THE ECONOMIC IMPACT OF RESTRICTING COMPETITION IN 5G NETWORK EQUIPMENT

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To discuss the report further please contact:

Henry Worthington: hworthington@oxfordeconomics.com

Oxford Economics
4 Millbank, London SW1P 3JA, UK
Tel: +44 203 910 8000

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EXECUTIVE SUMMARY

The next generation of mobile technology, 5G, offers enormous opportunities for countries who facilitate its widespread provision. 5G has the potential to both reduce costs and unlock new income streams across all sectors of industry, improving productivity levels throughout the global economy.

$160 billion

Annual investment in the construction of new 5G networks around the world, according to the GSMA.

THE TELECOMMUNICATIONS NETWORK INFRASTRUCTURE MARKET

Globally, the telecommunications network infrastructure market, is dominated by three players—Ericsson, Huawei and Nokia. These companies were largely responsible for the rollout of 4G networks via the deployment of mobile base stations which facilitate connections to mobile user devices.

However, the participation of one of these organisations—Huawei—in the rollout of 5G is likely to be constrained by a series of political decisions. In the **US** and **Australia**, Huawei has been blocked from competing for further 5G infrastructure contracts in the wake of concerns expressed by the US government about the security of its equipment. In several other markets including **Canada**, **France**, **Germany**, **India**, **Japan** and the **UK**, respective governments have announced they are either considering exclusion or have imposed partial restrictions.

WHY WOULD RESTRICTING COMPETITION MATTER?

Such restrictions will be costly to businesses and consumers alike. It is broadly agreed that restricting such a significant player from bidding for contracts will lead to higher prices, rollout delays and hence a slower diffusion of associated technological innovation. However, to-date, there has been no systematic attempt to quantify the potential scale of these effects. **In this context, Huawei has commissioned Oxford Economics to assess the economic cost of restricting competition in the eight aforementioned markets.**

$1 billion

Additional annual costs of building 5G infrastructure in the US under restricted competition, in our central cost scenario.

ECONOMIC IMPACTS OF RESTRICTING 5G COMPETITION

To reflect the uncertainty inherent in such a process, we modelled three alterative scenarios. These are termed "low cost", "central cost", and "high cost" respectively. All give results relative to our baseline scenario in which no competition restrictions are imposed on the 5G infrastructure market.

Restricting a key supplier of 5G infrastructure from helping to build a country's network would increase that country's 5G investment costs by a total of between 8% and 29% over the next decade (see Fig. 1)**.** In the US, this translates to an average increase in investment costs of almost $1 billion per year over the next decade in our central cost scenario.

The increase in investment costs linked to the restriction of 5G competition would also delay 5G access to millions of people over the next decade. Linked to these investment cost increases, the restriction in competition for 5G infrastructure would lead to delays in the network rollout that

mean millions fewer people would be covered by the 5G network in 2023. It would also significantly reduce economic growth over the next decade and beyond.

A delay in the rollout of 5G would also result in slower technological innovation and reduced economic growth. In our central cost scenario, this would result in reductions to national GDP in 2035 ranging from $2.8 billion in Australia to $21.9 billion in the US. Across all eight countries in our study, this means GDP per capita would be lower by an average of $100 per person in 2035, compared with a world where there is no such restriction in 5G infrastructure provision.

The uncertainty of the economic impact of restrictions on competition is reflected in the range of estimates presented in Fig. 1 below.

Fig. 1. Economic impacts of restricting a player of Huawei's size from competing in the 5G infrastructure market, central cost scenario

Market	Price impact (% increase in investment costs)	Reduction in number of people with access to 5G by 2023 (millions)	Reduction in GDP in 2035 (US$ billions, 2019 prices)
Australia	8% to 27%	0.0 to 3.1	0.8 to 8.2
Canada	8% to 24%	2.2 to 5.7	1.0 to 6.7
France	9% to 29%	2.1 to 5.7	2.6 to 15.6
Germany	9% to 29%	3.8 to 0.0	2.4 to 13.8
Japan	9% to 27%	5.8 to 15.3	5.3 to 34.3
India	8% to 27%	15.9 to 45.3	4.7 to 27.8
United Kingdom	9% to 29%	3.9 to 10.4	1.8 to 11.8
United States	8% to 24%`	0.0 to 27.1	8.6 to 36.0

Note: In Australia and the US, 5G rollout is expected to cover a vast majority of the population over the next 2-3 years with almost no increase in coverage in the following years. In our low cost scenario, the increase in investment costs leads to delays in rollout of a few months, despite which a vast majority of the population receives access by 2023. Source: Oxford Economics

Note: for a glossary of the terms used in this report, see Appendix 1.

INFOGRAPHIC: THE IMPACTS OF 5G INFRASTRUCTURE RESTRICTION IN OUR CENTRAL COST SCENARIO

Canada
100 - 400 (8%-27%)
2.2 to 5.7 (6% to 15%)
1.0 to 3.5

UK
200 - 700 (9%-29%)
3.9 to 10.4 (6% to 15%)
1.8 to 11.8

Germany
200 - 600 (9%-29%)
3.8 to 10.0 (5% to 12%)
2.4 to 13.8

Japan
700 – 2,100 (9%-27%)
7.2 to 19.1 (6% to 15%)
5.3 to 34.3

US
500 - 1,500 (8%-24%)
0.0 to 27.1 (0% to 8%)
8.6 to 63.0

France
200 - 600 (9%-29%)
2.1 to 5.7 (6% to 8%)
2.6 to 15.6

India
200 - 700 (8%-27%)
15.9 to 45.3 (1% to 3%)
4.7 to 27.8

Australia
100 - 300 (8%-27%)
0.0 to 3.1 (0% to 11%)
0.8 to 8.2

Legend

Country name

Increase in average annual investment costs for 5G infrastructure over the next decade, USD millions (%)

Absolute number of people that will have delayed access to 5G (millions of people) by 2023, millions of people (% of population)

Estimated permanent loss in Gross Domestic Product (GDP) due to delay in 5G rollout in 2035 (USD bn)

1. THE 5G OPPORTUNITY

As the next generation of mobile wireless network technology, 5G will provide a better consumer experience and improve business performance through faster data transmission and more reliable connectivity. 5G will reduce the cost of mobile internet use, with prices expected to drop 10-fold per gigabyte of data, compared with current 4G mobile networks.

5G will also unlock new income streams for businesses in all sectors of the economy, and increase their productivity levels, through enhanced capabilities including higher data speeds, lower latency,[1] and network slicing.[2]

Fig. 2. Summary of 5G's key benefits to businesses and consumers

Faster connection speeds	5G, characterised as Enhanced Mobile Broadband (eMBB), is expected to improve mobile internet use with higher speeds and seamless user experience in dense or high-mobility environments. It will support high-bandwidth services such as Augmented Reality (AR) and Virtual Reality (VR) apps.
Greater bandwidth for more devices	5G will enable Massive Machine-type Communications (mMTC). Put simply, it will enable the connection of a very large number of connected devices, which together comprise the Internet of Things.
Quicker response times	5G will also provide Ultra-reliable and Low Latency Communications (URLLC). Low latency means the response times for 5G will be much quicker than for previous generations of mobile technology, and that access to 5G will be far more reliable. This will allow the development of "mission critical" applications—for example, in transport (vehicle-to-vehicle communications), healthcare (remote monitoring), and logistics (drone delivery).

Source: Ofcom, Oxford Economics

Businesses are preparing for millions of new wireless devices—from smartwatches and other wearable items to sensors embedded in industrial products—to be connected to the next generation of 5G mobile networks. These devices, which together constitute the **Internet of Things** (IoT), will not use a lot of data (a sensor built into a highway, for example, will need to send only small amounts of digital information across the network every couple of hours). But when combined, these hundreds of millions—potentially billions—of new sensors will require almost universal connectivity, forcing operators to extend their networks to practically every corner of a country. Fig. 3 gives an indication of how 5G and the IoT will affect people and businesses throughout every sector of the economy.

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[1] Latency is the amount of time between a command and its corresponding action over the internet.

[2] Network slicing allows the physical infrastructure to be split into several virtual networks that can be tailored to different end-users, thereby facilitating dedicated disruption-free networks for critical users such as health and transport services that are free from disruption from other consumer and business uses.

Fig. 3. Examples of 5G and IoT applications by sector

Sector	Examples of applications
Health and social care	IoT enables remote health monitoring, creating timely alerts for patients, nurses, or carers.
Smart cities	Optimisation of street lighting, monitoring of parking, rubbish collection timing, and environmental monitoring.
Utilities	Smart meters and smart thermostats allowing for more accurate billing and better control of energy consumption.
Automotive	Connected smart cars for tracking mechanical diagnostics, autonomous vehicles (e.g., driverless cars), locations, and media streaming.
Manufacturing	Digitisation and automation of production lines , and remote control of industrial processes.
Logistics	Connected containers to record and share the item's location and temperature to streamline production and reduce the risk of damage to temperature-sensitive produce.

Source: Ofcom, Oxford Economics

1.1 THE CURRENT STATE OF 5G ROLLOUT

Amidst hype and high expectation, the 5G rollout has begun. By 2025, GSMA forecast that there will be 1.2 billion 5G mobile users globally, with network coverage extending to roughly a third of the planet's population.[3]

Fig. 4 offers a snapshot of 5G networks as of October 2019. Multiple operators have launched services in Austria, Australia, Bahrain, Germany, Italy, Kuwait, Qatar, South Korea, Romania, Switzerland, United Arab Emirates, United Kingdom, and United States. The first operators have also switched on their 5G networks in Finland, Ireland, Maldives, Monaco, Philippines, Saudi Arabia, Spain, and South Africa.

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[3] GSMA. 2018. *The Mobile Economy 2018*.

Fig. 4. Global 5G rollout as of October 2019

KEY

- No launches
- Single Launch
- Multiple Launches

Source: GSMA (2019)

Commercial 5G networks began going live in 2019 while the rate of new launches is expected to pick up in 2020[4], with an estimated $160 billion being invested each year in the construction of 5G networks.[5] Numerous national governments are working to facilitate the rapid rollout of 5G by making the 5G spectrum available in a timely manner, and by creating a policy and regulatory environment that supports a competitive and innovative communications market.
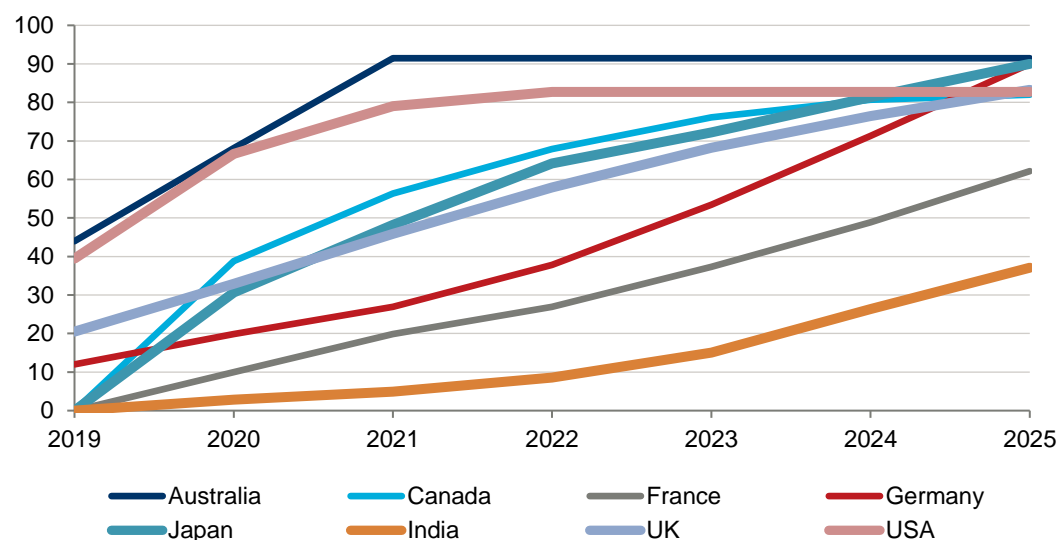
Fig. 5 shows the expected rate of 5G network rollout in the eight countries in our study, from 2019 to 2025. In the short term, Australia and the US have the highest proportions of 5G network coverage, with these countries' network operators having invested most to date in nationwide coverage and initial commercial deployments. Canada, Germany, the UK, and Japan are forecast to catch up over the next six years, with all four achieving 5G network coverage for more than 80% of their populations by 2025. France and India are also expected to see rapid growth in their 5G network coverage over the first half of the next decade.

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[4] Arthur D. Little. 2019. "The Race to 5G." *www.adl.com/RaceTo5G .* March. Accessed October 15, 2019. https://www.adlittle.com/sites/default/files/reports/adl_the_race_to_5g_report_-min.pdf.

[5] GSMA. 2019. *New GSMA Study: 5G to Account for 15% of Global Mobile Industry by 2025 as 5G Network Launches Accelerate.* Accessed 10 25, 2019. https://www.gsma.com/newsroom/press-release/new-gsma-study-5g-to-account-for-15-of-global-mobile-industry-by-2025/

Fig. 5. Projected 5G rollout as proportion of population covered, 2019-2025

5G projections: Percentage of population covered

Source: Oxford Economics

1.2 THE ECONOMIC BENEFITS OF 5G

To date, only a small number of studies have attempted to estimate the macroeconomic impact of 5G around the world. The magnitude of the findings varies greatly across different studies, reflecting different underlying assumptions and methodological approaches taken (see Fig. 6).

Summarising these findings, 5G's contribution to global GDP is estimated at between US$1.4 trillion and US$3.5 trillion over the next 10-to-15 years.

A 2018 study commissioned by GSMA put the total contribution of 5G over the 2020-2034 period at $2.2 trillion—5.3% per cent of total GDP growth during this period. In a 2017 report, IHS Markit predicted that the global 5G value chain would generate a US$3.5 trillion contribution to GDP, and support 22 million jobs, by the year 2035. While this study found that some of the largest gains would occur in information technology and communications, it also predicted large gains for the manufacturing and wholesale & retail trade sectors.

At the regional level, studies have put 5G's contribution to GDP at €113 billion (US$125.4 bn) in the European Union by 2025, US$500 billion in the US, and 6.3 trillion yuan (US$925 bn) in China over the same time period.

Fig. 6. Estimates of 5G's contribution to GDP growth

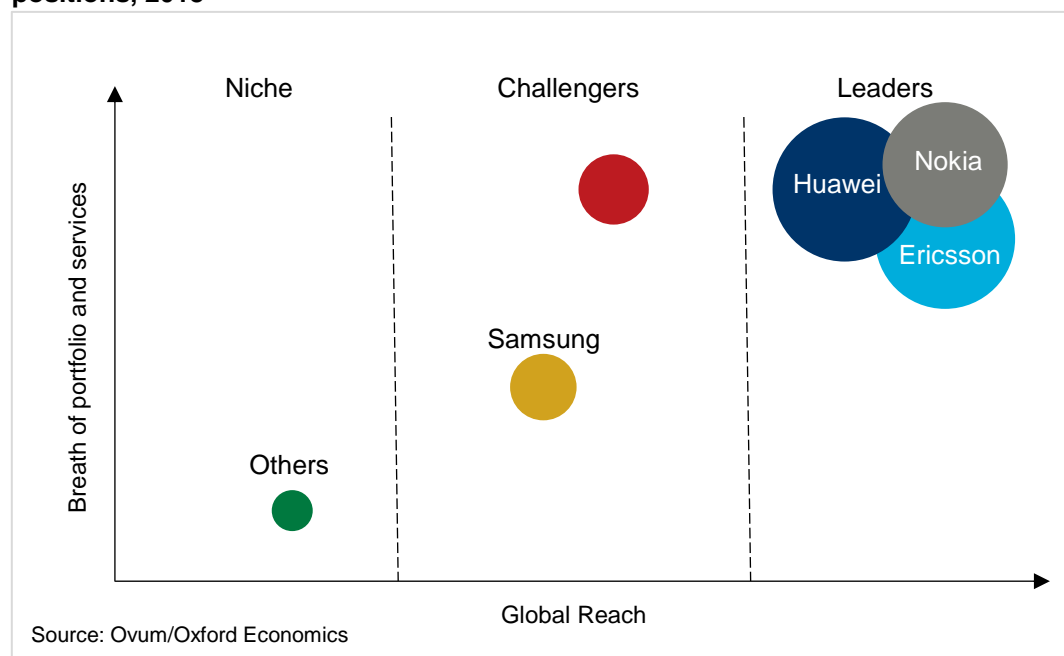| Geographic scope	Technological scope	Time period	Economic contribution	Study
Global	Entire 5G value chain	2035	**US$3.5 trillion in GDP, 22 million jobs**	IHS Markit (2017)
Global	High-bandwidth 5G technology	2020-2034	**US$565 billion in GDP**	GSMA (2018)
Global	5G technology	2020-2034	**US$2.2 trillion in GDP** (5.3% of total GDP growth)	GSMA (2018)
Global	5G technology	2030	**US$1.4 trillion in GDP**	STL Consulting (2019) for Huawei
EU	5G technology	2025	**€113 billion in GDP (**US$125.4 billion)	Tech4i2 et al (2016) for the European Commission
US	5G technology	2018-2025	**US$500 billion in GDP, three million jobs**	Accenture (2017) for the US CTIA and The Lost Economy (2017)
China	5G technology	2019-2030	**6.3 trillion yuan in GDP** (US$925 billion), **eight million jobs**	China Daily (2017)

Source: Oxford Economics

2. HOW THE 5G INFRASTRUCTURE MARKET WORKS

To understand the impact of restrictions on 5G equipment providers, it is important to understand the current market structure, and the nature of competition in this market. The telecoms infrastructure underlying the 5G network consists predominantly of the Radio Access Network (RAN), which in turn consists mainly of mobile base stations that connect telecom networks wirelessly to mobile user devices.

2.1 WHO ARE THE KEY PLAYERS IN THIS GLOBAL MARKET?

Ericsson (29% market share), Huawei (31%), and Nokia (23%) are the largest players in the global RAN market, across all generations of mobile technology. These three companies have the broadest product portfolios and widest global reach (see Fig. 7), as well as the strongest service support, and are expected to remain key global players as 5G becomes more prominent.

Fig. 7. Key players' global shares of RAN market and relative market positions, 2018

Source: Ovum/Oxford Economics

While network providers are global players with a worldwide footprint, there are some differences in their regional market shares (see Fig. 8). Currently, Huawei has a small presence in North America, where Ericsson and Nokia dominate with a combined market share of close to 90%. On the other hand, ZTE has a small but significant presence in the Asia Pacific region, at the expense of Nokia and Ericsson.

Despite these differences, responses to a 2015 European Commission review suggested that there are no obvious geographical barriers to the reach of the largest network providers[6].

Fig. 8. Regional market shares in the RAN market, 2018

Legend
ERICSSON ■ HUAWEI ■ NOKIA ■ SAMSUNG ■ ZTE ■ OTHERS

Source: Dell Oro

2.2 THE 5G INFRASTRUCTURE TENDER PROCESS

Having declined over the last few years, the RAN market is expected to start growing again—driven by the rollout of 5G networks. In 2019, worldwide RAN sales are forecast at around US$31 billion, to which 5G equipment is expected to contribute roughly US$3.6 billion. The contribution of 5G is then expected to grow rapidly over the next decade as the contribution of 4G declines, resulting in total RAN sales exceeding US$35 billion by 2023 (see Fig. 9).

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[6] *Nokia/Alcatel-Lucent Merger.* 2015. Case No COMP/M.7632 - REGULATION (EC) No 139/2004 Merger Proceure (European Commission, 24 July).

Fig. 9. RAN revenues and forecast, 2016-2023

US $ million

Source: Ovum

Mobile network operators, such as EE and Vodafone in the UK, issue tenders to the network providers for building 5G networks. These tender processes are already under way in many countries, with the duration of such contract awards being around three years, on average. Economic theory implies that a competitive tender will typically yield benefits for consumers, in terms of prices, quality of service, and technological innovation.

In South Korea, SK Telecom announced Ericsson, Nokia, and Samsung as its initial 5G network partners. Vodacom launched its commercial service in South Africa in 2018 using Huawei. China's operators have also started to tender commercial 5G offers.

However, the situation in the US and Australia has been complicated by their governments' decisions, as of October 2019, to restrict Huawei from competing in tenders for 5G network infrastructure provision in these countries. In the next chapter, we discuss the theoretical impact of restricting competition on the 5G network provision market, before going on to explain our three-stage modelling approach. Then in Chapter 4, we quantify the economic consequences of such a restriction across the eight countries in our study, in terms of increased investment costs, delayed 5G rollout, and lost productivity.

3. HOW WE ASSESS THE IMPACT OF RESTRICTING 5G COMPETITION

The technological benefits of 5G are expected to be transformational, and potentially revolutionary. As the world prepares to roll out 5G, a healthy and competitive market will help to ensure that the network infrastructure is installed as efficiently, quickly, and cheaply as possible.

However, concerns expressed about cyber security have led several countries to consider imposing restrictions on Chinese network providers from selling 5G network equipment to telecoms companies. In particular, as of October 2019, Huawei is blocked from competing in any 5G provision tenders in the United States and Australia, despite the company confirming it has never engaged in industrial espionage, nor allowed its technology to be knowingly hacked by the Chinese state.[7]

Economic theory suggests imposing restrictions on a major global provider such as Huawei could be expected to increase prices, which might in turn slow down 5G rollout. Furthermore, the quality of the infrastructure may be diminished, and productivity growth delayed, or worse, lost (see Box 2).

BOX 2: WHAT CAN ECONOMIC THEORY TELL US ABOUT THE 5G MARKET?

According to economic theory, competition between firms is good for consumers as well as other businesses which operate in other sectors of the economy. Competitive markets mean consumers get better products at lower prices, and typically ensure that firms which offer the highest quality and best value products are the ones that succeed.

Applying this to 5G infrastructure provision, competitive tenders should help to maximise the gains from this technological innovation. However, this does not mean that simply increasing the number of competitors in the 5G network infrastructure market would necessarily lead to reduced prices or faster innovation. In markets where firms must incur sizeable fixed costs (e.g., investment in R&D facilities or large production facilities) before realising profits, having a large number of firms implies duplication of these set-up costs, which represents a loss in productive efficiency. In this case, the presence of a few large operators who have already invested substantially in R&D and acquiring technological know-how may be efficient and welfare-enhancing.

In contrast, restricting a large player from competing in the 5G network will lead to reduced competitive pressures on the other large providers. This will lead to increased investment costs, delaying the speed of rollout which, in turn, will result in slower technological growth and innovation, and lower incomes for households across the economy.

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[7] The Guardian. 2019. "Huawei boss: UK 'won't say no to us' over 5G rollout." *The Guardian*, 16 August.
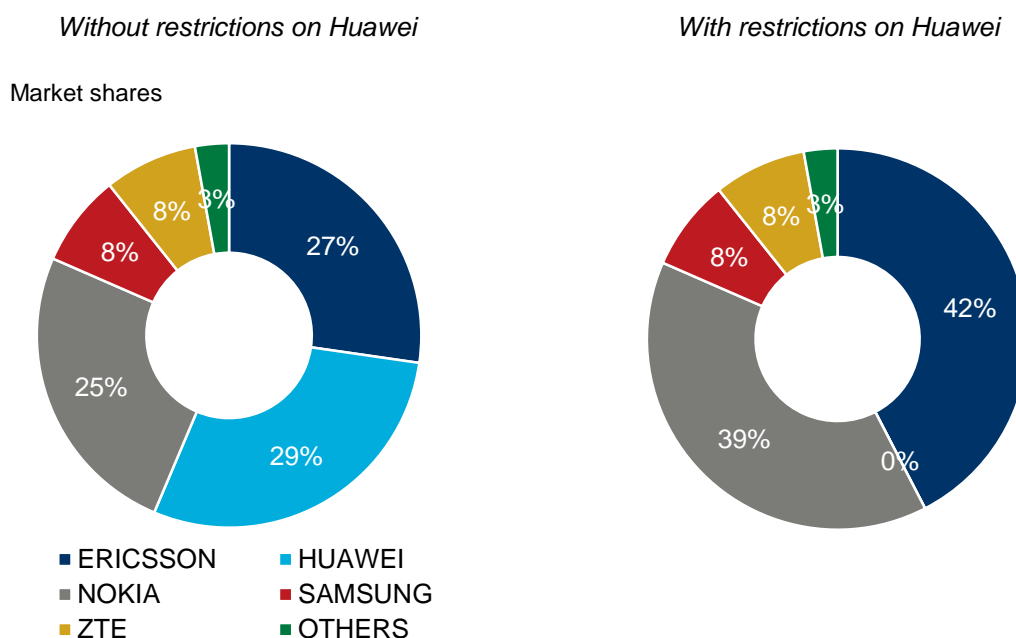
3.1 WHAT HAPPENS IF HUAWEI IS RESTRICTED FROM COMPETING?

For this study, we assume that if Huawei is restricted in each country's 5G infrastructure market, network operators in that market would switch to one of the two other large providers, Ericsson and Nokia, in proportion to their existing market shares. We believe that the other providers do not have the same global reach or breadth of products and services that would allow them to successfully compete for Huawei's customers, and therefore their market shares would remain unchanged.

We assume that 5G network equipment market shares over the next decade in the baseline (no restrictions on Huawei) will be closest to 4G market shares in 2018. In 2018, Huawei had 29% of the global 4G market, while Ericsson and Nokia had 27% and 25% respectively of the global 4G market.

With Huawei blocked from the market, our assumption means that Ericsson and Nokia's market shares would increase to 42% and 39% respectively, while Samsung, ZTE, and the other operators would not see a change in their market shares (Fig. 11).

Fig. 10. Worldwide market shares without and without restrictions on Huawei (based on 2018 4G revenues)

Without restrictions on Huawei   *With restrictions on Huawei*

Market shares

- ERICSSON
- HUAWEI
- NOKIA
- SAMSUNG
- ZTE
- OTHERS

Source: Oxford Economics

This results in an increase in concentration in markets across the globe. In our study, we focus on eight developed technology markets: Australia; Canada, France; Germany; India; Japan; the United Kingdom; and the United States. To tailor our analysis to different markets, we use regional market shares to account for differences in the network providers' geographic reach.[8] In particular, we use North American market shares for Canada and the

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[8] Ideally, we would have used national market share data to tailor our analysis to the individual markets, but we had to use regional market shares as the corresponding national data was not available.

United States; European market shares for France, Germany and the UK; and worldwide market shares for Australia, India and Japan. [9]

Fig. 11 shows the market shares of the three major players in North America, Europe, and worldwide. Huawei has a small presence in North America due to existing restrictions. Further restrictions will therefore lead to a very small increase in concentration. In contrast, in other countries in our study, Huawei has the largest market share, and restrictions on Huawei would therefore lead to a significant increase in concentration.

Fig. 11. Expected regional 5G RAN market shares with no restrictions on Huawei (based on regional 4G LTE market shares in 2018)

Region	Country in our study	Huawei	Nokia	Ericsson
North America	Canada, USA	2%	42%	47%
Europe	France, Germany, UK	36%	26%	28%
Worldwide	Australia, India and Japan	29%	25%	27%

Source: Dell Oro

Note: in this study, we only consider the economic impact due to increases in concentration and do not account for the loss of the technological know-how, experience and capabilities that are unique to Huawei. Huawei is among the leading spenders on R&D and is considered to have an advantage over its competitors due to its technological prowess.[10] Therefore, the rest of the modelling, described further in the following chapter, is more appropriately described as being based on the exclusion of a competitor of Huawei's size.

3.2 OUR THREE-STAGE MODELLING APPROACH

Lower competition due to restrictions on Huawei is expected to increase investment costs, slow down rollout and delay productivity improvements. Using Oxford Economics' world-leading Global Economic Model (GEM) and a host of other sophisticated industry and market structure models, we analysed the impact of a supplier of Huawei's size being restricted from each market's 5G network infrastructure[11], in terms of the projected increase in investment costs, delays in 5G rollout, and reduced national GDP levels. We used a three-stage modelling framework to assess the economic impact of restricting competition in the provision of 5G network equipment.

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[9] We used the worldwide LTE market shares for Australia, India and Japan instead of the regional, i.e., APAC, measures. The APAC measure is likely to be heavily dominated by China. Vendor market shares in China are not representative of vendor market shares in Australia, India and Japan.

[10] Strategy Analytics. 2019. "Comparison and 2023 5G Global Market Potential for leading 5G RAN vendors - Ericsson, Huawei and Nokia."

[11] In our study, we focus on eight developed technology markets: Australia, Canada, France, Germany, India, Japan, the United Kingdom, and the United States.

Stage 1: Impact on investment costs

To calculate the economic impact of restricting competition, we started by estimating the increase in mobile network operators' investment costs when a major infrastructure provider is restricted from the market. We did this using a range of techniques developed in collaboration with Dr Martin Pesendorfer from the London School of Economics.

The techniques used were:

- a **theoretical model of oligopoly** characterising the 5G network infrastructure market that simulates the change in price of network infrastructure associated with restrictions on competition;

- **merger simulation techniques** that are used by competition authorities to estimate the price impact following changes to the market structure e.g. following the completion of a merger; and

- **empirical evidence** from a range of studies across industries that estimated the change in price following a merger.

Given the worldwide nature of the network infrastructure market, we made some adjustments to standardise the price impacts across our eight countries of interest.

Stage 2: Impact on rollout

We translated the increase in investment costs to delays in rollout using a network rollout model built in collaboration with Dr Edward Oughton (Cambridge Judge Business School). This model translates an increase in investment costs to a reduction in the share of the population covered for each country and scenario by assuming that the overall operators' capex remains the same.

Our baseline—i.e. with no competition restrictions—forecasts for 5G rollout and capital expenditure were sourced from the GSMA. Based on this, we calculated the average investment expenditure required to extend 5G coverage on a per person basis. The increase in investment costs due to restricted competition, as estimated in Stage 1, was used as an input into the rollout model. Assuming that nominal investment remains unchanged, the higher cost of rollout results in lower coverage.

Stage 3: Impact on productivity and macroeconomic growth

The increase in investment costs and delays in rollout were translated into lower productivity growth using estimates of the productivity benefits of 5G from various academic and industry studies. The lower productivity growth is partly due to the increase in the costs of building the 5G network and partly due to the reduced investment in 5G and related services due to delays in rollout.

These were then fed into the Oxford Economics Global Economic Model to estimate the impact on a range of macroeconomic indicators such as GDP and household consumer spending.

3.3 TRANSMISSION MECHANISM OF COMPETITION RESTRICTIONS

There are a large number of ways through which restrictions on competition in the network infrastructure market results in loss in productivity and GDP. Fig. 12summarises the transmission mechanism, highlighting the channels that have not been included in our modelling.

Fig. 12. Transmission mechanism of restrictions in competition

Notes: The grey boxes indicate channels that are not considered in our modelling approach. Only the channels described in the blue boxes are modelled.

In general, restricting competition in the 5G network infrastructure market leads to lower competitive pressures on the unrestricted network providers, who will be able to charge higher contract prices for 5G equipment.

Our modelling approach does not account for a number of other potential costs of restricting competition. For example, in addition to the increase in prices, there may also be a reduction in quality and technological innovation in the 5G network equipment as the unrestricted firms do not face the same pressures to invest in R&D and innovation. Further, network operators and providers may face some transition costs as they adapt their plans and existing infrastructure to adequately fill in the gap left by a large competitor such as Huawei.

The higher network equipment prices translate into higher investment costs, which translates into delays in rollout. We assume that network operators do not suffer from any capital constraints or increased costs of capital as they increase their investment expenditure.

The increase in investment costs and the consequent delays in rollout lead to productivity losses across the economy.

3.4 ACCOUNTING FOR UNCERTAINTY

However, the precise extent of this negative impact will depend on the potential future benefits of 5G, and the market reactions to competition restrictions. To capture the uncertainty around the future benefits of 5G and the different market responses to competition restrictions, we modelled three scenarios which are summarised in Fig. 13.

Fig. 13. Definitions of scenarios modelled to reflect uncertainty

Source of uncertainty	LOW COST scenario	CENTRAL COST scenario	HIGH COST scenario
Potential future benefits of 5G	5G, characterised as Enhanced Mobile Broadband (eMBB), provides higher broadband speeds and supports high-bandwidth services such as Augmented Reality (AR) and Virtual Reality (VR) apps.	5G enables Massive Machine-type Communications (mMTC): i.e. the connection of a very large number of connected devices (one million per sq. km), supporting low-power, low-energy devices which enables large-scale IoT deployments across sectors.	5G is revolutionary, providing Ultra-reliable and Low Latency Communications (URLLC) that enables applications which are heavily dependent on low latency and high reliability, and supports critical applications in transport, healthcare and energy.
Market reaction to competition restrictions	We assume that the scope for other 5G infrastructure vendors to exercise their market power and increase prices is limited.	Other vendors are able to increase their prices to some extent but are not fully able to exercise their market power.	Given the revolutionary impact of 5G, infrastructure vendors can fully exercise their market power and increase prices to the maximum extent.

The modelling assumptions corresponding to the scenarios above are shown in Fig. 14 below. To model the low cost scenario, we assumed that 5G leads to productivity benefits of 0.15% in GDP growth per year, which is based on the lower end of estimates from various studies. To account for limited increases in prices in the low cost scenario, we assumed that investment costs increase by the lower end of the range of estimates from our three price models.

For the high cost scenario, we assumed that 5G leads to productivity benefits of 0.30% in GDP growth per year, which is based on the higher end of the estimates from the various studies. Similarly, the increase in investment costs

was based on the higher end of the range of estimates from our three price models in Stage 1.

In the central cost scenario, we assumed that 5G leads to productivity benefits of 0.15% in GDP growth per year in the first year of 5G rollout, increasing to 0.30% in five years. The increase in investment costs was based on the median of estimates from the three price models in Stage 1.

Fig. 14. Modelling assumptions to reflect uncertainty

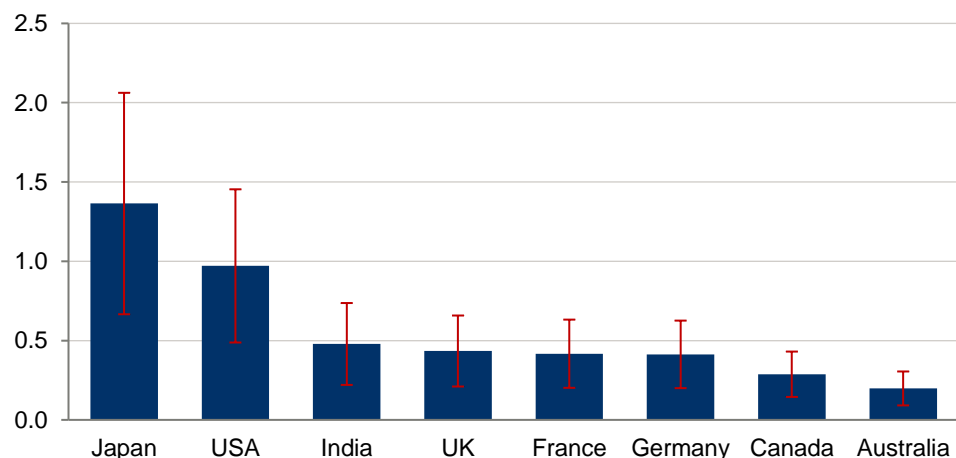| Source of uncertainty	LOW COST scenario	CENTRAL COST scenario	HIGH COST scenario
Potential future benefits of 5G modelled using GDP growth per year in the baseline (no restrictions scenario)	0.15% per year from 2020-2035	0.15% in 2020; increasing to 0.30% in 2025 and constant at 0.30% per year after.	0.30% per year from 2020-2035
Market reaction to competition restrictions modelled using increase in investment costs (varies by country)	8%-9% increase per year	16%-19% increase per year	24%-29% increase per year

4. INDIVIDUAL COUNTRY RESULTS

In our central cost scenario, restricting a key supplier of 5G infrastructure from helping to build a country's network was found to increase overall 5G investment costs by between 16% and 19%, among the eight countries covered in this study.

In the US and Canada, this equates to an average annual increase in 5G network investment costs of US$1.0 billion and US$300 million, respectively, over the next decade. In the three European countries in our study, we estimate restrictions on competition could lead to average annual investment cost increases of US$400 million each in France, Germany, and the UK over the same time period, in our central cost scenario. In Japan, the equivalent average annual increase would be US$1.4 billion, in India US$500 million, and in Australia US$200 million.

Fig. 15. Increase in average annual 5G network investment costs due to competition restrictions, 2019-2030

Increase in average annual investment costs (US$ billions)

Note: The red bars indicate the range for the high cost and low cost scenarios.
Source: Oxford Economics.

Linked to these investment cost increases, the restriction in competition for 5G infrastructure would lead to delays in the network rollout that mean millions fewer people would be covered by the 5G network in 2023. It would also significantly reduce economic growth over the next decade and beyond.

In the remainder of this chapter, we detail the full results for the eight countries in our study, according to all three scenarios: low cost, central cost, and high cost. In each case, the results are given relative to our baseline scenario in which no competition restrictions are imposed on the 5G infrastructure market.

AUSTRALIA

HEADLINE RESULTS

Restricting a major participant (central cost scenario):

- **US$200 million (17%) increase** in average annual cost of building 5G network over the next decade
- **1.5 million fewer people** will have access to 5G in 2023 (**5.6%** of population)
- **US$2.8 billion (0.13%)** reduction in GDP in 2035 compared with unrestricted forecast

	Low cost	Central cost	High cost
Increase in average annual investment costs for 5G infrastructure over the next decade, US$ millions (%)	100 (8%)	200 (17%)	300 (27%)
Absolute number of people that will have delayed access to 5G (millions of people) by 2023, millions of people (% of population)	0.0 (0%)	1.5 (5.6%)	3.1 (11.4%)
Estimated permanent loss in Gross Domestic Product (GDP) due to delay in 5G rollout in 2035 (US$ bn)	0.8	2.8	8.2

5G rollout with and without competition restrictions in Australia

Percentage of population covered

Source: GSMA, Oxford Economics

MARKET ANALYSIS: AUSTRALIA

Australia is among the top three countries in terms of 5G preparedness along with South Korea and the US[12]. A competitive market for 5G infrastructure would help maximise the gains from technological innovation and growth in Australia. A study for the Australian government estimates that 5G technology could add an additional $1,300 to $2,000 in GDP per person in 2030 after the first decade of the rollout[13].

On the other hand, restricting competition can have significant adverse economic impacts. Our modelling suggests restricting a major participant could increase the cost of building the 5G network by US$200 million per year over the next decade (17% of baseline costs) in our central cost scenario. Due to these price increases, 1.5 million people (5.6% of the population) who would have otherwise had access to the 5G network could be left without access to a 5G network in 2023.

Restricting competition in the network infrastructure market may significantly reduce economic growth in Australia over the next 15 years. We estimate this could reduce GDP in 2035 by US$2.8 billion.

The potential future benefits of 5G are hard to predict. While most industry players expect 5G to transform the economy, 5G may end up being merely an enhancement to the existing 4G technology. Or it could be revolutionary in the way the steam engine or electricity was. The uncertainty about the nature of benefits will also be reflected in the economic consequences of restricting competition in the network infrastructure market.

To account for this, we have modelled two additional scenarios that capture the lower and higher end of the range of potential future outcomes from competition restrictions in the 5G network market.

Across our scenarios, we expect the increase in average annual investment costs over the next 10 years due to competition restrictions to vary between US$100 million (8%) and US$300 million (27%). The wide range in these estimates is due to the uncertainty around the reaction of other vendors of network infrastructure.

This increase in prices would translate into delays in rollout. We estimate that these delays would leave up to 3.1 million people (11.4% of the population) without access to 5G by 2023.

The resulting loss in productivity has significant economic consequences. Lower economic growth due to delays in 5G rollout and the associated slower technological growth reduces GDP by between $0.8 billion to $8.2 billion in 2035.

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[12] Arthur D. Little. 2019. *The Race to 5G*.
https://www.adlittle.com/sites/default/files/reports/adl_the_race_to_5g_report_-min.pdf.

[13] Department of Communications and the Arts (Australian Government). 2018. *Impacts of 5G on productivity and economic growth*. Working Paper.
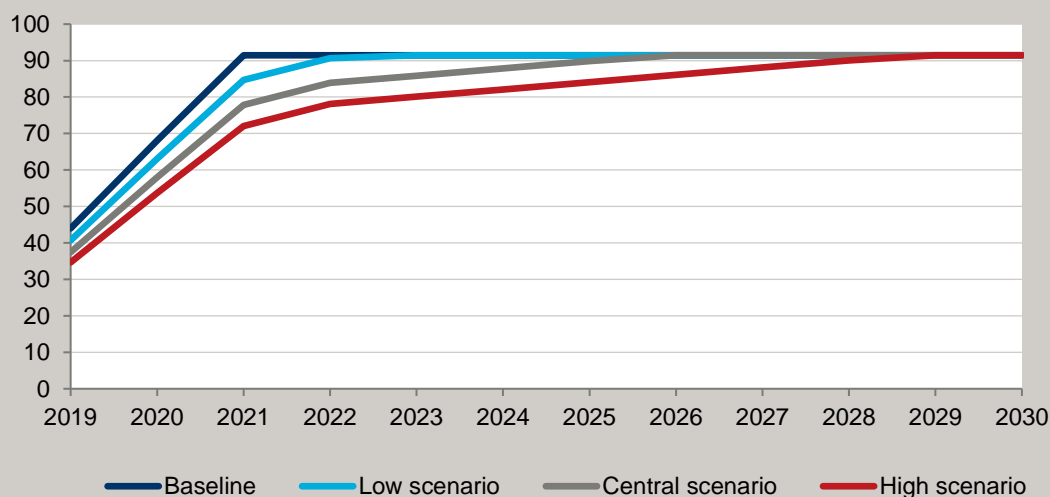
CANADA

HEADLINE RESULTS

Restricting a major participant (central cost scenario):

➢ **US$300 million (16%) increase** in average annual cost of building 5G network over the next decade

➢ **4.1 million fewer people** will have access to 5G in 2023 (**10.5%** of population)

➢ **US$3.5 billion (0.17%)** reduction in GDP in 2035 compared with unrestricted forecast

	Low cost	Central cost	High cost
Increase in average annual investment costs for 5G infrastructure over the next decade, US$ millions (%)	100 (8%)	300 (16%)	400 (24%)
Absolute number of people that will have delayed access to 5G (millions of people) by 2023, millions of people (% of population)	2.2 (5.7%)	4.1 (10.5%)	5.7 (14.7%)
Estimated permanent loss in Gross Domestic Product (GDP) due to delay in 5G rollout in 2035 (US$ bn)	1.0	3.5	6.7

5G rollout with and without competition restrictions in Canada

Percentage of population covered

Source: GSMA, Oxford Economics

MARKET ANALYSIS: CANADA

A comprehensive study conducted by Accenture found that the adoption of 5G technology in Canada will propel innovation across industries and significantly improve Canadians' quality of life and the economy to the tune of a nearly $40 billion annual GDP uplift by 2026. The benefits will be felt not only in national GDP, but also in terms of Canadian jobs. It is estimated that by this same time close to 250 thousand permanent jobs will be added to the Canadian economy.[14]

On the other hand, restricting competition can have significant adverse economic impacts. Our modelling suggests restricting a major participant could increase the cost of building the 5G network by US$300 million per year over the next decade (16% of baseline costs) in our central cost scenario. Due to these price increases, 4.1 million people (10.5% of the population) who would have otherwise had access to the 5G network could be left without access to a 5G network in 2023.

Restricting competition in the network infrastructure market may significantly reduce economic growth in Canada over the next 15 years. We estimate this could reduce GDP in 2035 by US$3.5 billion.

The potential future benefits of 5G are hard to predict. While most industry players expect 5G to transform the economy, 5G may end up being merely an enhancement to the existing 4G technology. Or it could be revolutionary in the way the steam engine or electricity was. The uncertainty about the nature of benefits will also reflected in the economic consequences of restricting competition in the network infrastructure market.

To account for this, we have modelled two additional scenarios that capture the lower and higher end of the range of potential future outcomes from competition restrictions in the 5G network market.

Across our scenarios, we expect the increase in average annual investment costs over the next 10 years due to competition restrictions to vary between US$100 million (8%) and US$400 million (24%). The wide range in these estimates is due to the uncertainty around the reaction of other vendors of network infrastructure.

This increase in prices would translate into delays in rollout. We estimate that these delays would leave between 2.2 million people to 5.7 million people (5.7% to 14.7% of the population) without access to 5G by 2023.

The resulting loss in productivity has significant economic consequences. Lower economic growth due to delays in 5G rollout and the associated slower technological growth reduces GDP by between $1.0 billion to $6.7 billion in 2035.

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[14] Accenture. 2018. *Fuel for innovation: Canada's Path in the Race to 5G.* Accenture Strategy Report.
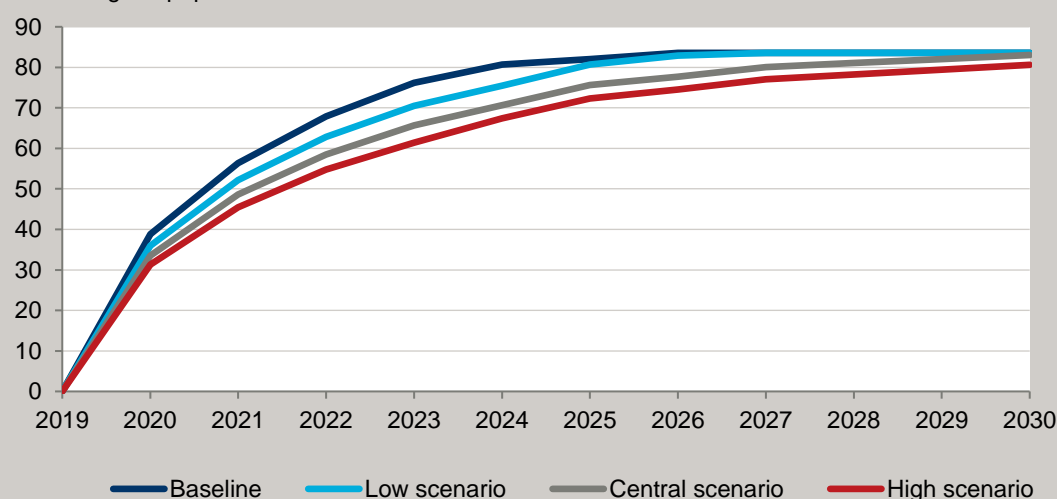
FRANCE

HEADLINE RESULTS

Restricting a major participant (central cost scenario):

➢ **US$400 million (19%) increase** in average annual cost of building 5G network over the next decade

➢ **4.0 million fewer people** will have access to 5G in 2023 (**6%** of population)

➢ **US$8.3 billion (0.39%)** reduction in GDP in 2035 compared with unrestricted forecast

	Low cost	Central cost	High cost
Increase in average annual investment costs for 5G infrastructure over the next decade, US$ millions (%)	200 (9%)	400 (19%)	600 (29%)
Absolute number of people that will have delayed access to 5G (millions of people) by 2023, millions of people (% of population)	2.1 (3.2%)	4.0 (6.0%)	5.7 (8.4%)
Estimated permanent loss in Gross Domestic Product (GDP) due to delay in 5G rollout in 2035 (US$ bn)	2.6	8.3	15.6

5G rollout with and without competition restrictions in France

Percentage of population covered

Source: GSMA, Oxford Economics

MARKET ANALYSIS: FRANCE

France is among the countries expected to be at the forefront of 5G development. A competitive market for 5G infrastructure would help maximise the gains from technological innovation and growth in Australia. 5G services will stimulate economic activity worth $85bn in GDP and support around 396 thousand jobs in France in 2035.[15]

On the other hand, restricting competition can have significant adverse economic impacts. Our modelling suggests restricting a major participant could increase the cost of building the 5G network by US$400 million per year over the next decade (19% of baseline costs) in our central cost scenario. Due to these price increases, 4.0 million people (6% of the population) who would have otherwise had access to the 5G network could be left without access to a 5G network in 2023.

Restricting competition in the network infrastructure market may significantly reduce economic growth in France over the next 15 years. We estimate this could reduce GDP in 2035 by US$8.3 billion.

The potential future benefits of 5G are hard to predict. While most industry players expect 5G to transform the economy, 5G may end up being merely an enhancement to the existing 4G technology. Or it could be revolutionary in the way the steam engine or electricity was. The uncertainty about the nature of benefits will also reflected in the economic consequences of restricting competition in the network infrastructure market.

To account for this, we have modelled two additional scenarios that capture the lower and higher end of the range of potential future outcomes from competition restrictions in the 5G network market.

Across our scenarios, we expect the increase in average annual investment costs over the next 10 years due to competition restrictions to vary between US$200 million and US$600 million (9% and 29%). The wide range in these estimates is due to the uncertainty around the reaction of other vendors of network infrastructure.

This increase in prices would translate into delays in rollout. We estimate that these delays would leave between 2.1 million people to 5.7 million people (3.2% to 8.4% of the population) without access to 5G by 2023.

The resulting loss in productivity has significant economic consequences. Lower economic growth due to delays in 5G rollout and the associated slower technological growth reduces GDP by between $2.6 billion to $15.6 billion in 2035.

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[15] IHS. 2017. *The 5G economy: How 5G technology will contribute to the global economy.* Economic Impact Analysis, IHS Economics & IHS Technology.
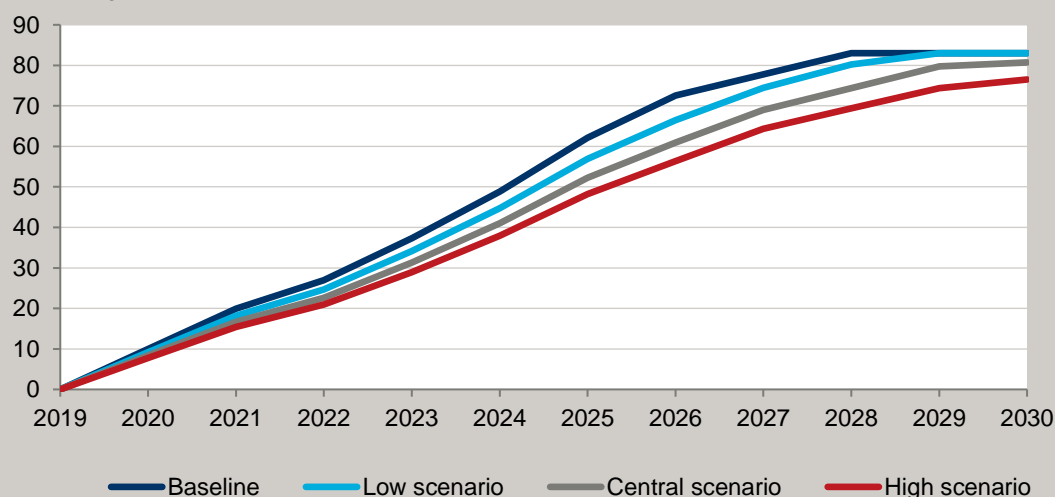
GERMANY

HEADLINE RESULTS

Restricting a major participant (central cost scenario):

➢ **US$400 million (19%) increase** in average annual cost of building 5G network over the next decade

➢ **7.1 million fewer people** will have access to 5G in 2023 (**8.5%** of population)

➢ **US$6.9 billion (0.25%)** reduction in GDP in 2035 compared with unrestricted forecast

	Low cost	Central cost	High cost
Increase in average annual investment costs for 5G infrastructure over the next decade, US$ millions (%)	200 (9%)	400 (19%)	600 (29%)
Absolute number of people that will have delayed access to 5G (millions of people) by 2023, millions of people (% of population)	3.8 (4.5%)	7.1 (8.5%)	10.0 (12.0%)
Estimated permanent loss in Gross Domestic Product (GDP) due to delay in 5G rollout in 2035 (US$ bn)	2.4	6.9	13.8

5G rollout with and without competition restrictions in Germany

Percentage of population covered

Source: GSMA, Oxford Economics

MARKET ANALYSIS: GERMANY

The German government has set out a plan to create the necessary infrastructure prerequisites to have near universal 5G connectivity by 2025. A competitive market for network infrastructure is critical to meet this ambitious target for 5G rollout[16]. The benefits from 5G are substantial: 5G services are expected to stimulate economic activity worth $202bn in GDP and support around 1.2 million jobs in Germany in 2035.[17]

On the other hand, restricting competition can have significant adverse economic impacts. Our modelling suggests restricting a major participant could increase the cost of building the 5G network by US$400 million per year over the next decade (19% of baseline costs) in our central cost scenario. Due to these price increases, 7.1 million people (8.5% of the population) who would have otherwise had access to the 5G network could be left without access to a 5G network in 2023.

Restricting competition in the network infrastructure market may significantly reduce economic growth in Germany over the next 15 years. We estimate this could reduce GDP in 2035 by US$6.9 billion.

The potential future benefits of 5G are hard to predict. While most industry players expect 5G to transform the economy, 5G may end up being merely an enhancement to the existing 4G technology. Or it could be revolutionary in the way the steam engine or electricity was. The uncertainty about the nature of benefits will also reflected in the economic consequences of restricting competition in the network infrastructure market.

To account for this, we have modelled two additional scenarios that capture the lower and higher end of the range of potential future outcomes from competition restrictions in the 5G network market.

Across our scenarios, we expect the increase in average annual investment costs over the next 10 years due to competition restrictions to vary between US$200 million and US$600 million (9% and 29%). The wide range in these estimates is due to the uncertainty around the reaction of other vendors of network infrastructure.

This increase in prices would translate into delays in rollout. We estimate that these delays would leave between 3.8 million people to 10 million people (4.5% to 12.0% of the population) without access to 5G by 2023.

The resulting loss in productivity has significant economic consequences. Lower economic growth due to delays in 5G rollout and the associated slower technological growth reduces GDP by between $2.4 billion to $13.8 billion in 2035.

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[16] The German Federal Government . 2017. 5G *Strategy for Germany*. Federal Ministry of Transport and Digital Infrastructure.

[17] IHS. 2017. *The 5G economy: How 5G technology will contribute to the global economy*. Economic Impact Analysis, IHS Economics & IHS Technology.
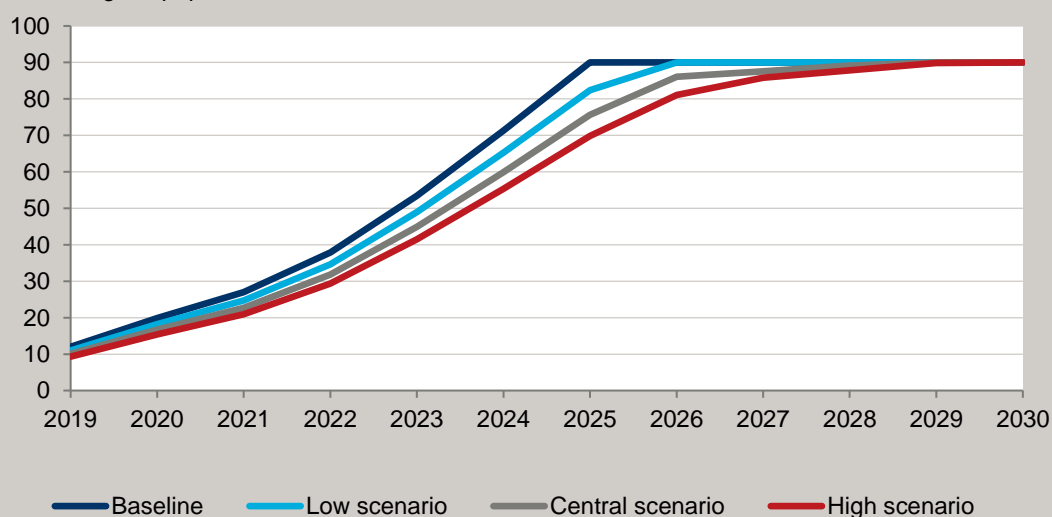
INDIA

HEADLINE RESULTS

Restricting a major participant (central cost scenario):

➢ **US$500 million (17%) increase** in average annual cost of building 5G network over the next decade

➢ **31.8 million fewer people** will have access to 5G in 2023 (**2.2% of population**)

➢ **US$15.5 billion (0.36%)** reduction in GDP in 2035 compared with unrestricted forecast

	Low cost	Central cost	High cost
Increase in average annual investment costs for 5G infrastructure over the next decade, US$ millions (%)	200 (8%)	500 (17%)	700 (27%)
Absolute number of people that will have delayed access to 5G (millions of people) by 2023, millions of people (% of population)	15.9 (1.1%)	31.8 (2.2%)	45.3 (3.2%)
Estimated permanent loss in Gross Domestic Product (GDP) due to delay in 5G rollout in 2035 (US$ bn)	4.7	15.5	27.8

5G rollout with and without competition restrictions in India

Percentage of population covered

Source: GSMA, Oxford Economics

25

MARKET ANALYSIS: INDIA

India is one of the largest and fastest growing telecoms markets in the world. By 2025, 208 million new subscribers are expected get connected in India, accounting for a quarter of global new subscribers over 2017-2025 period. By this time, smartphone connections in the country will account for three quarters of total connections. A competitive market for 5G infrastructure would help maximise the gains from technological innovation and growth in India. 5G is expected to be launched in India by 2020 and is predicted to create a cumulative economic impact of US$ one trillion in India by 2035.[18]

On the other hand, restricting competition can have significant adverse economic impacts. Our modelling suggests restricting a major participant could increase the cost of building the 5G network by US$500 million per year over the next decade (17% of baseline costs) in our central cost scenario. Due to these price increases, 31.8 million people (2.2% of the population) who would have otherwise had access to the 5G network could be left without access to a 5G network in 2023.

Restricting competition in the network infrastructure market may significantly reduce economic growth in India over the next 15 years. We estimate this could reduce GDP in 2035 by US$15.5 billion.

The potential future benefits of 5G are hard to predict. While most industry players expect 5G to transform the economy, 5G may end up being merely an enhancement to the existing 4G technology. Or it could be revolutionary in the way the steam engine or electricity was. The uncertainty about the nature of benefits will also reflected in the economic consequences of restricting competition in the network infrastructure market.

To account for this, we have modelled two additional scenarios that capture the lower and higher end of the range of potential future outcomes from competition restrictions in the 5G network market.

Across our scenarios, we expect the increase in average annual investment costs due to competition restrictions to vary between US$200 million and US$700 million (8% and 27%). The wide range in these estimates is due to the uncertainty around the reaction of other vendors of network infrastructure.

This increase in prices would translate into delays in rollout. We estimate that these delays would leave between 15.9 million people to 45.3 million people (1.1% to 3.2% of the population) without access to 5G by 2023.

The resulting loss in productivity has significant economic consequences. Lower economic growth due to delays in 5G rollout and the associated slower technological growth reduces GDP by between $4.7 billion to $27.8 billion in 2035.

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[18] Telecoms Regulatory Authority of India (TRAI). 2019. *Enabling 5G in India*. White Paper.
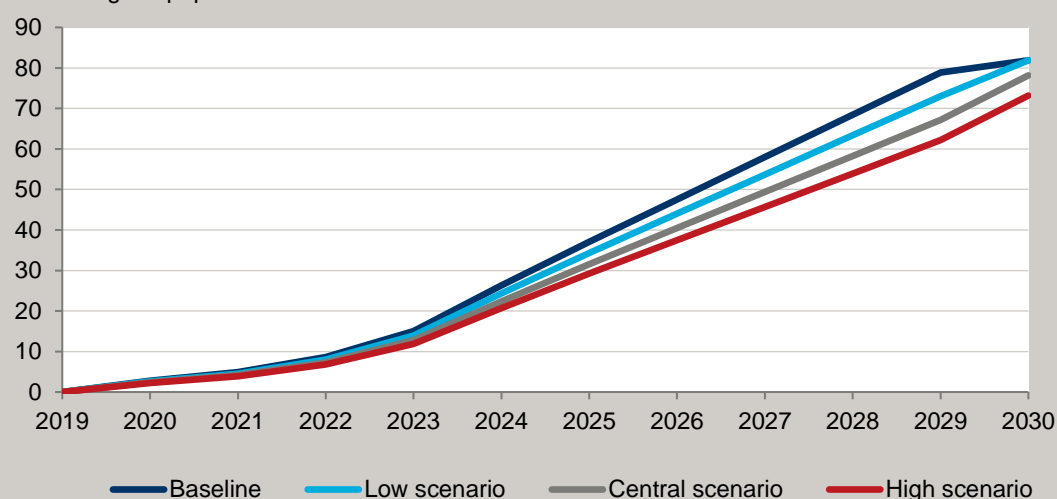
JAPAN

HEADLINE RESULTS

Restricting a major participant (central cost scenario):

➤ **US$1.4 billion (18%) increase** in average annual cost of building 5G network over the next decade

➤ **13.6 million fewer people** will have access to 5G in 2023 (**10.9%** of population)

➤ **US$15.6 billion (0.25%)** reduction in GDP in 2035 compared with unrestricted forecast

	Low cost	Central cost	High cost
Increase in average annual investment costs for 5G infrastructure over the next decade, US$ millions (%)	700 (9%)	1,400 (18%)	2,100 (27%)
Absolute number of people that will have delayed access to 5G (millions of people) by 2023, millions of people (% of population)	7.2 (5.8%)	13.6 (10.9%)	19.1 (15.3%)
Estimated permanent loss in Gross Domestic Product (GDP) due to delay in 5G rollout in 2035 (US$ bn)	5.3	15.6	34.3

5G rollout with and without competition restrictions in Japan

Percentage of population covered

Source: GSMA, Oxford Economics

MARKET ANALYSIS: JAPAN

Japan has been a global leader in mobile communications for the past four decades. By 2020, Japanese operators will roll out 5G, the next-generation mobile network, in time to host the Olympic and Paralympic Games. Japan will, once again, be one of the first movers to deploy a next-generation network. 5G services will stimulate economic activity worth $492bn in GDP and support around 2.1 million jobs in Japan in 2035.[19]

On the other hand, restricting competition can have significant adverse economic impacts. Our modelling suggests restricting a major participant could increase the cost of building the 5G network by US$1.4 billion per year over the next decade (18% of baseline costs) in our central cost scenario. Due to these price increases, 13.6 million people (10.9% of the population) who would have otherwise had access to the 5G network could be left without access to a 5G network in 2023.

Restricting competition in the network infrastructure market may significantly reduce economic growth in Japan over the next 15 years. We estimate this could reduce GDP in 2035 by US$15.6 billion.

The potential future benefits of 5G are hard to predict. While most industry players expect 5G to transform the economy, 5G may end up being merely an enhancement to the existing 4G technology. Or it could be revolutionary in the way the steam engine or electricity was. The uncertainty about the nature of benefits will also reflected in the economic consequences of restricting competition in the network infrastructure market.

To account for this, we have modelled two additional scenarios that capture the lower and higher end of the range of potential future outcomes from competition restrictions in the 5G network market.

Across our scenarios, we expect the increase in average annual investment costs due to competition restrictions to vary between US$ 700 million and US$2.1 billion (9% and 27%). The wide range in these estimates is due to the uncertainty around the reaction of other vendors of network infrastructure.

This increase in prices would translate into delays in rollout. We estimate that these delays would leave between 7.2 million people to 19.1 million people (5.8% to 15.3% of the population) without access to 5G by 2023.

The resulting loss in productivity has significant economic consequences. Lower economic growth due to delays in 5G rollout and the associated slower technological growth reduces GDP by between $5.3 billion to $34.3 billion in 2035.

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[19] IHS. 2017. *The 5G economy: How 5G technology will contribute to the global economy*. Economic Impact Analysis, IHS Economics & IHS Technology.
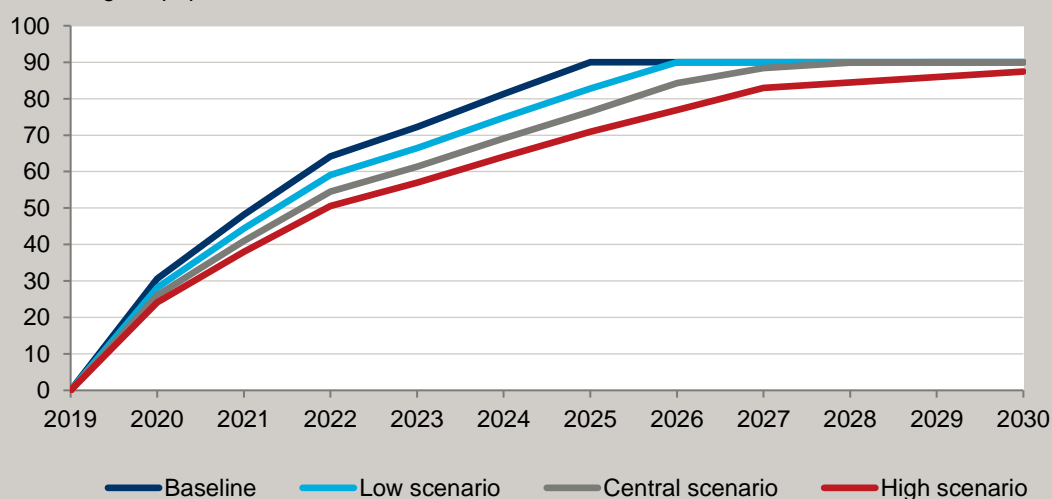
UNITED KINGDOM

HEADLINE RESULTS

Restricting a major participant (central cost scenario):

➢ **US$400 million (19%) increase** in average annual cost of building 5G network over the next decade

➢ **7.4 million fewer people** will have access to 5G in 2023 (**10.9% of population**)

➢ **US$6.2 billion (0.37%)** reduction in GDP in 2035 compared with unrestricted forecast

	Low cost	Central cost	High cost
Increase in average annual investment costs for 5G infrastructure over the next decade, US$ millions (%)	200 (9%)	400 (19%)	700 (29%)
Absolute number of people that will have delayed access to 5G (millions of people) by 2023, millions of people (% of population)	3.9 (5.8%)	7.4 (10.9%)	10.4 (15.3%)
Estimated permanent loss in Gross Domestic Product (GDP) due to delay in 5G rollout in 2035 (US$ bn)	1.8	6.2	11.8

5G rollout with and without competition restrictions in the UK

Percentage of population covered

Source: GSMA, Oxford Economics

MARKET ANALYSIS: THE UK

The UK Government is keen for the UK to become a world leader in 5G, and the UK telecom regulator, Ofcom, is working with the Government and industry to make this happen. 5G services will stimulate economic activity worth $76bn in GDP and support around 605 thousand jobs in the UK in 2035[20]. A competitive market for 5G infrastructure would help maximise the gains from technological innovation and growth in the UK.

On the other hand, restricting competition can have significant adverse economic impacts. Our modelling suggests restricting a major participant could increase the cost of building the 5G network by US$400 million per year over the next decade (19% of baseline costs) in our central cost scenario. Due to these price increases, 7.4 million people (10.9% of the population) who would have otherwise had access to the 5G network could be left without access to a 5G network in 2023.

Restricting competition in the network infrastructure market may significantly reduce economic growth in the UK over the next 15 years. We estimate this could reduce GDP in 2035 by US$6.2 billion.

The potential future benefits of 5G are hard to predict. While most industry players expect 5G to transform the economy, 5G may end up being merely an enhancement to the existing 4G technology. Or it could be revolutionary in the way the steam engine or electricity was. The uncertainty about the nature of benefits will also reflected in the economic consequences of restricting competition in the network infrastructure market.

To account for this, we have modelled two additional scenarios that capture the lower and higher end of the range of potential future outcomes from competition restrictions in the 5G network market.

Across our scenarios, we expect the increase in average annual investment costs due to competition restrictions to vary between US$200 million and US$700 million (9% and 29%). The wide range in these estimates is due to the uncertainty around the reaction of other vendors of network infrastructure.

This increase in prices would translate into delays in rollout. We estimate that these delays would leave between 3.9 million people to 10.4 million people (5.8% to 15.3% of the population) without access to 5G by 2023.

The resulting loss in productivity has significant economic consequences. Lower economic growth due to delays in 5G rollout and the associated slower technological growth reduces GDP by between $1.8 billion to $11.8 billion in 2035.

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[20] IHS. 2017. *The 5G economy: How 5G technology will contribute to the global economy*. Economic Impact Analysis, IHS Economics & IHS Technology.
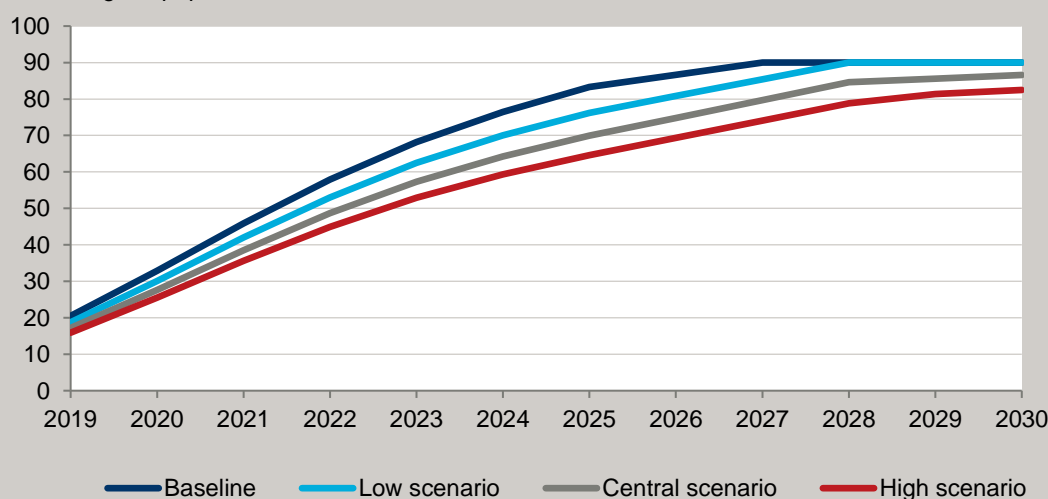
UNITED STATES

HEADLINE RESULTS

Restricting a major participant (central cost scenario):

➢ **US$1 billion (16%) increase** in average annual cost of building 5G network over the next decade

➢ **11.6 million fewer people** will have access to 5G in 2023 (**3.4%** of population)

➢ **US$21.9 billion (0.09%)** reduction in GDP in 2035 compared with unrestricted forecast

	Low cost	Central cost	High cost
Increase in average annual investment costs for 5G infrastructure over the next decade, US$ millions (%)	500 (8%)	1,000 (16%)	1,500 (24%)
Absolute number of people that will have delayed access to 5G (millions of people) by 2023, millions of people (% of population)	0.0 (0%)	11.6 (3.4%)	27.1 (8.0%)
Estimated permanent loss in Gross Domestic Product (GDP) due to delay in 5G rollout in 2035 (US$ bn)	8.6	21.9	63.0

5G rollout with and without competition restrictions in the US

Percentage of population covered

Source: GSMA, Oxford Economics

MARKET ANALYSIS: THE US

The US is among the top three countries in terms of 5G preparedness along with South Korea and Australia.[21] A competitive market for 5G infrastructure would help maximise the gains from technological innovation and growth in Australia. 5G services will stimulate economic activity worth $719bn in GDP and support around 10 million jobs in the US in 2035[22].

On the other hand, restricting competition can have significant adverse economic impacts. Our modelling suggests restricting a major participant could increase the cost of building the 5G network by US$1.0 billion per year over the next decade (16% of baseline costs) in our central cost scenario. Due to these price increases, 11.6 million people (3.4% of the population) who would have otherwise had access to the 5G network could be left without access to a 5G network in 2023.

Restricting competition in the network infrastructure market may significantly reduce economic growth in Australia over the next 15 years. We estimate this could reduce GDP in 2035 by US$21.9 billion.

The potential future benefits of 5G are hard to predict. While most industry players expect 5G to transform the economy, 5G may end up being merely an enhancement to the existing 4G technology. Or it could be revolutionary in the way the steam engine or electricity was. The uncertainty about the nature of benefits will also reflected in the economic consequences of restricting competition in the network infrastructure market.

To account for this, we have modelled two additional scenarios that capture the lower and higher end of the range of potential future outcomes from competition restrictions in the 5G network market.

Across our scenarios, we expect the increase in average annual investment costs due to competition restrictions to vary between US$500 million and US$1.5 billion (8% and 24%). The wide range in these estimates is due to the uncertainty around the reaction of other vendors of network infrastructure.

This increase in prices would translate into delays in rollout. We estimate that these delays would leave up to 27.1 million people (8.0% of the population) without access to 5G by 2020.

The resulting loss in productivity has significant economic consequences. Lower economic growth due to delays in 5G rollout and the associated slower technological growth reduces GDP by between $8.6 billion to $63.0 billion in 2035.

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[21] Arthur D. Little. 2019. *The Race to 5G*.
https://www.adlittle.com/sites/default/files/reports/adl_the_race_to_5g_report_-min.pdf.

[22] IHS. 2017. *The 5G economy: How 5G technology will contribute to the global economy*. Economic Impact Analysis, IHS Economics & IHS Technology.
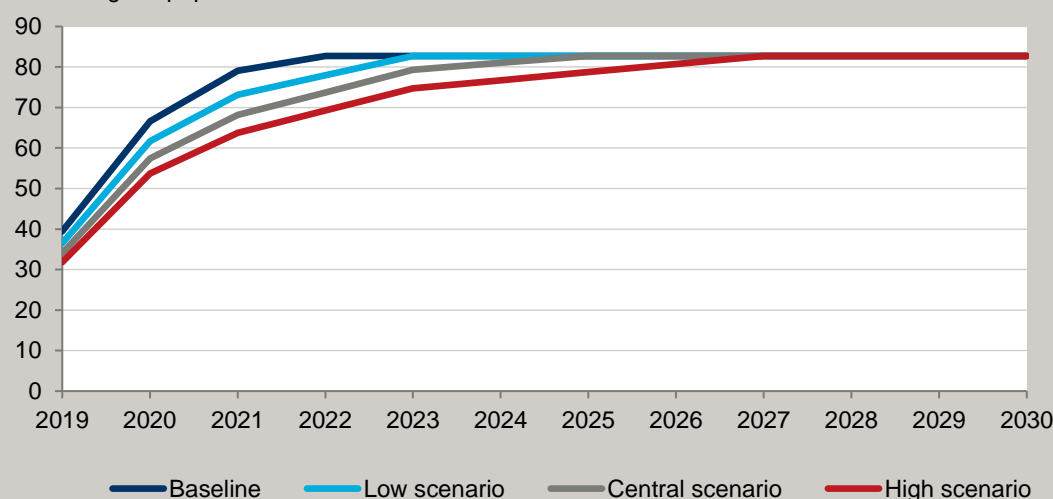
5. SUMMARY AND CONCLUSIONS

In this study, we have estimated the potential economic costs of restricting a 5G network infrastructure vendor of Huawei's size. Our study focuses on the impact with regard to price, time, and productivity across eight leading 5G markets.

The next generation of 5G technology is expected to significantly increase the speed of communication and lower response times (latency), which will create opportunities for new use cases and the widespread adoption of the Internet of Things (IoT). Estimates of 5G's total contribution to global GDP over the next 10-to-15 years range from US$1.4 trillion to US$3.5 trillion.

To take advantage of the next wave of technological progress, the plans to roll out 5G are being prepared with a sense of urgency. Despite requiring larger investments in network infrastructure, the rollout of 5G is expected to be completed more quickly than 4G in most markets, due to higher perceived economic returns.

Mobile network operators across the world will be commissioning 5G equipment from the network equipment vendors. Huawei, Nokia, and Ericsson are the three largest vendors in the network equipment market globally, with a combined market share of more than 80%. Samsung and ZTE have small but significant market shares of 8% each, with a few other smaller players making up the remaining 4% of the market.

RESTRICTING COMPETITION IN THE 5G MARKET

In light of expressed security concerns about Huawei's 5G equipment, the US and Australia have currently blocked Huawei from participating in the rollout of 5G equipment, with other countries considering restrictions.

Oxford Economics was commissioned by Huawei to estimate the potential economic impacts of such a restriction on competition in the 5G network infrastructure market. We have analysed the impacts of restricting a player of Huawei's size from eight markets: Australia, Canada, France, Germany, India, Japan, the United Kingdom, and the United States.

We considered only the economic impacts occurring as a result of the increase in network vendor concentration caused by such a restriction in competition. Our results are based on assumptions relating to both the potential future benefits of 5G, and the market reactions to competition restrictions, captured in three scenarios: low cost, central cost, and high cost scenarios.

ECONOMIC IMPACT OF RESTRICTING COMPETITION

Our modelling suggests that restricting a key supplier of 5G infrastructure from helping to build a country's network **would increase that country's overall 5G investment costs by between 16% and 19%, in our central cost scenario.**

The increase in investment costs linked to the restriction of 5G competition would also delay 5G access to millions of people over the next decade. In the US alone, 11.6 million fewer people (some 3.4% of the population) are projected to have access to 5G by 2023 than if there was no such restriction to competition, under our central cost scenario. Over the same period, 31.8 million fewer people are projected to have access to 5G in India, while in Europe, the UK, Germany, and France would respectively have 7.4 million, 7.1 million, and 4.0 million fewer people with access to 5G by 2023, under our central cost scenario.

A delay in the rollout of 5G would also result in slower technological innovation and reduced economic growth. In our central cost scenario, this would result in reductions to national GDP in 2035 ranging from $22 billion for the US to $3 billion for Australia. Across all eight countries in our study, this means GDP per capita would be lower by an average of $100 per person in 2035, compared with a world where there is no such restriction in 5G infrastructure provision.

Fig. 16. Headline economic impacts under the central cost scenario

Market	Price impact (% increase in investment costs)	Reduction in number of people with access to 5G by 2023 (millions)	Reduction in GDP in 2035 (US$ billions, 2019 prices)
Australia	8% to 27%	0.0 to 3.1	0.8 to 8.2
Canada	8% to 24%	2.2 to 5.7	1.0 to 6.7
France	9% to 29%	2.1 to 5.7	2.6 to 15.6
Germany	9% to 29%	3.8 to 0.0	2.4 to 13.8
Japan	9% to 27%	5.8 to 15.3	5.3 to 34.3
India	8% to 27%	15.9 to 45.3	4.7 to 27.8
United Kingdom	9% to 29%	3.9 to 10.4	1.8 to 11.8
United States	8% to 24%`	0.0 to 27.1	8.6 to 36.0

Source: Oxford Economics
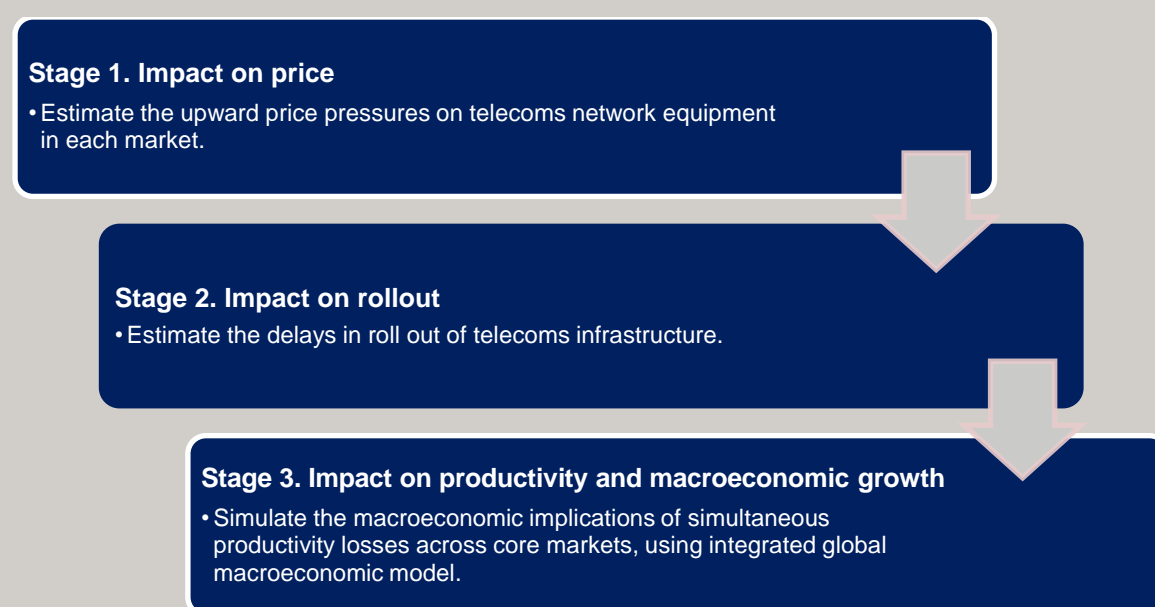
APPENDIX 1: GLOSSARY OF TERMS

TERM	DESCRIPTION
1G	The first generation of mobile networks used analogue radio systems that allowed users to make phone calls but not send text messages.
2G	The second generation of mobile networks relied on digital signals, not analogue, which improved its capacity and allowed users to send text and multimedia messages.
3G	The third generation of mobile networks could transmit greater amounts of data that allowed users to video call, share files and surf the internet.
4G	4G, or the fourth generation of mobile networks, allowed for five-times faster data transmission compared to 3G networks which allowed users to experience less buffering, higher voice quality, easy access to messaging services and social media, higher quality streaming and faster downloads.
5G	The fifth generation of mobile networks is expected to significantly improve speeds and capacity of mobile networks which could lead to new trends such as connected cars, smart cities and smart homes and offices.
Augmented Reality	Augmented Reality combines virtual pictures or sounds with the real, or physical, world to enhance the environment. AR is being used in gaming, medicine, education, archaeology and architecture. For example, AR is used to support surgeries by providing virtual overlays to guide medical practitioners.
Average Revenue Per User (ARPU)	ARPU is the total revenue divided by the number of subscribers. a commonly used measure in communications, digital media and subscription services.
Compound Annual Growth Rate (CAGR)	CAGR is the annual rate of return required for a variable, say investment, to grow from its beginning value to its ending value assuming that the variable has been compounding over the time period.
Enhanced Mobile Broadband (eMBB)	Enhanced mobile broadband is one of the three possible use scenarios defined by the ITU (see below) for 5G. Under the eMBB use case, 5G will enable data-driven services that will require high speeds across a wide coverage area such as 360-degree video streaming, immersive virtual reality and augmented reality.
Global Economic Model (GEM)	We simulated the macroeconomic implications of restrictions in competition across the eight economies using our Global Economic Model (GEM). See Appendix 3 for further details.

TERM	DESCRIPTION
Internet of Things (IoT)	Internet of Things is a system of connected computing, mechanical and digital devices that can transfer data over a network without the need for human interaction. This will enable services such as remote health monitoring and automatic emergency notification systems.
International Telecommunications Union (ITU)	The ITU facilitates international cooperation to enable standardisation of global communications networks so that networks and technologies seamlessly interconnect.
Latency	Latency is the amount of time between a command and its corresponding action over the internet
Long Term Evolution (LTE)	Long Term Evolution, a 4G mobile communications standard
mMTC	Massive Machine Type Communications (mMTC) is one of the three possible use scenarios defined by the ITU (see above) for 5G. Under the mMTC use case, 5G will enable fully automatic generation, exchange and processing by devices, which would enable widespread adoption of the Internet of Things (IoT).
Mobile network operators (MNO)	Mobile Network Operators are providers of wireless communications services that own or control all the infrastructure necessary to deliver mobile network services to consumers (end users).
Network slicing	Network slicing allows the physical infrastructure to be split into several virtual networks that can be tailored to different end-users, thereby facilitating dedicated disruption-free networks for critical users such as health and transport services that are free from disruption from other consumer and business uses
Radio Access Network (RAN)	Radio Access Network (RAN) is a component of 5G network infrastructure. RAN consists mainly of mobile base stations that connect telecom networks wirelessly to mobile devices.
Ultra-Reliable Low-Latency Communication (URLLC)	Ultra-Reliable Low-Latency Communication (URLLC) is one of the three possible use scenarios defined by the ITU (see above) for 5G. Under this use scenario, 5G will cater to multiple advanced services that rely on quick response times such as autonomous driving, factory automation, smart grids and robotic surgeries.
Virtual Reality (VR)	Virtual Reality creates a simulated environment that is completely different from the real, or physical world. A person using VR equipment can look around the artificial world, move around in it and interact with features or items.

APPENDIX 2: MODELLING APPROACH AND METHODOLOGY

Economic theory dictates that restricting competition in any market will lead to upward prices pressures as well as negative implications for innovation. We have assessed the economic impact of banning Huawei from competing in the market for telecommunications network equipment, through a three-stage modelling framework as illustrated in Fig. 17. We describe each step in more detail below.

Fig. 17. Three-stage modelling framework for assessing the economic costs of excluding Huawei from the telecoms network equipment market

Stage 1. Impact on price
• Estimate the upward price pressures on telecoms network equipment in each market.

Stage 2. Impact on rollout
• Estimate the delays in roll out of telecoms infrastructure.

Stage 3. Impact on productivity and macroeconomic growth
• Simulate the macroeconomic implications of simultaneous productivity losses across core markets, using integrated global macroeconomic model.

STAGE 1: PRICE OF NETWORK EQUIPMENT

In the first stage of our assessment, we start by exploring the implications for the price of network equipment in each of our eight target markets. We applied three alternate approaches, developed in collaboration with Dr Martin Pesendorfer (LSE), to establish an estimated range of impacts, to add credibility and depth to the findings:

The techniques used are:

- a **theoretical model of oligopoly** characterising the 5G network infrastructure market that simulates the change in price of network infrastructure associated with restrictions on competition;
- **merger simulation techniques** that are used by competition authorities to estimate the price impact following changes to the market such as a merger; and
- **empirical evidence** from a range of studies across industries that estimated the change in price following a merger.

For this study, we assume that if Huawei is restricted in each country's 5G infrastructure market, network operators in that market would switch to one of the two other large providers, Ericsson and

Nokia, in proportion to their existing market shares. We believe that the other providers do not have the same global reach or breadth of products and services that would allow them to successfully compete for Huawei's potential customers, and therefore their market shares would remain unchanged.

We assume that 5G network equipment market shares over the next decade in the baseline (no restrictions on Huawei) will be closest to 4G (LTE) market shares in 2018. All our methods rely on the change in the Herfindahl-Hirschman Index (HHI) due to restrictions on Huawei. The Herfindahl-Hirschman Index (HHI), which is a measure of concentration, increases by 1106 based on worldwide 4G market shares. Fig. 18 shows the estimated change in HHI due to restrictions on Huawei.

Fig. 18. Expected change in HHI due to restrictions on Huawei

Region	Country in our study	HHI (no restrictions on Huawei)	HHI (restrictions on Huawei)	Change in HHI
North America	Canada, USA	4,049	4,197	148
Europe	France, Germany, UK	2,781	4,072	1,291
Worldwide	Australia, India and Japan[23]	2,348	3,454	1,106

Source: Oxford Economics

Theoretical models of oligopoly

There are two standard models of oligopoly used in economic theory:

- **Cournot**: where firms compete by choosing quantity supplied and let market forces set prices;

- **Bertrand**: where firms compete by choosing prices and let market forces set quantities.

However, we do not believe that either of these standard models characterises the 5G network infrastructure market. Vendors, when participating in a tender, make decisions on prices, and therefore the Bertrand model may appear the most appropriate for our study. However, we understand that firms compete in prices as well as capacities and the decision to participate in tenders by network operators. Kreps and Scheinkman (1983) show that outcomes in the Bertrand market where firms make additional decisions on tender participation and capacities is similar to the outcomes from a Cournot setting.

We have built two variations of the Cournot model: with linear demand curves (Motta 2007) and with constant elasticity of substitution (CES)[24] demand curves (Pindyck and Rubinfeld 2017).

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[23] We used the worldwide LTE market shares for Australia, India and Japan instead of the regional Asia-Pacific (APAC) measures. The APAC market shares are likely to be heavily dominated by China and is not representative of vendor market shares in Australia, India and Japan.

[24] Constant Elasticity of Substitution (CES) implies that the percentage change in demand for a 1% change in price remains constant at all levels of RAN equipment. We use estimates of the elasticity of digital infrastructure estimates from the literature (UK National Infrastructure Commission 2017) – between -0.4 to -0.8 – as proxies for RAN elasticities.

The price impact in the linear demand curve model relies on the number of existing credible competitors (which we define as the number of competitors with more than 5% market share in the 4G LTE network market). Fig. 19 shows the change in credible competitors due to restrictions and the impact on price in the RAN market based on 4G LTE network equipment market shares in 2018. We used the worldwide LTE market shares for Australia, India and Japan instead of the regional, (i.e., APAC) measures, which are likely to be heavily dominated by China. Vendor market shares in China are not representative of vendor market shares in Australia, India and Japan.

Fig. 19. Price impact based on the theoretical model (linear demand curves)

Country	Change in the number of "credible" competitors[1]	Market shares used	Change in price
Australia	5 to 4	Worldwide LTE	12%
Canada	3 to 2	North America LTE	23%
France	4 to 3	Europe LTE	16%
Germany	4 to 3	Europe LTE	16%
India	5 to 4	Worldwide LTE	12%
Japan	5 to 4	Worldwide LTE	12%
United Kingdom	4 to 3	Europe LTE	16%
United States	3 to 2	North America LTE	23%
Worldwide	5 to 4	Worldwide LTE	12%

Source: Oxford Economics

The price impact in the CES model depends on the change in HHI[25]. Fig. 20 shows the change in HHI due to restrictions and the impact on price in the RAN market based on 4G LTE network equipment market shares in 2018.

Fig. 20. Price impact based on the theoretical model (CES demand curves)

Country	Change in HHI	Market shares used	Median change in price (various assumptions)
Australia	0.11%	Worldwide LTE	23%
Canada	0.01%	North America LTE	14%
France	0.13%	Europe LTE	24%
Germany	0.13%	Europe LTE	24%
India	0.11%	Worldwide LTE	23%
Japan	0.11%	Worldwide LTE	23%
United Kingdom	0.13%	Europe LTE	24%
United States	0.01%	North America LTE	14%
Worldwide	0.11%	Worldwide LTE	23%

Source: Oxford Economics

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[25] HHI is an indicator of market concentration, calculated as the sum of squared market shares. We assume that when Huawei is restricted, Huawei's market share is distributed between Nokia and Ericsson proportionate to their market shares in the counterfactual (with Huawei). We use market shares in the 4G network equipment market as the basis for our calculations.

Merger simulation techniques

We have also adapted the merger simulation tool (used by economists to quantify the impact of mergers) to estimate the price impact of restrictions on Huawei. The price impact depends on the diversion ratio[26] and the profit margin. Fig. 21 shows the diversion ratios, industry margins and the change in price based on merger simulation techniques due to restrictions on Huawei.

Margins based on Gross Margins for the Telecom Equipment sector from the NYU Stern dataset (Damodaran, 2019). Country-level margins were only available for the US and Japan. We have used the regional averages for the other countries: Europe (for France, UK and Germany), APAC (Australia and India). We have used the US figures as a proxy for margins in Canada.

Fig. 21. Price impact based on merger simulation techniques

Country	Diversion of market share to Ericsson	Diversion of market share to Nokia	Industry margins	Market shares used	Change in price
Australia	52.0%	48.0%	27%	Worldwide LTE	6%
Canada	53.3%	46.7%	53%	North America LTE	27%
France	52.4%	47.6%	34%	Europe LTE	9%
Germany	52.4%	47.6%	34%	Europe LTE	9%
India	52.0%	48.0%	27%	Worldwide LTE	6%
Japan	52.0%	48.0%	33%	Worldwide LTE	9%
UK	52.4%	47.6%	34%	Europe LTE	9%
USA	53.3%	46.7%	53%	North America LTE	27%
Worldwide	52.0%	48.0%	38%	Worldwide LTE	10%

Source: Oxford Economics

Empirical evidence

We have also estimated the price increase by adapting the findings from a European Commission retrospective review of mergers. The European Commission (2015) reviewed 27 papers that used different econometric techniques to estimate the price effects following a merger.

Of these, 11 studies included information on HHI that allowed us to adapt the findings to our study. Fig. 22 shows the change in price corresponding to the 11 mergers. The change in price is adjusted by the change in HHI to enable comparison across studies. The median price increase is 2.43% per 100 unit change in HHI.

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[26] A diversion ratio measures "where product goes" from Firm A (Huawei, in this instance) when there is a price rise or other event (restrictions on Huawei, in this instance). For example, if 20% of sales would go to Firm B when Firm A raises its price, then the diversion ratio of A to B would be 20%.

Fig. 22. Estimated change in price following a merger, percentage change per 100 unit change in HHI

Change in price per 100 unit change in HHI

Source: Oxford Economics

We then combine the median price increase per 100 unit change in HHI along with our estimated increase in HHI to estimate the price impact. The results are shown in Fig. 23.

Fig. 23. Price impact based on merger simulation techniques

Country	Change in HHI	Market shares used	Change in price
Australia	0.04%	Worldwide LTE	27%
Canada	0.01%	North America LTE	4%
France	0.13%	Europe LTE	31%
Germany	0.13%	Europe LTE	31%
India	0.04%	Worldwide LTE	27%
Japan	0.04%	Worldwide LTE	27%
United Kingdom	0.13%	Europe LTE	31%
United States	0.01%	North America LTE	4%
Worldwide	0.05%	Worldwide LTE	27%

Source: Oxford Economics

Combining results from various price models

The results from the three approaches above are combined to provide a range of estimates for the price impact as shown in Fig. 24, below. The wide range of estimates for each country presented on the previous slide reflect the competitive nature of the regional markets.

Fig. 24. Price impacts due to restrictions on Huawei – range of estimates from price models

Increase in prices (%)

Source: Oxford Economics

However, the market for RAN equipment is global – vendors compete internationally. To reflect the global nature of the market, we adjust the range for each country. We limit the minimum and maximum estimates for each country on either side by two percentage points over the worldwide ranges. For example, if the minimum estimate for Australia is 4%, we set the lower end of the range for Australia as 8% (i.e., the minimum worldwide estimate of 10% less 2%). The central estimate is the median of the adjusted ranges. The adjusted range is presented in Fig. 25, below.

To capture the range of potential reactions following the imposition of restrictions on Huawei, we define three scenarios—low, central and high—based on the lower end, median and higher end of the range of estimates for each country.

Fig. 25. Price impacts due to restrictions on Huawei—adjusted range of estimates

Country	Price impact: low cost scenario	Price impact: central cost scenario	Price impact: high cost scenario
Australia and India	8%	17%	27%
Canada and USA	8%	16%	24%
France, Germany and the UK	9%	19%	29%
Japan	9%	18%	27%

STAGE 2: IMPACT ON ROLLOUT

An increase in the price of network equipment will reduce the commercial incentive to build the network, thereby delaying the rollout of 5G. This is more likely in areas with lower population densities or more remote areas. Further, if the costs of 5G network are high, then operators are likely to charge higher prices for 5G services. This could affect the potential take up of the technology and focus 5G activity on the most profitable business uses. With slower adoption rates, businesses are less likely to invest in technologies that use 5G such as IoT. We used the price impacts (i.e., investment costs for network operators) from Stage 1 to estimate the delay in rollout in each of the eight countries.

We translated the increase in investment costs to delays in rollout using a network rollout model built in collaboration with Dr Edward Oughton (Cambridge Judge Business School). This model translates an increase in investment costs to a reduction in the share of the population covered for each country and scenario by assuming that the overall operators' capex remains the same.

Baseline rollout and required capex per person

To estimate the impact on rollout due to restrictions on Huawei, we first estimate 5G rollout to 2030 and associated per capita capital expenditure required.

To define the baseline, we start with the GSMA network coverage forecasts, which provides the share of population covered by 5G for each year until 2025. We extend these forecasts for subsequent years until 2030 using our judgement and relying on the 4G forecasts in comparable years.
The share of population covered is translated into the number of people covered using population forecasts from WDI.

To estimate the associated capex required per person covered, we use:

- GSMA yearly capex forecasts (kept constant at the 2025 level for years beyond 2025); and
- the number of people covered (from the previous step).

The impact on rollout is estimated by re-drawing the rollout curves with the same level of capex as in the baseline but with increased required capex per capita.

Translating the price impact into a capex impact

For each country and scenario, the increase in prices translates into an increase in the capex required per capita. For example, if restrictions on Huawei lead to a 10% increase in prices, then the per capita capex required to extend 5G coverage increases by 10%.

Re-drawing rollout curves with increased prices

Assuming the operators maintain their capex budgets, they are now able to cover fewer people due to the increase in required per capita capex. For each country and scenario, we calculate the number of people who would be covered by 5G using:

- the increased per capita required capex; but

- with the same *levels* of capex as in the baseline.

The new rollout curve is derived by translating the absolute number of people into a share of the population for each year.

STAGE 3: IMPACT ON PRODUCTIVITY AND MACROECONOMIC GROWTH

Next, we estimated the productivity implications of such price changes across each economy. The associated loss of productivity will be derived from two channels as follows:

- The higher cost of rolling out the 5G network will represent a direct loss of productivity reflecting a reduced level of allocative efficiency.

- The delays and reduced scale of 5G rollout will diminish the future productivity gains that will be yielded by 5G.

The former is based on the results of the price model and estimates of 5G expenditure based on the GSMA capex forecasts and our judgement. We will then assess how this increase in investment costs raises the costs to businesses resulting in a loss of productivity across the economy.

There are a wide range of estimates of how 5G will improve productivity in the future. Fig. 26 shows the range of estimates for a variety of different technologies (both ICT and non-ICT) from various studies. We use the estimates from these studies to define the baseline (i.e., no restrictions on Huawei) productivity impact from 5G. Restrictions on Huawei lead to slower rollout and therefore slower productivity growth. The productivity gains from 5G with restrictions is therefore calculated as the baseline productivity growth scaled down to reflect the slower roll out estimated in Stage 2. The productivity impact is the difference between the productivity growth in the no-restrictions and restrictions scenarios.

The impact on productivity due to slower rollout depends on the baseline (i.e., no restrictions) productivity growth assumptions. To capture the uncertainty in the productivity growth assumptions, again, we use three different scenarios:

- **Low cost scenario** to reflect only an increase in speed: 0.15% based on the estimates of productivity growth from 2G to 3G;

- **Central cost scenario** to reflect a transformative change in technology: 0.15% per year in the first year of rollout and increasing to 0.30% per year over a five-year period; and

- **High cost scenario** to reflect a revolutionary change in technology: 0.30% per year.

The 0.15% per year assumption is based on the estimated productivity growth associated with the transition from 2G to 3G, whereas the 0.30% per year growth assumption is based on the median values from Fig. 26, excluding the top- and bottom-four outlying estimates.

The low cost, central cost, and high cost scenarios are paired with the low cost, central cost, and high cost scenarios for prices respectively, to limit the number of scenarios in our study to three.

Fig. 26. Impact of technology on productivity, average annual growth rate

Change in productivity due to technology (average annual growth rate)

Category	Value
MFP growth - Household internet access	0.01%
LP growth - Steam technology	0.01%
LP growth - Steam technology	0.02%
GDP per capita growth - 2G to 3G	0.15%
MFP increase - ICT use	0.20%
LP growth - Steam technology	0.20%
LP growth - Steam technology	0.21%
MFP contribution - Railways	0.26%
GDP per capita growth - Mobile usage	0.28%
MFP growth - Mobile telecoms	0.28%
GDP increase - Mobile sector productivity	0.28%
Productivity growth - ICT use	0.29%
Productivity growth - Broadband	0.32%
MFP contribution - Steam engine	0.38%
LP growth - Steam technology	0.38%
GDP per capita growth - Doubling mobile…	0.50%
GDP per capita growth - Mobile data use	0.50%
MFP contribution - Electricity	0.51%
Productivity growth - IT	0.75%

Source: BCAR (2018), Oxford Economics

Finally, we simulated the macroeconomic implications of this simultaneous slowdown in productivity growth across the eight economies using our Global Economic Model (GEM).[27] The inputs from the previous stages are used as inputs to the GEM which we can use to quantify the macroeconomic implications of these changes. The slowdown in productivity growth will reduce the respective economy's capacity to supply goods and services. The equation structure of each economy works to ensure that in the long-term such a slowdown in trend growth is matched by a commensurate drop in the actual level of GDP so that demand equals supply, a state that economists refer to as 'equilibrium'.

For this type of scenario, it is appropriate to focus on the long-term structural implications of these changes as opposed to any short-term cyclical effects. Therefore, we have used a reference year—2035—to report the results.

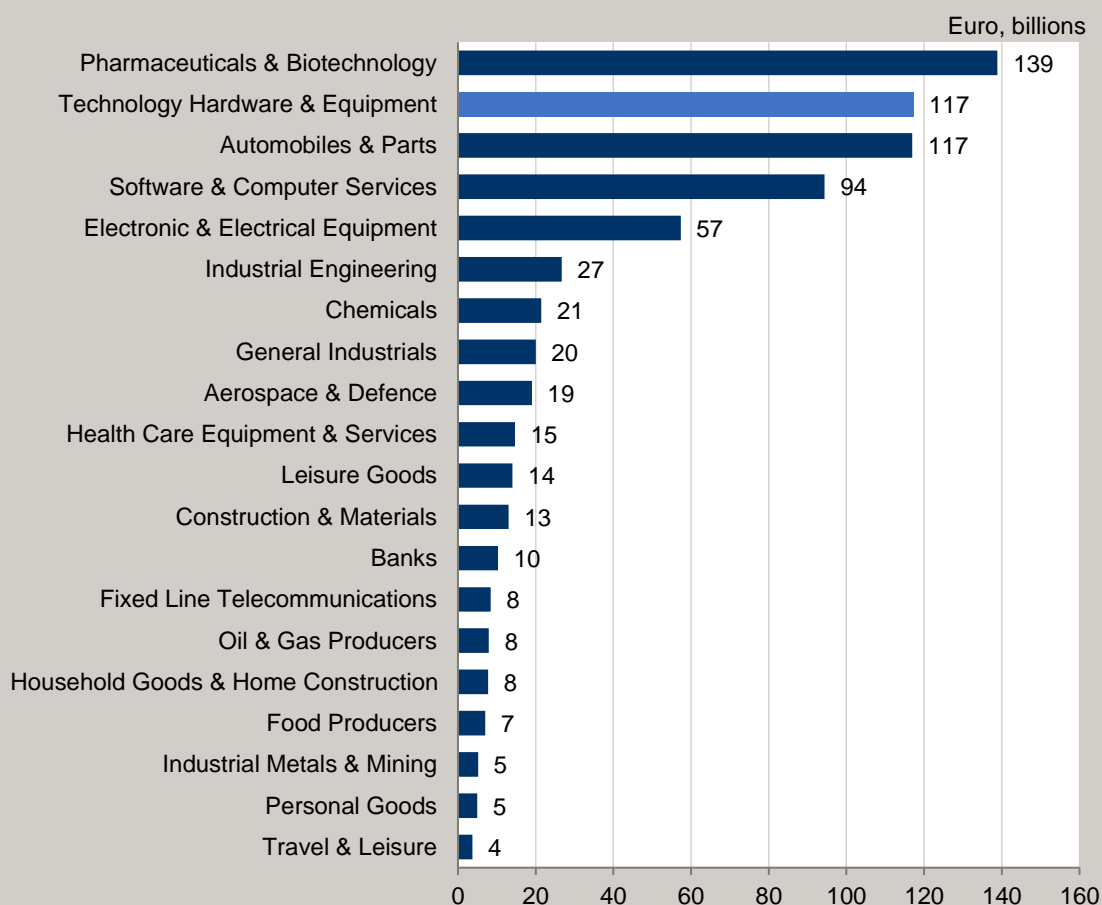[27] See Appendix 3 for a detailed description of the GEM

KEY MODELLING ASSUMPTION: REDUCED INVESTMENT IN R&D AND LOSS IN INNOVATION

Our modelling methodology only models the economic impact of a reduction in competition when a vendor of Huawei's size is excluded from the market. We do not estimate the impact due to the reduction innovation due to the loss in Huawei's technological and operational capabilities.

Equipment vendors have engaged in continuous innovation in new generations of radio access technology and core system products. Telecom network equipment vendors are among the largest spenders on R&D globally. As shown in Fig. 27 and Fig. 28, the technology, hardware and equipment industry is the second-largest spender on R&D and also has the second-highest R&D intensity (share of revenues spent on R&D) [28].

As shown in Fig. 29, Huawei is the largest spender on R&D in the Technology, Hardware and Equipment industry—more than EUR$10 billion—more than Intel and Cisco as well as other competitors in the RAN market such as Ericsson and ZTE.
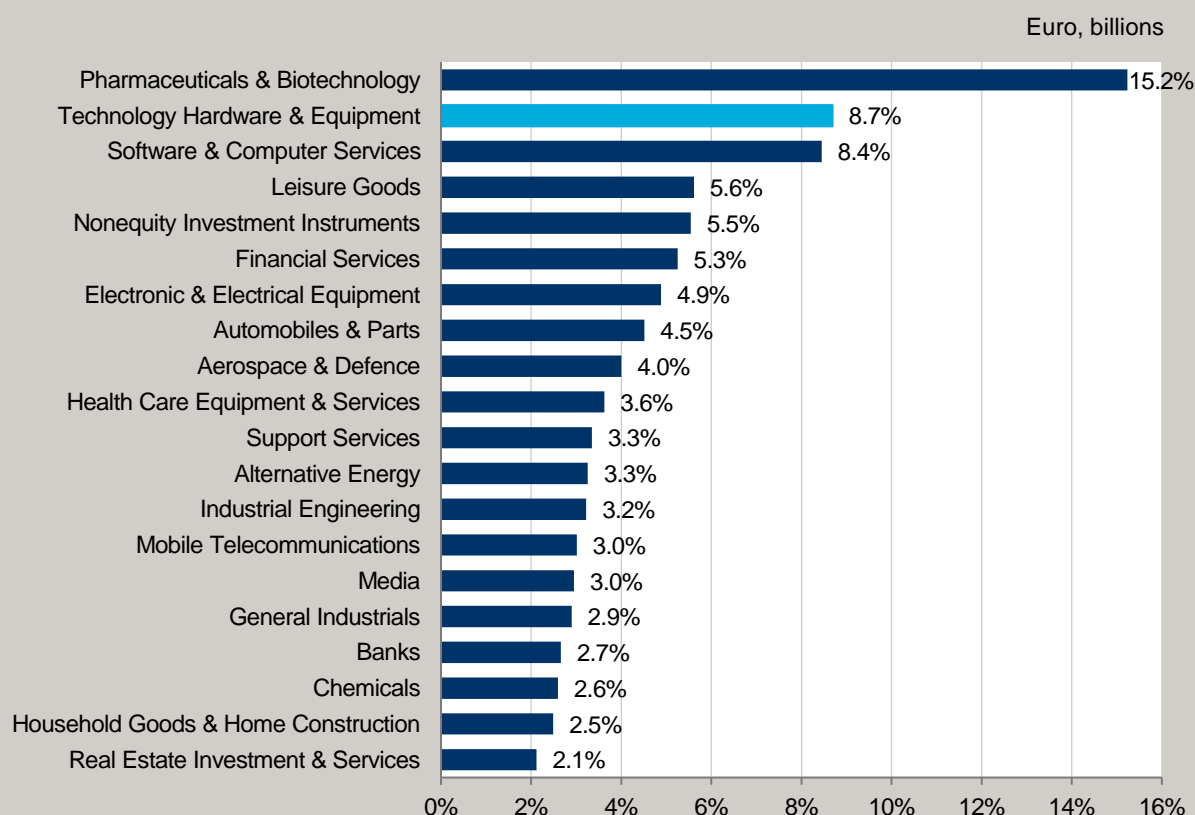
Fig. 27. R&D expenditure by the top 2,500 companies globally, categorised by their main industrial sector of activity, 2017/18

Source: The 2018 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD, Oxford Economics

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[28] The 2018 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD.
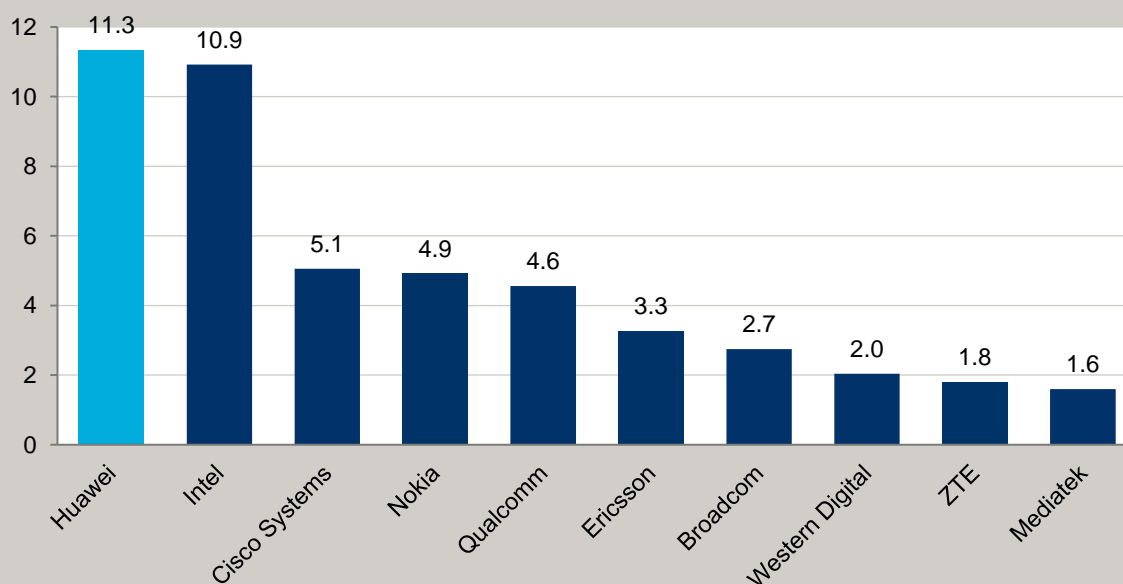
Fig. 28. R&D intensity by the top 2,500 companies globally, categorised by their main industrial sector of activity, 2017/18

Euro, billions

Sector	%
Pharmaceuticals & Biotechnology	15.2%
Technology Hardware & Equipment	8.7%
Software & Computer Services	8.4%
Leisure Goods	5.6%
Nonequity Investment Instruments	5.5%
Financial Services	5.3%
Electronic & Electrical Equipment	4.9%
Automobiles & Parts	4.5%
Aerospace & Defence	4.0%
Health Care Equipment & Services	3.6%
Support Services	3.3%
Alternative Energy	3.3%
Industrial Engineering	3.2%
Mobile Telecommunications	3.0%
Media	3.0%
General Industrials	2.9%
Banks	2.7%
Chemicals	2.6%
Household Goods & Home Construction	2.5%
Real Estate Investment & Services	2.1%

Source: The 2018 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD, Oxford Economics

Fig. 29. R&D by top 10 companies in the Technology, Hardware and Equipment industry, 2017/18

Euro, billions

Company	Value
Huawei	11.3
Intel	10.9
Cisco Systems	5.1
Nokia	4.9
Qualcomm	4.6
Ericsson	3.3
Broadcom	2.7
Western Digital	2.0
ZTE	1.8
Mediatek	1.6

Source: The 2018 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD, Oxford Economics

ACCOUNTING FOR UNCERTAINTY

While we have used a wide range of industry and academic estimates to inform our modelling, it is not possible to predict the potential benefits of 5G, or the market reaction to excluding a company the size of Huawei, with any certainty. Hence our inclusion of scenarios to capture the higher and lower end of the range of potential productivity benefits from 5G, as well as the central cost scenario.

LIMITATIONS OF THIS STUDY

In addition, it should be noted that this report focuses on the quantifiable economic impacts of an increase in the concentration of the 5G infrastructure market, due to restrictions on a vendor of Huawei's size. We do not account for the loss of technological knowhow and capabilities that are unique to Huawei—which is among the world's leading spenders on R&D, and is considered to have an advantage over its competitors due to its technological prowess.

We assume that Huawei's customers are serviced by the two other competitors which have the global reach and breadth of services and products comparable to Huawei's, i.e., Nokia and Ericsson. The price impacts would be higher if these network providers do not have the capacity to take on Huawei's customers. Conversely, the price impacts would be lower if another competitor could scale up its global reach and range of products to successfully take up Huawei's place in the market.

When modelling the delays in rollout due to increases in investment costs, we assume that the operators do not face additional constraints in the capital markets. For example, an increase in investment costs would increase capital requirements which in turn could increase the cost of capital and therefore, would further increase the adverse productivity impacts.

While our scenarios aim to capture a wide range of uncertainty, the factors listed above, while unlikely in our opinion, could result in impacts beyond the range suggested by our scenarios.

APPENDIX 3: THE GLOBAL ECONOMIC MODEL

The GEM is the most widely used commercial macroeconomic model in the world. 46 of the largest economies (which together account for over 90 percent of global GDP) are covered in depth by individual country models, with the remainder accounted for by regional blocs. Most of the core behavioural equations are specified in an Error Correction Mechanism (ECM) format.

We simulated the macroeconomic implications of restrictions in competition across the eight economies using our Global Economic Model (GEM).

Below, the key theoretical features of the model are discussed in more detail.

SUPPLY SIDE

The structure of each of the country models is based on the income-expenditure accounting framework. However, the models have a coherent treatment of aggregate supply. In the long run, each of the economies behaves like the classic one sector economy under Cobb-Douglas technology. Countries have a natural growth rate, which is determined by its capital stock, labour supply adjusted for human capital, and TFP. Output cycles around a deterministic trend, so the level of potential output at any point in time can be defined, along with a corresponding natural rate of unemployment.

Firms are assumed to set prices given output and the capital stock, but the labour market is characterized by imperfect competition. Firms bargain with workers over wages but choose the optimal level of employment. Under this construct, countries with higher real wages demonstrate higher long-run unemployment, while countries with more rigid real wages demonstrate higher unemployment relative to the natural rate.

INFLATION AND MONETARY POLICY

Inflation is a monetary phenomenon in the long run. All of the models assume a vertical Phillips curve, so expansionary demand policies place upward pressure on inflation. Unchecked, these pressures cause an unbounded acceleration of the price level. Given the negative economic consequences of this (as seen in the 1970s in developed economies and more recently in some emerging markets), most countries have adopted a monetary policy framework which keeps inflation in check. The model mirrors this, by incorporating endogenous monetary policy. For the main advanced economies, monetary policy is underpinned by the Taylor rule, captured using an inflation target, such that interest rates are assumed to rise when inflation is above the target rate, and/or output is above potential. The coefficients in the interest rate reaction function, as well as the inflation target itself, reflect assumptions about the hawkishness of different country's monetary policymakers.

Quantitative easing, whereby the central bank prints money and uses it to purchase assets in order to stimulate the economy, has played an important role as a policy tool in the aftermath of the Great Recession. The model introduces this policy using an exogenous variable for the US, Japan, the Eurozone, and the UK. All else equal, QE lowers government bond yields and boosts share prices through portfolio effects.

In addition, a number of central banks have begun using Forward Guidance in an attempt to influence the yield curve using verbal descriptions of their expectations about future monetary policy. The GEM also introduces this policy as an exogenous variable for the US, Japan, and the UK. This variable affects exchange rates, long-term government bond yields, and share indices. US Forward Guidance also affects confidence levels and exchange rates in a number of other countries, which in turn alter consumption, investment, and impose additional amplification on share price effects. The relative

effects of changes in Forward Guidance were calibrated after the Fed's May 18 2009 policy announcement.

AGGREGATE DEMAND

Private consumption is modelled as a function of real incomes, real financial wealth, real interest rates and inflation. Investment equations are underpinned by Tobin's Q Ratio, such that the investment rate is determined by the return relative to the opportunity cost, adjusted for taxes and allowances. Countries are assumed to be "infinitely small", in the sense that exports are determined by aggregate demand and a country cannot ultimately determine its own terms of trade. Consequently, exports are a function of world demand and the real exchange rate, and the world trade matrix ensures adding-up consistency across countries. Imports are determined by real domestic demand and competitiveness.

GDP AND EMPLOYMENT BY SECTOR

In addition to the income-expenditure approach, the Global Economic Model includes a break-down of value added and employment by sector. Consistency between the income-expenditure and value added approaches to output is ensured by scaling value added in each sector up or down to obtain expenditure-based value added as the sum of value added in the sectors.
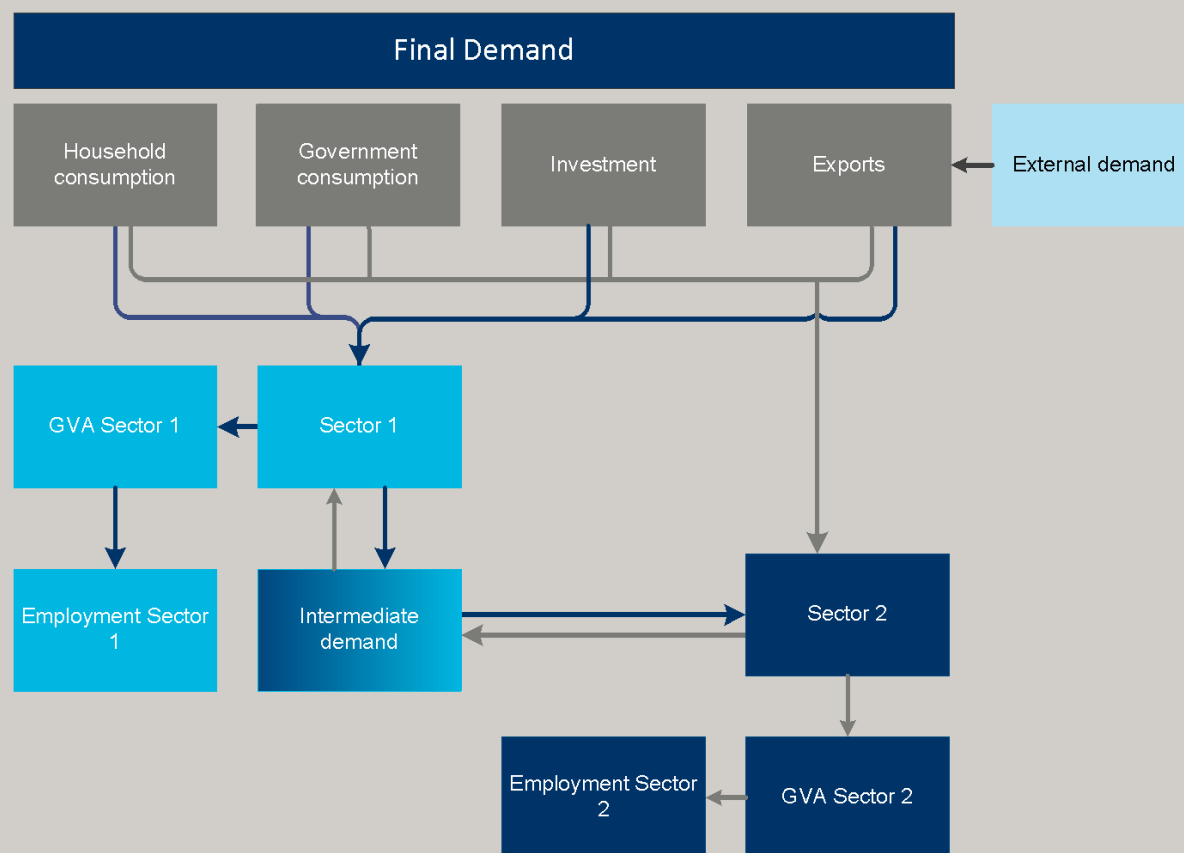
The sector breakdown reflects the input-output structure of each economy. For each sector total demand is calculated as a weighted average of value added in other sectors and final expenditure, with the weights taken from input-output tables. We then use total demand to estimate the value added for that respective sector since in the long run (everything else equal) value added and demand must grow in line with each other. Value added is also affected by competitiveness (measured by relative unit labour costs) to a degree that reflects the international openness of each sector.

Employment by sector is derived from value added in that sector and sector-specific productivity trends. As in the case of value added, consistency between the total employment forecast and employment in all sectors is achieved by scaling the sector employment variables up or down.

The breakdown of value added and employment by sector depends on data availability and varies by country. For instance, for the European Union it consists of 14 sectors – agriculture and forestry, extraction, manufacturing, utilities, construction, distribution services, hotels and catering, transport and communications, financial services, business services, public administration, education, health and other services. Several additional sectors such as entertainment, arts and recreation and real estate are also included for the United States. The breakdown for Asia is less detailed.

Fig. 30. Interaction between Intermediate and Final Demand

TREATMENT OF EXPECTATIONS

Finally, the Oxford Global Economic Model assumes adaptive rather than forward looking expectations because we believe that introducing expectations on the basis of economic theory is more advantageous than using the forward looking assumption ubiquitously. There is disagreement among economists about whether forward looking expectations are consistent with observed data, which has become even more acute in light of the difficulties with obtaining accurate data on expectations for model-building purposes.

Instead, we adopt adaptive expectations, which are introduced using a framework in which expectations are formed using the actual predicted values from the model. Exogenous variables are assumed to be known a priori. Where appropriate, the model does introduce expectations implicitly and explicitly, therefore accounting for how and the extent to which agents respond to information about changes in fundamentals. An example of this includes our derivation of exchange rate forecasts which implicitly capture expectations: in the short-run, the exchange rate is driven by movements in domestic interest rates relative to the US, therefore accounting for uncovered interest rate parity. Another example is our use of a variable for forward guidance to capture expected movements in interest rates.

OXFORD ECONOMICS

Global headquarters
Oxford Economics Ltd
Abbey House
121 St Aldates
Oxford, OX1 1HB
UK
Tel: +44 (0)1865 268900

London
4 Millbank
London, SW1P 3JA
UK
Tel: +44 (0)203 910 8000

New York
5 Hanover Square, 8th Floor
New York, NY 10004
USA
Tel: +1 (646) 786 1879

Singapore
6 Battery Road
#38-05
Singapore 049909
Tel: +65 6850 0110

**Europe, Middle East
and Africa**

Oxford
London
Belfast
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Americas

New York
Philadelphia
Boston
Chicago
Los Angeles
Toronto
Mexico City

Asia Pacific

Singapore
Hong Kong
Tokyo
Sydney
Melbourne

Email:
mailbox@oxfordeconomics.com

Website:
www.oxfordeconomics.com

Further contact details:
www.oxfordeconomics.com/
about-us/worldwide-offices