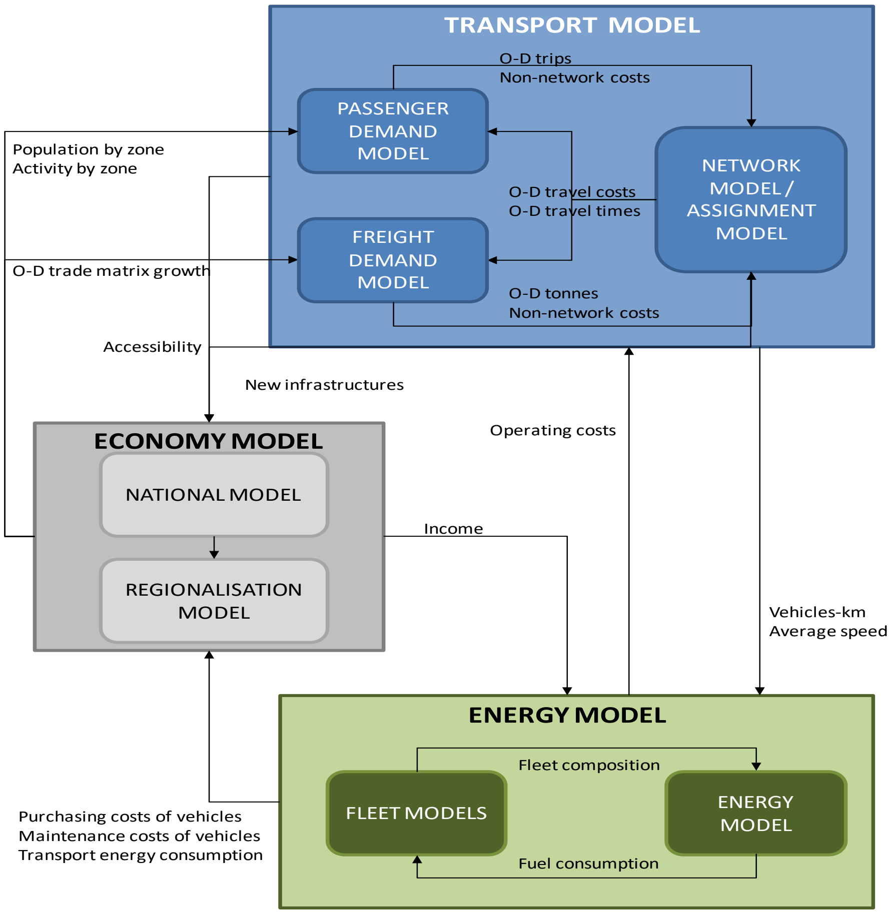



*Figure 5: Structure of the TRIMODE model*

*Source: TRT et al. (2020).*

Figure 5 presents the structure of a recently developed *integrated assessment model* for the European transport policy evaluation. It includes modules for the macro- and regional economies, passenger and freight transport, energy, environment, and technology (vehicle fleet). This model called TRIMODE is composed of detailed components for every area included and is a common platform for data exchange. The model generates a detailed data background for transport investment analysis with a high level of granularity which is sufficient for assessing large single projects or project ensembles.

## 5.3 Risk analysis and management

Many megaprojects have been planned by public authorities. In the public fiscal systems risks do not play a role and this is the reason for the paradox that the relevance of risk aspects is diminishing with increasing project budgets. Large projects which are expected to push technological change and productivity in the long-run are particularly exposed to high risk because long-run-scenarios must be developed which may include speculative components for quantifying impacts in the long-term future. This adds to risks which occur through uncertainty and appraisal optimism for the short and medium-term impacts. Figure 6 gives an overview on the type of risks occurring in the life cycle of projects. The root causes of many risks can be found already in the early phase of planning (see German Reform commission, 2015). *Appraisal optimism* and the administrative processes of approval (in some countries like Germany) stimulate the promoters and planners to generate high figures for benefits and low figures for costs and to start projects when planning is still immature. Therefore, it is most important to control such incentives which is possible for instance by constructing public-private partnerships (PPPs). An essential element of risk avoidance consists in an appropriate procurement for project management and control which is provided by PPPs. PPPs will avoid selecting a regional public agency as a project manager and a regional public authority as a controller, which was one reason for the planning disaster with the Berlin international airport.

Risks can be better controlled after a project start if clear change management is applied with allocating the costs of changes appropriately to the responsible parties. The management of the London Olympic Games in 2012 gives an example for an effective control of project management and its protection against permanent interventions of political decision makers and interested stakeholders.

| **Phase of the Life Cycle** | **Resource input risk** | **Market risk** | **Financial risk** | **Construction risk** | **Environmental Risk** | **Social Risk** | **Political Risk** |
|---|---|---|---|---|---|---|---|
| **Planning** | | | | | | | |
| **Procurement** | | | | | | | |
| **Costruction** | | | | | | | |
| **Operation** | | | | | | | |

*Figure 6: Project life cycle and type of risk.*
*Source: Rothengatter (2017).*

Of course, the risk identification and management can be supported by scientific methods from statistics (e.g.: Monte Carlo simulation) or *building information modeling* (BIM).[16] While BIM is a widely used instrument in architecture and facility management its application for large infrastructure projects is still lagging behind. BIM allows for an integrated modeling of the macro facility, including its links to other facilities, as well as to the micro-components of its construction. The critical early phase of planning can be effectively supported by BIM for generating more reliable figures on inputs. Furthermore the change management and the control of incentives of involved stakeholders can be performed effectively. After several planning disasters in Germany with large projects the Reformkommission (2015) has suggested a radical change to the application of such *digital instruments* in public infrastructure planning.

[16] See The Institution of Civil Engineers (2021)

## 6 Conclusions

Although many megaprojects have failed with adhering to cost and time plans this does not give reason to recommend avoiding megaprojects in general and to prefer marginal changes for investment strategies instead. A step change in technology and customer service may require a megaproject or an ensemble of linked big projects. This is underlined by historical examples like the Suez canal for transportation or the Sydney opera for the cultural area although both projects generated big problems during construction and the initial phase of operation. The conclusion from the above discussion is that megaprojects need careful preparation by applying more sophisticated integrated assessment methods and an appropriate organisation, procurement and management. It has been shown that instruments are available for analyzing long-term dynamic impacts, as for instance system dynamics, and for preparing an integrated assessment of wider economic, environmental and technological impacts, as for instance by combination of sector models on a common platform.

Megaprojects may provide – partly speculative - prospects for innovation and technological change in the long run and therefore require the development of alternative scenarios for quantifying the variance of potential impacts. Risks are also occurring in the short and medium stages of project life which should be managed in all phases of the project cycle. Particularly, the first phase of planning is very critical with initiating root causes of risk which in later phases are very hard to manage without expensive changes of plans and follow-up cost overruns. Such risks are often caused by starting megaprojects in an immature planning phase because of administrative approval procedures, over-optimistic estimations or pressure through promoting stakeholders. Risk and change management from the beginning of the planning process are therefore necessary elements megaproject planning which have been neglected in many publicly procured projects in the past which contributed to the negative image of megaproject planning.

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## Appendix

### Megaproject HS2 in the UK and the role of productivity changes

HS2 denotes the second high-speed rail project in the UK after the link from the Channel tunnel (Folkstone) to London (St. Pancras Station). Characteristics of this project are:

- Three phases foreseen: phase 1 Greater London to West Midlands (230 km); phase 2a: Birmingham-Manchester (60 km), phase 2b: Birmingham-East Midlands (85 km). In the meantime, discussion is coming up about cancelling the northern parts of the project.
- Design speed: max. 400 km/h.
- Use of high-speed sections and conventional sections (two classes of trains).
- Time savings for passengers: London- Carlisle 54 min., Birmingham-Leeds 69 min.
- Modal shift (optimistic estimation[17]): For the travel between London and Glasgow the share of rail passenger is expected to grow from 47 to 70%, the share of air travel is expected to decrease from 50 to 28%.
- Additional capacity for freight service.
- Construction cost estimations: £ 30.9 bill. (2010), £ 80.7 - 106 bill. (2019, at 2019 prices).
- Wider economic benefits expected by DfT in the order of magnitude of £ 13 bill. over 60 years.[18]
- Heavy opposition was expressed by experts and environmentalists, underlining the problems of finding routes for infrastructure tracks in a densely populated area. Also, several economists argued that the wider economic benefits were marginal.

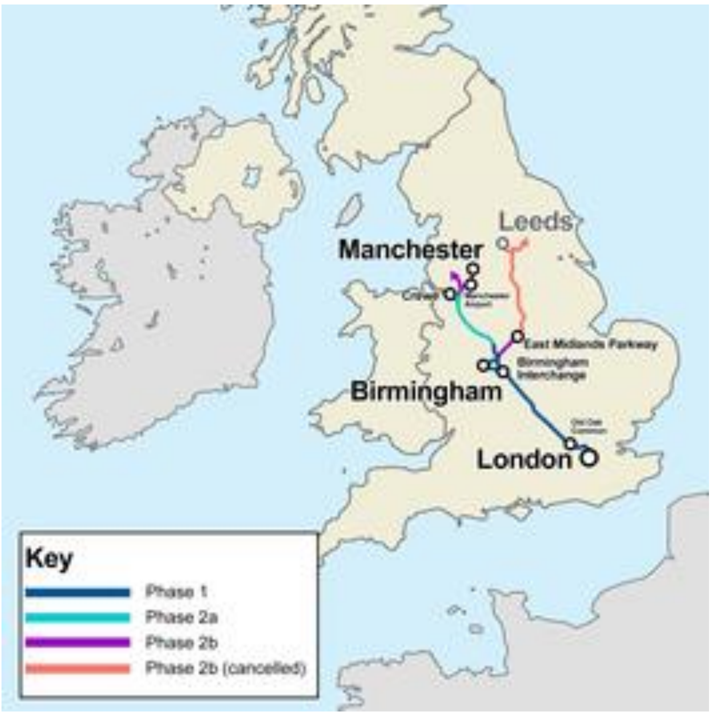


*Figure A1: High Speed 2 in the UK.*

[17] High Speed Rail Group, 2022: Modal shift matters – and HS2 delivers. These figures are heavily debated, more pessimistic forecasts are existing.
[18] The Economic Affairs Committee, 2015: The Economics of High Speed 2.

**Statements of experts of the Economic Affairs Committee with respect to productivity changes**

239. Professor Overman told us that there were three reasons why improving connectivity might increase productivity:

It would enable businesses to employ workers from a larger labour market.

It would allow businesses to access specialised services located in other cities. For example, businesses in Manchester would more easily be able to access specialist legal, financial, or accounting services based in other cities more easily.

It would help specialised services access their customers more easily and expand the market that they can potentially serve.[288]

240. Ms Rosewell and Professor Venables considered the mechanisms through which connecting places may lead to productivity gains in their paper *High Speed Rail, Transport Investment and Economic Impact*. They argued that transport improvements allowed economic activity to concentrate at high density in a particular place.[289] This connectivity enabled skills and knowledge to be transferred more easily, facilitating local specialisations and providing a comparative advantage for businesses in the location.[290]

*Source: Economic Affairs Committee (2015).*