National Physical Laboratory

NPL REPORT IEA 2

THE ECONOMIC IMPACT OF THE NATIONAL TIMING CENTRE ON COLLABORATING COMPANIES

THE VALUE OF ADDITIONAL PUBLIC FUNDING TO SUPPORT THE ADOPTION OF MORE RESILIENT TIMING AND SYNCHRONISATION SOLUTIONS IN THE UK

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The value of additional public funding to support the adoption of more resilient timing and synchronisation solutions in the UK

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EXECUTIVE SUMMARY
This document explains how the preferred option for the National Timing Centre (NTC) programme will aid the growth of UK-based firms, operating in specific sectors, whose innovation activities are supported by the centre. According to NPL's preferred option, the centre will provide access to specialist facilities to test the performance of new products and will build expertise through collaborative R&D projects and training services. (This document only considers the preferred option and does not review the expert-led options analysis given in the outline business case.)

NPL has a long history of evaluating the economic effect of its programmes, demonstrating a strong connection between firms' employment growth and past use of NPL's products and services. This evidence has been used to populate parameters in a model that connects public funding from BEIS to employment growth among firms that received support from NPL. In short, the analysis in this document estimates the expected effect of the NTC on customers and collaborators by regarding the resourcing of this new centre as equivalent to an increase in the funding that NPL receives from BEIS.

Moreover, the analysis in this document does not account for the cost of setting up the NTC; but nor does it consider the potential benefits of preventing (or mitigating) disruption to infrastructure that relies on GNSS signals for timing and synchronisation. Rather, it considers the extra costs and benefits of the innovation activities entailed by the preferred option. That is, the analysis proceeds as if the NTC had already been built, thus, providing some back-up in case of disruption to GNSS, so that question now being asked is 'should government provide additional funding (e.g. resources spending at NPL and grants for firms) so that the NTC can support the development and commercialisation of new timing and synchronisation solutions?' Based on this approach, the analysis finds an expected gross benefit of £83m, which leads to a net present value of £57m once investment costs are deducted over a ten-year appraisal horizon.

The first section motivates the document and presents a sketch of the analysis. Sections 2 to 4 provide a market analysis, some technology foresighting, and explain how the NTC will generate value through supporting innovation. Section 5 to 10 set up the model and take the reader through the analysis. Lastly, there is a series of annexes that discuss benefit mechanisms and further details of an econometric analysis.

1. INTRODUCTION

1.1. THE UK'S MEASUREMENT INFRASTRUCTURE

1.1.1 What is the National Measurement System?

Every time you use your GPS, put petrol in your car, or receive a medical diagnosis, you are putting your trust in measurements that are underpinned by a system that ensures they are both reliable and internationally recognised. The UK National Measurement System (NMS) consists of a core infrastructure of measurement laboratories and a wider community of service providers that ensure you can have confidence in the measurements you make or are made on your behalf. Our reliance on the NMS is often overlooked, but, like many of our infrastructures such as roads or water, it would be noticed if it did not work. The fact that it is invisible to many is indicative of its success, but our economy, our quality of life and often our very lives depend on the robust and reliable measurements it enables.

The UK, like all developed nations, has a national measurement infrastructure that ensures a robust system of measurement and forms an essential component of being part of a global economy. At its core, the NMS ensures that measurement in the UK is consistent with the global common system of measurement units: The International System of Units – the SI (Système International d'Unités).

Each country has one National Measurement Institute (NMI), whose role it is to take the lead in international representation and to underpin delivery of a measurement infrastructure consistent with the SI system. The National Physical Laboratory (NPL) is the UK's NMI and works in partnership with a number of other designated institutes to maintain and strengthen the national measurement infrastructure.

1.1.2 What is the National Physical Laboratory?

NPL is a government owned and funded national laboratory that specialises in measurement science. In particular, NPL conducts research into fundamental metrology and develops primary standards, as well as new instrumentation. NPL also supplies commercial calibration, testing, and training services to firms, hospitals, and universities. Lastly, NPL works with Innovate UK to offer grant funded collaborative R&D projects, involving a mixture of firms and research organisations. One of the main routes for delivering these projects is a programme called Analysis-for-Innovators (A4I).

The time of its scientists is split between:

- Maintaining capabilities through conducting international comparisons
- Doing research that generates articles in peer-reviewed scientific journals
- Delivering commercial measurement services (e.g. calibrations) or training;
- Working with organisations on grant funded collaborative R&D projects.

To give a clearer picture of what NPL is, it is helpful to introduce some the basic numbers:

NPL at a glance	NPL has 820 scientific and technical staff and 280 administrative or managerial staff.
	It has a turnover of around £90m with £56.8m in annual NMS funding.
	It generates £13m of revenue from sales of measurement services.
	NPL publishes around 350 articles in peer reviewed journals each year
	It works with or otherwise provides services to around 500 UK-based firms each year.

Lastly, NPL commissioned a survey asking its users about the sales of new products that they feel would not have been achieved without the support of NPL and the other NMS laboratories.[1] This survey found that users of the NMS laboratories believe that without NPL's support their total annual sales of new products would decrease by at least **£470M**. Furthermore, they believe that about **£2bn** worth of new products might be at risk without this support. The self-reported nature of these estimates may make the exact size of these benefits doubtful, but it still provides evidence that such benefits exist.

1.2. GROWING RELIANCE ON THE GNSS SIGNALS FOR TIMING

The world is becoming more digitally enabled and many new technologies are using the capabilities of Global Navigation Satellite Systems (GNSS) for position, navigation and timing information. 11.3% of UK GDP (£206 billion), is supported by GNSS, used by critical sectors such as telecommunications, finance and energy as well as vital defence and security requirements.

However, the reliance on timing from GNSS is a serious risk identified by the UK Government: GNSS is based on weak (low power) signals that are naturally vulnerable to interferences such as jamming, spoofing, and solar storms. Errors or outages of the service can have a significant impact and the Blackett Review identifies critical sectors of the economy that depend on timing from GNSS. The National Timing Centre (NTC) programme intends to respond to this risk by creating a new network of atomic clocks to act as an alternative to GNSS and provide a fully resilient timing infrastructure to safe-guard critical sectors.

It can also be seen that there is a non-trivial economic opportunity for the UK: Timing and synchronisation solutions are a component of a growing market for GNSS-based services; of which the timing and synchronisation element is anticipated to be worth £1.1 billion by 2025[2]. Moreover, timing and synchronisation solutions will be vital for many of the technologies that feature in the Industrial Strategy, such as, autonomous vehicles, 5G communication networks, and quantum technologies.

1 (Winning Moves, 2017)
2 (European Global Navigation Satellite Systems Agency, 2017)

1.3. OBJECTIVES OF THE NTC

The National Timing Centre (NTC) programme will address both the reliance on GNSS for time by critical industries including military and security needs and the opportunity to put the UK in a world-leading position.

The project will be delivered by a partnership led by the National Physical Laboratory (NPL), the UK's National Metrology Institute and holder of the UK time source (UTC (NPL)). There will be two partners, who will host new clocks. Innovate UK will be delivering Innovation funding grants to approximately 40 projects, involving around two firms per project.
Its objectives are:

Objective 1

- Deliver a resilient UK national time infrastructure through the building and linking of a new atomic clock network distributed geographically in secure locations.

Objective 2

- Provide innovation opportunities for UK companies through funding projects in partnership with Innovate UK based on a successful NPL and Innovate UK partnership model.

Objective 3

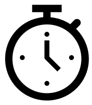
- Respond to the specialist skills shortage in time and synchronisation solutions through specialist, apprentice and post graduate training opportunities.

The outline business case for the NTC emphasised that the primary objective of the centre has always been mitigating the effects of disruption to GNSS. However, this business case has also claimed that the centre will support the innovation activities of those sectors of the economy that need synchronisation solutions, as well as the UK-based firms developing synchronisation products to meet the needs of such sectors.

It should be recognised that innovation and mitigation are not really two separate things, rather they are strongly entwined to the extent that mitigation will not be achieved without innovation and investment by the private sector. Nonetheless, there is now an expectation that NPL substantiate its claim that the NTC will generate non-trivial economic benefits by making a reasonable estimate of the additional value from providing more support to firms' innovation activities. The objective of this document is to meet this expectation by treating the creation of the NTC as roughly equivalent to an increase in NPL's funding and then showing how such an increase in funding leads to additional economic value by increasing the number of firms that can work with NPL.

1.4. WHY USE A TOP DOWN ANALYSIS?

It might be thought that NPL should have commissioned a survey of firms in the sectors most likely to use the NTC. The hope being that such a survey could have been used to estimate the effect of support on the development and commercialisation of inventions relating to synchronisation or the dissemination of time across a network. However, there were some major drawbacks to commissioning such a survey:



The time frame for submitting the NTC to PIC made it unlikely that such a survey would have produced findings in time to support the case. That is, it would have delayed the submission which doesn't sit well with the notion that the centre needs to be established urgently if it is to support the rapid roll out of technologies like 5G.

Many of the potential innovations in the market for timing and synchronisation solutions will come from radically new generic technologies that haven't yet been fully commercialised even by spin-out companies; meaning that there isn't yet an established population of firms that can be used as a sample frame for the survey.

One of the of the first tasks of the NTC is to raise awareness of the dangers of relying solely on GNSS for timing; and this will be done by engaging extensively with industry during the first year of the project. In other words, it would be more profitable to conduct such a survey once NPL has had more time to prepare the ground.

Therefore, rather than commission a survey, NPL has focussed on engaging with a wide range of research organisations and government departments, asking them to provide feedback on the extent to which they recognise a pressing need for the establishment of the NTC. Such organisations have the scientific background to provide foresight of emerging needs but did not attempt to quantify the economic benefits. So, whilst this this process of stakeholder engagement has been helpful in shaping the business case, the qualitative nature of the information supplied means that it can't be used to generate an estimate of the NTC's likely economic impact based on aggregating the expected effect across the population of potential beneficiaries.

Secondly, NPL has either funded (or participated in) a number of economic studies, which have provided specific information on the effect of the organisation's support on the success of its users' innovation activities, as well as, their subsequent employment growth. That is, these studies can be used to estimate an average treatment effect for working with NPL or using its services. However, this information is not yet sufficiently granular to segment by characteristics, such as, the type or mode of support, a firm's industrial sector, or a project's technological area. In short, the current evidence-base provides little justification for moving beyond an estimate for the average effect on firms' subsequent employment.

This impossibility of conducting a bottom-up analysis means that the following analysis is based on a top-down argument in which the effect of establishing the NTC is thought of as being equivalent to an increase in funding that will enable NPL to work with more firms than it has in the past. The idea being that the NTC is an extension of NPL's existing capabilities, which can be thought of as the know-how that underpins NPL*Time*®. However, access to these capabilities and services will necessarily continue to be restricted, mainly to those around Greater London, unless the NTC programme provides funds so that new (regional) clock facilities are built and fibre links are established in other parts of the country.

1.5. A SKETCH OF THE MAIN ANALYSIS

The NTC will support innovation activities of high-tech companies that either supply specialised timing devices/services, or that need to procure timing solutions to enable their own innovation activities (e.g. for the provision of 5G by the telecommunications sector). These new products and services are expected to enable the supported companies to grow faster than they would have without the support.

The analysis set out in this document is mainly based on combining the following pieces of information:

1. The NTC programme will increases resource funding for NPL by £8m over three years, which will allow it to collaborate with more companies and set up new training programmes. (There is also £7m of grant funding for the firms.)
2. Providing NPL with an additional £1 million per annum of funding will enable it to directly support an additional 10 UK companies. (These additional companies will either become NPL paying customers or they will engage in collaborative R&D projects.)
3. The independent econometric analysis by Frontier Economics[3] found that companies supported by NPL grow more rapidly than unsupported comparators - on average, supported companies have around 20 additional employees 2-3 years after working with NPL, when compared to a matched control group of similar unsupported ones.
4. Companies with a propensity to engage with NPL pay higher wages than the typical firm, because of the knowledge and experience needed to work with NPL.
    a. Summary statistics contained in the report by Frontier Economics can be used to show that employees in treated firms earn an average wage of £44,000, whereas those in the control group have an average wage of £35,500. Hence, the supported firms pay a gross wage premium of £8,500; although this is not taken to be a result of the support they received.
    b. Ongoing research with economists from Innovate UK and Belmana Consulting suggest this figure might be £4.2k. (This is based on observed on data from ASHE which show the change in wages that occurs when employees join or leave firms that NPL has supported.) In our analysis we have used is more conservative figure.

Therefore, if the NTC programme increases the funding for NPL by £8 million to work with more companies, then it will have the capacity to directly support 80 additional UK-based companies over the last three years of the project. Moreover, after 2-3 years, the expected growth of 20 employees in collaborating companies would mean that these 80 additional UK-based companies will employ 1600 more people with a wage premium of around £4,200.

Lastly, the NTC will cost around £21m to establish, with most of this money going toward building four new atomic clocks. However, the analysis proceeds as if the NTC had already been built and that the question now being asked is ‘should government provide additional funding (e.g. resources spending at NPL and grants for firms) so that the NTC can support the development and commercialisation of new timing and synchronisation solutions?’ That is, the analysis attempts to weigh the innovation benefits against the additional resource funding.

3 (Frontier Economics, 2016)

2. MARKET ANALYSIS

The measurement of time is all pervasive but like most well run utilities, the dissemination of time often goes unnoticed in daily life. However, for some strategic sectors of the economy, such as, energy distribution[4] or telecommunications[5], access to a reliable source of time remains core to their internal operations and processes. These sectors comprise complex national networks composed of a multitude of nodes that need to work in a coordinated fashion. Time is a key element to ensure the synchronisation between connected interfaces of a network. Lack of synchronization can lead to poor performance of the overall system and thus have a significant impact on end-users.[6]

The following information can be used to estimate the income that UK-based firms make from sales of timing and synchronisation solutions that depend on GNSS signals. Firstly, according to the European Global Navigation Satellite Systems Agency the global market for timing and synchronisation (T&S) solutions, making use of GNSS signals, will be around £1.1 billion per year by 2020[7]. Secondly, around six firms have a presence in the UK, amounting to 20% of the 31 firms identified by the GSA. Lastly, as the six firms may also operate in many other countries, it might be better to consider using the UK's portion of the Space Market; which is around 5% of the global Space Market. Therefore, reasonable estimates of the annual income from T&S products is between £55m and £220m. (This suggests that the number of people employed in the T&S segment is somewhere between 550 and 2000.) Of course, this looks rather small but it's important to keep in mind that this is a specialist area and the important thing is that the UK already has some specialist firms to build on.

Nonetheless, one implication is that, since T&S solutions constitute a niche segment of the market for GNSS services, any increase in revenue from sales of T&S solutions will be in the low tens of millions, as opposed to being in the tens of billions. And, thus, the NTC needs to be directing resources at the users (e.g. telecoms) as opposed to focussing solely on the suppliers. That is, the GSA expect a country the size of the UK to invest around £33m per year in updating timing and synchronisation devices and services. And, by working with these users, that NTC can help to ensure that this money is spent efficiently and effectively. Lastly, NPL has conducted an initial analysis to identify potential beneficiaries of the NTC. Using information from ORBIS, NPL estimates that there are around 250 firms, operating in the UK, with patents whose abstracts refer to 'timestamping' or 'synchronisation'.

The purpose of this section was largely to demonstrate that there is sufficient headroom (latent demand) for the type of services and collaboration opportunities that the NTC will offer. Although the domestic part of the T&S supply chain employs a rather modest number of people, the sectors that depend on T&S solutions are actually vast. Three sectors of the economy have been identified as being particularly dependent on GNSS time signals, which makes them vulnerable to interferences caused by jamming[8], spoofing[9], and solar storms[10]. a key element to ensure the synchronisation between connected interfaces of a network.

4 (Symmetricom, Inc., 2004)
5 (Bregni, 2002)
6 For example, incorrect time keeping at the base stations effects the accuracy and stability of the signals that underpin the mobile telecommunications network. Problems in the dissemination of time across the network of base stations can lead to dropped calls, impede handover, and increased interference (Bregni & Barbieri, 2003).
7 (European Global Navigation Satellite Systems Agency, 2017)
8 (GPS World Staff, 2016)
9 (Goward, 2017)
10 (The Royal Academy of Engineering, 2011)

A. Energy Sector

Electronic devices known as *phasor measurement units* measure voltage and current thousands of times per second[11]. If GNSS were to be lost or disrupted, the clocks in these devices would switch to taking time from a less stable oscillator (or holdover) that cause measurements to drift about two milliseconds in a couple of hours[12]. An unsynchronised power grid would likely cause blackouts[13]. In the event of major nation-wide disruption to the energy sector (electricity) for a single day, the direct economic loss to the UK would be very significant.

B. Telecommunications Sector

Precise timing from GNSS is used to synchronise communications networks[14]. In the US, the telecoms industry has installed receivers across its huge number of mobile base stations to enable timing and synchronisation to operate across the network[15]. Currently, in the UK this frequency signal is transported across the terrestrial or core mobile network from a few central nodes which, in some cases, get this information from GNSS[16]. Moreover, 5G will depend much more on accurate timing than 4G does, with a time alignment tolerance of nanoseconds[17]. Hence, the dependency of the UK telecoms industry on precise timing from GNSS is likely to considerably increase soon[18].

C. Financial Sector

The financial sector depends on GNSS timing for clock synchronisation in trading firms, stock exchanges, ATM and credit card transactions, and for regulatory control[19]. A new era of electronic and algorithmic trading has developed, underpinned by new European and international regulatory controls that have increased dependency on GNSS time in the financial sector. The Markets in Financial Instruments Directive (MiFID) was amended in January 2018 to include tight demands on timestamp accuracy (MiFID II)[20]. All firms must now synchronise their clocks to the international time scale, UTC, to ensure that they never deviate by more than a defined amount, which can be as low as 100 microseconds. This caused widespread confusion and the assumption that GNSS would meet the regulation, which it does not because of issues of resilience and traceability to UTC.

11 (Government Office of Science, 2018)
12 (The Royal Academy of Engineering, 2011)
13 (Andersson, et al., 2005)
14 (Government Office of Science, 2018)
15 (Alliance for Telecommunications Industry Solutions)
16 (Government Office of Science, 2018)
17 (Laufer, 2018), (Ericsson, 2018)
18 (Alliance for Telecommunications Industry Solutions)
19 (Government Office of Science, 2018)
20 (European Securities and Markets Authority, 2017)

3. TECHNOLOGY FORESIGHTING

The NTC has the potential to make integral contributions to the innovations that will transform our daily life in the coming decades. From 5G telecommunications and encrypted blockchain transactions, to autonomous vehicles and smart cities, the NTC could provide a fundamental breakthrough to the generic technologies that support these disruptive market applications.

3.1. HIGH ACCURACY TIME TRANSFER

Time transfer is a scheme where multiple sites share the same precise reference time. The technique is commonly used for creating and distributing standard time scales such as Universal Coordinated Time (UTC). A recent example of a time transfer technology is the White Rabbit (WR) project[21]. It consists of a collaborative venture including the European Organisation for Nuclear Research (CERN), to develop hardware and software for data and high accuracy time transfer through an ethernet network. This is a major development because, formerly, a separate network for time transfer was required to achieve a sub-nanosecond level of accuracy. Hence, the WR technology allows users to reduce deployment costs because both data and time, can be now transmitted by the same physical architecture.

WR has been successfully deployed and tested for precise GNSS time transfer using ground fibre. This has been achieved as part of the Horizon 2020 project DEMETRA, which aims to demonstrate the feasibility of delivering timing services to end users by utilising an operational demonstrator and conducting tests with pilot applications[22]. DEMETRA is targeting several market sectors to find potential users such as, energy distribution, finance or telecommunications. Moreover, several European companies have begun to distribute WR solutions for commercial applications by developing their own hardware and software[23]. The NTC will support the development of this market in the UK by playing a similar role to DEMETRA. It will put in place a testbed facility that will support innovative research and product validation to develop and commercialise new timing and synchronisation solutions, as well as put in place the fibre links needed to make available those solutions for UK-based end users.

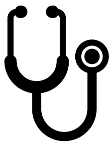
21 (Serrano, et al., 2013)
22 (INRIM, 2016)
23 Ahead in this race, is the privately held Spanish company Seven Solutions which provides systems and leading products for the accurate sub-nanosecond time transfer and frequency distribution for reliable industrial and scientific applications.

5G telecommunications	The transition to 5G mobile technology promises massive improvements in mobile device data rates, improved coverage and connectivity. Achieving this requires significant enhancements in network synchronisation. One of the biggest architectural changes that comes with to 5G deployment is the *virtualisation*[24] of the network. This reduces significantly the deployment costs but introduces the need for tighter synchronisation. Moreover, some crucial mobile device applications, such as the use of small-cell triangulation to give someone's precise location, will require even higher and more precise synchronisation standards. Accurate time alignment can help identify the exact source of an emergency call, which can make a difference between life and death by reducing the time it takes the emergency services to arrive at the scene.
Smart grid	With the rise of the smart city comes the need for smart power, that is, a more reliable and robust electrical grid that intelligently monitors itself to efficiently deliver energy on demand. A true smart grid needs to be managed in real time, making the integration of time synchronisation capabilities essential. With up-to-the-nanosecond information at hand, the power grid of the future will be better equipped to use energy efficiently, raising and lowering power levels according to demand while reducing line stresses and losses in the process. Additionally, it will make use of monitoring capabilities to make better decisions regarding fault detection and prevention. A smart grid could have prevented the massive blackout of August 2003[25] when a relatively small fault resulted in power loss for an estimated 55 million people across eight states and portions of Canada. According to the report[26] that investigated the incident, while it was initially caused by an overloaded transmission line sagging and touching a tree branch, it was actually the inability to detect that fault quickly and eliminate any cascading effect what led to the events that followed.
Autonomous vehicles	Although it is clear the importance of GNSS navigation for autonomous guidance, proper timing is also paramount. In a closed loop control system, which is what an autopilot system is, precisely synchronizing the engine and compensating for sensor and processing delays is key to ensuring a stable and agile trajectory. All the sensors in the car and all the data streams, no matter its source, has to be timestamped using a centralised, reliable time-keeper[27]. In other words, the data must have a timestamp that allows for perfect synchronization of the multiple elements that make up the autonomous vehicle.

24 Network virtualisation is the process of combining hardware and software network resources and network functionality into a single, software-based administrative entity, a virtual network.
25 (Andersson, et al., 2005)
26 (U.S.-Canada Power System Outage Task Force, 2004)
27 (Fridman, et al., 2017)

3.2. BLOCKCHAIN

A blockchain is a growing list of records, also called *blocks*, which are linked using a cryptographic technique. Each block contains a cryptographic hash[28] from the previous block, a timestamp, and transaction data. One of the main features of the blockchain technology is that it is completely decentralised. Unlike a centralised system, it is not easy to get an agreement about time in a distributed system like the blockchain. In the former case, it is possible to determine the absolute order of the blocks based on the globally shared clock, but in the latter case, it is difficult to share absolute time because of problems caused by clock errors. Due to such ambiguity, there is a possibility that double recording occurs[29]. Hence timing and synchronisation are vital to this technology that has applications for many sectors of the economy like finance or the retail industry.

Cross-border transactions 	The digital revolution is going to change the way that financial international transactions are made. Today, banks continue to use a very complex infrastructure to run simple transactions like sending money abroad. This is because the finance industry needs highly secure private databases to keep their customers data and their businesses protected. Blockchain technology allows for financial institutions to create secure instantaneous direct links between each other[30], avoiding the need for traditional correspondent banking[31]. In other words, competing financial institutions will be able to use a common decentralised architecture to keep track of the execution, clearing and settlement of transactions without the need to involve any central database or management system.
Controlling outbreaks of a foodborne disease 	Nowadays, when a batch of contaminated products with harmful effects for health reaches the shelves of supermarkets, it can take days, if not weeks, to find its source. Better traceability could help save lives by allowing companies to act faster and protect the livelihoods of farmers by only discarding produce from the affected farms. The blockchain technology can provide such traceability for the decentralized food supply ecosystem. In fact, recently the American retailer Walmart has run two proof of concept projects to test this idea[32]. One project was about tracing mangos sold in Walmart's US stores and the other aimed to trace pork sold in its China stores. The results were astonishing. For pork in China, it allowed uploading certificates of authenticity to the blockchain, bringing more trust to a system where that used to be a serious issue. And for mangoes in the US, the time needed to trace their provenance went from 7 days to 2.2 seconds. Walmart can now trace the origin of over 25 products from 5 different suppliers and has recently announced that it will start requiring all of its suppliers of fresh leafy greens to trace their products using the system[33].

28 A cryptographic hash function is a mathematical algorithm that maps data of arbitrary size (often called the *message*) to a bit string of a fixed size (the so-called *hash*). Cryptographic hash functions are mainly used in digital signatures, message authentication codes and other forms of authentication.

29 (Tanenbaum & Van Steen, 2007)

30 (Chang, Iakovou, & Shi, 2019)

31 A correspondent bank is a bank that provides services on behalf of another, equal or unequal, financial institution. It can facilitate wire transfers, conduct business transactions, accept deposits, and gather documents on behalf of another financial institution.

32 (Hyperledger, 2018)

33 (Smith, 2018)

4. RATIONALE FOR THE NTC AND ROUTES TO IMPACT

4.1. WHY CAN'T THE NECESSARY INVESTMENT BE LEFT TO THE PRIVATE SECTOR?

There is strong evidence that critical sectors of the economy have become dependent upon GNSS for timing and synchronisation. Moreover, unmitigated dependence on GNSS could become a barrier to the widespread use of some of the emerging technologies. Hence, value would be created by investing in a single national infrastructure for the dissemination of time that can be drawn on by many organisations from a range of different sectors. Nonetheless, the following issues create a market failure that means that the private sector will not provide the required investment.

Coordination failure

- The community of suppliers and users of timing services are diverse, spanning multiple sectors, meaning that any investments are piecemeal and lack coordination. Current activities comprise an ad hoc collection of technologies, processes and approaches that lack integration and do not meet future demands.

Information failure

- There is little awareness of the dependency or security concerns stemming from the current reliance upon GNSS for time, the risks involved in its use, and the need to develop mitigations in the event of the service being compromised.

Externalities

- No one organisation in the private sector is prepared to sufficiently invest in the necessary technologies as there would be positive spill overs to other companies. Hence, all such organisations have the incentive to try and free ride on the efforts of other firms rather commit substantial investment themselves.

Non-market goods

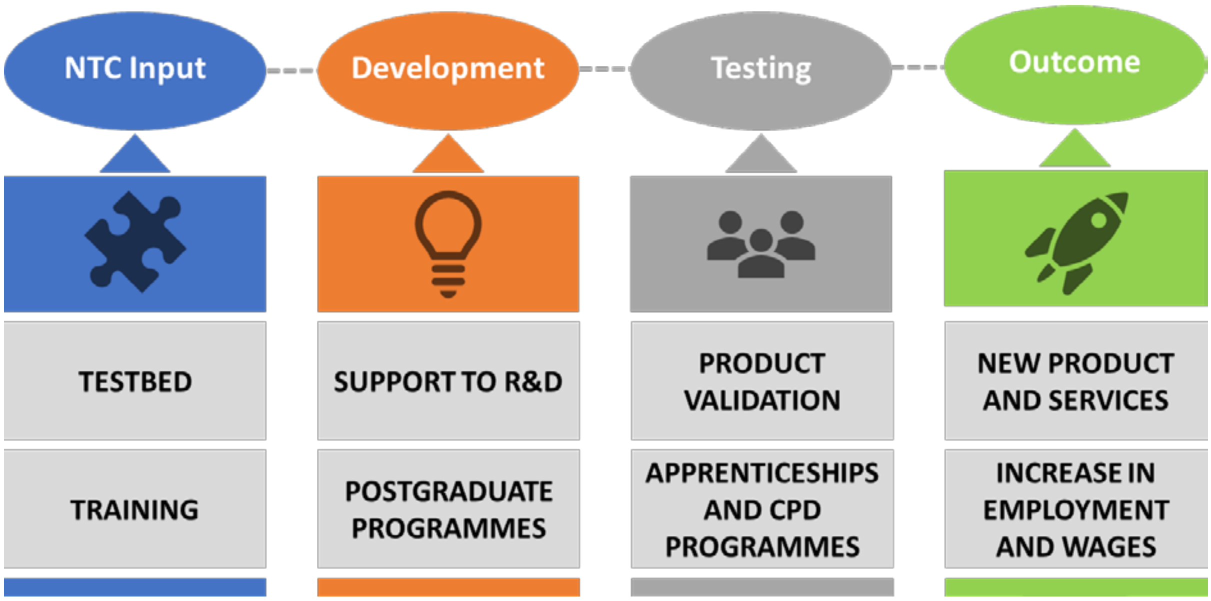
- The NTC would aid national defence and security by helping to protect strategically important sectors of the economy (e.g. electricity distribution). The centre would help to mitigate some of the effects of malicious jamming and spoofing by hostile agents. A private company will not supply a reliable national infrastructure for distributing time without government funding

4.2. SUPPORTING TWO PHASES OF PRODUCT INNOVATION

The NTC will provide the collaborating companies with two main inputs:

A testbed facility that supports innovative research and product validation to develop and commercialise new products and services.	Postgraduate, apprentices and CPD training programmes to develop the required skills in time and synchronisation solutions.

Both elements will support the collaborating companies through the development and the testing phase of new products and services. These phases correspond to a number of Technology Readiness Levels (TRLs): ‘development’ corresponds to TRLs 3 - 6; and ‘testing’ corresponds to TRLs 5 - 7. In addition, the NTC will have an initial boost of £7 million from Innovate UK grants.



Development phase

The NTC testbed facility will promote investment in supported firms by providing direct support to R&D projects. This is achieved by providing a technical infrastructure (facilities) that reduces the cost of R&D projects; and by acting as an intermediary, matching firms that supply time and synchronisation solutions with customers in sectors, such as, telecommunications, who are searching for new services or devices. Moreover, during the development phase, the postgraduate program will allow PhD students to get involved in R&D projects. This will allow the supported companies to enrich their innovation activities and provide the doctoral students with industrial experience. As a result of this collaboration, knowledge spillovers[34] are expected to promote additional benefits for the UK.

Testing phase

The NTC's testbed facility will also help UK-based companies to validate the performance of their new products and services. Hence, the supported firms are enabled to bring, either a fundamentally new product to the market, or one that performs better than those produced by their competitors. This will increase the demand for their output and will allow their new product to command a higher mark-up[35]. The new capabilities housed at the NTC increase innovation by providing new tools and techniques for research and make available the means of demonstrating the functionality of novel technologies. This is precisely one of the main objectives of the NTC's testbed that will be made available to UK firms. It will allow the participating companies to demonstrate the enhanced functionality of their new product and services, and to make them known to potential users.

Outcomes

Assuming that the collaborating firms operate efficiently, to undertake new production they will need to increase their staff[36]. Since high-tech firms are assumed to operate in a near to full employment environment, the increase in the number of workers will come largely from training apprentices. However, the NTC will also provide CPD training on time dissemination and exploitation for systems engineers, developers and other experienced workers of the collaborating firms. In any case, since firms have to rent the new knowledge acquired by the trained workers, they will pay higher wages[37]. Therefore, the collaboration with the NTC translates into both an increase in employment and a wage premium.

34 (Griliches, 1979)
35 (Schumpeter, [1912] 1934)
36 (Marshall, 1890)
37 (Dearden, Reed, & Van Reenen, 2006)

4.3. HOW WILL THE NTC GENERATE VALUE FOR THE UK?

The logic models present the step-by-step account of how the NTC will generate economic impact. We have divided into three phases:

1. **Design and development** - the project will focus its efforts on coordinating the activities of the stakeholders to identify UK priorities from both a commercial and national security perspective. As a result, the foundations of the future infrastructure will be cemented. Also, a wasteful duplication of efforts in the construction of equivalent civil and military infrastructures will be avoided.
2. **Building phase** - will establish the NTC under the coordination of the programme's Management Board. The necessary capital will be purchased, configured and installed to mitigate the effect of disruption of the GNSS service. Moreover, this will allow the monitoring of the integrity of the GNSS signal in what constitutes a gain of sovereign capability for the UK.
3. **Operations phase** - will allow for the deployment and utilisation of the new network and develop the UK skill base though training and secondments. NPL provides training and collaboration opportunities that help to sustain a wage premium for employees at the firms it engages with. NPL and Innovate UK will support users with funding. and two major routes to impact will be generated:
    - A UK wide interconnected network that can mitigate the effect of a sustained disruption to timing and synchronisation.
    - Establish the UK as a player in the supply of timing equipment and services.

Inputs	Have already demonstrated the feasibility of establishing a multimodal network for disseminating precise time. Resource funding and co-funding. Employment of engineers and scientists.
Activities	Set up and run a structured training programme that spans from apprentices to PhDs. Work with Innovate-UK to run and fund a programme to support companies make use of the testbed. Facilities used to probe areas of fundamental physics such as relativity and dark matter.
Outputs	Build new skill sets with 50% of secondments and guest workers from industry. Facilities used by SMEs and large primes from across the UK. Collaborators include 5GIC; Arqiva; JISC; Raytheon; e2v. Used as testbed for space clocks. Generate revenue from projects using testbed so that revenue makes the centre self-sustaining.
Outcomes	1. Have addressed the skills deficit in timing related technology. Facilities have actively supported government investment in areas like 5G, quantum technologies, and autonomous vehicles. 2. Develop technical standards and test methods needed to prepare the market for the next generation of timestamping and synchronisation solutions.
Impacts	1. A UK wide interconnected network that is able to mitigate the effect of sutatained disrution to timing and synchronisation services currently accessed through GNSS. In particular, have back-up systems in place for Telecommunications, Energy, and Finance. 2. Commercialisation of UK-sourced timing components and systems. Have established a UK supply chain for timing equipment and services.

5. PUBLIC AND PRIVATE COSTS OF THE FIRMS INNOVATION ACTIVITIES

The NTC will cost around £21m to establish, with most of this money going toward building four new atomic clocks. However, the analysis proceeds as if the NTC had already been built and the question now being asked is should government provide additional funding (resources spending at NPL and grants for firms) so that the NTC can support the development and commercialisation of new timing and synchronisation solutions. It follows that in what follows only considers resources spending and grants; and does not account for the cost of building the new clocks.

Through the NTC programme NPL will get an extra £8m of resource funding, over three years, to put into supporting firms' innovation activities:

£4m for NPL's scientist to support collaborative projects

£4m for NPL to develop and deliver training courses

However, it should be noted that the model outlined in the later sections of this document is not sophisticated enough to separate the effects of training for that of collaborative R&D projects. All that really matters in this context is that the NTC programme provides NPL with £8m of additional resource funding to support firms' innovation activities.

Now, if we consider who performs these innovation activities, then there is a 1:2 ratio between the amount of effort that NPL puts in to a project and that efforts that a firm puts in to a project. That is, if a project costs £90k in total, then NPL would do £30k of the work (e.g. research) and the firm would do £60k of the work (e.g. development). (This 1:2 ratio comes from the results of a survey of NPL's users conducted by Winning Moves in 2017[38].) It follows that if NPL contributes £8m to research or training, then the firms perform about £16m of development or training work (e.g. spending people to work or learn at the centre).

Most of NPL's contribution would typically be funded through a mixture of UK or EU innovation programmes. (NPL has very limited funds of its own and generally can't engage in collaborative projects without an external source of funding.) In contrast, in the case of the company, around 50% of its costs might be covered by a grant. However, in the case of the NTC programme, it's anticipated that Innovate UK will be providing around £7m of dedicated grant funding. This suggests that of the £16m of development work performed by supported firms, £9m will be contributed by the firms themselves and £7m will come from grants.

The total innovation spending will be £25m with around £15m coming from government (£8m of funding for NPL plus £7m of funding for grants) and £9m coming from the firms themselves. This spending and associated work will take place over a three-year period. It follows that private cost per year is £3m and the public costs per year is £5m.

38 (Winning Moves, 2017)

6. THE NUMBER OF FIRMS SUPPORTED BY NPL DEPENDS ON FUNDING

NPL is a government owned and (largely) government funded national laboratory that specialise in the measurement science. In particular, fundamental metrology and primary standards; developing new instrumentation; and the provision of calibration and testing services. The time of its scientists is split between maintaining capabilities (e.g. international key comparisons); doing the kind of research that generates articles in peer reviewed scientific journals; providing measurement services (e.g. calibrations) or training; and working with organisations on collaborative R&D projects.

To provide context it Is helpful to introduce the basic numbers for NPL:

NPL at a glance	NPL has 820 scientific and technical staff and 280 administrative or managerial staff.
	It receives £56.8m in annual NMS funding.
	It works with or otherwise provides services to around 500 UK-based firms each year.

This suggests that, on average, NPL needs around £110k of NMS funding per firm. However, this section of the document is focussed on the marginal cost of supporting an extra firm. NPL's technical staff (scientists and engineers) are distributed across 17 scientific groups. For the eight-year period 2010 to 2017, there is annual data on the funding, staffing, and output of these groups. NPL has used this data to analyse how changes in funding effect changes in staffing and how this feeds through in to changes in output. In particular, NPL has analysed the effect of NMS funding provided to a group on the uptake of its products and services by UK-based firms.

The analysis is based on a panel of 136 observations (17 groups x 8 years) containing the following variables:

- The number of distinct UK-based firms (distinct CRNs) supported by a given group during a certain year. Supported firms were those that either paid for services or collaborated with the group's scientists on R&D projects.
- The number of scientists who were working in a given group during a certain year
- The level of funding received by a given group in a certain year

The analysis starts from the linear expressions connecting: (1) the number of staff to the level of funding; and (2) output per staff member to the funding per staff member. Combining both expressions, the sensitivity to a change of the number of paying firms with respect to a change in funding can be derived. (Note that normalising the number of firms supported by the number of scientific staff in a group helps to make these groups comparable even though the groups actually vary in size.) Based on this, the effect of NMS funding on the number of paying customers can be split into two parts:

- The effect of the NMS funding per scientist on the number of paying customers per scientist
- The effect of NMS funding on the number of scientific and technical employees

The value of the two coefficients representing the strength of these effects can be estimated by a fixed effects regression using the panel dataset. This found that the number of firms supported by one of NPL's groups depends on its level of funding.
The outcome of the analysis shows a statistically significant positive relation between NMS funding and the number of supported firms. In particular, providing NPL with an additional £1 million per annum of resource funding, enables it to directly support 10 more UK companies. (Note that this implies that the marginal cost of supporting an additional firm is around £100k.) These additional companies will either become NPL paying customers or will engage in collaborative R&D projects.

7. THE IMPACT OF NPL'S SUPPORT ON JOBS AND WAGES

The first part of this section outlines the fundamental mechanisms through which this impact is achieved. Building on that, the second part of the document quantifies the contribution of the NTC to innovative activities of UK companies that either use or supply timing and synchronisation devices and solutions.

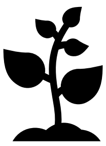
7.1. WORKING SIDE BY SIDE WITH THE PRIVATE SECTOR: THE MECHANISMS TO DELIVER IMPACT

While reducing the need for organisations to commit resources to piecemeal risk mitigation activities, the NTC will support the innovation activities of high-tech companies that, either supply timing and synchronisation devices and solutions, or use them to enable their own innovation activities (*e.g.* the adoption of 5G by the telecommunications sector). It is expected that the collaboration with the NTC will generate growth for these companies through one or more of the following mechanisms:

- The NTC will play an integral role in the development of a new or superior product which leads to a positive shift in demand, thus allowing firms to expand their output and increase their market share.
- The NTC will also affect the supported firm's willingness to invest. Collaborating with the NTC will support the supported firms' innovative activities. This will lead to a positive shift in investment demand which ultimately leads to an increase in output.

More detail on these mechanisms is given in the annex along with some examples.

7.2. EFFECT OF NPL'S SUPPORT ON EMPLOYMENT GROWTH



In 2016, Frontier Economics analysed the impact of NPL's support on the performance of UK companies. This report found that NPL's support had a positive effect on survival rates and employment growth[39]. This study was a major contribution that constitutes a first attempt to make use of micro econometric methods to assess the impact of the National Measurement System (NMS)[40]. Based on firm-level data, it analysed the effect on survival and employment up to four years after the receipt of support. To do so, Companies House reference numbers were used to link internal administrative records of invoices for paid services from 2008 to 2012, to annual data collected by the ONS (Office of National Statistics) on all UK companies with more than ten employees. The resulting dataset contained a mixture of customers and non-users that provided information on whether these companies had been R&D active or had received other types of public support.

This dataset was used to estimate the likelihood (*i.e.* propensity score) that a firm with certain characteristics would become a customer of the NMS laboratories. Each customer was matched to a set of non-customers who shared the same characteristics and propensity score. Hence, each customer was associated with a control group of non-users. The average outcome (employment growth and survival up to four years after using a service) for customers of the NMS laboratories was compared to the average outcome for their matched controls. The study argues that the difference between the average performance of customers and their matched controls can be attributed to the support, since three years

39 (Frontier Economics, 2016)

40 The NMS provides the UK with an infrastructure of laboratories that deliver world-class measurement science and technology and provide traceable and increasingly accurate standards of measurement. NPL is the largest of the measurement institutes that make up the NMS.

prior to using the NMS services both had similar growth rates. This indicates that the divergence in performance starts after the customers received support and not beforehand. Therefore, the results of the study show that companies who use NPL services have higher survival rates and experience an average employment growth of 20 employees within 2 to 4 years.

7.3. FIRMS THAT WORK WITH NPL PAY HIGHER WAGES THAN THEIR COMPARATORS

There is some evidence that wages at companies with a propensity to engage with NPL are higher than the average wage. Summary statistics contained in the report by Frontier Economics can be used to show that employees in treated firms earn an average wage of £44,000, whereas those in the control group have an average wage of £35,500. Hence, the supported firms pay a gross wage premium of £8,500.

Currently, NPL is working with economists from Innovate UK and Belmana Consulting to explore this using person-level data from ASHE (Annual Survey of Hours and Earnings). The ASHE dataset is longitudinal and tracks a group of people - based on the last digit of their NI number - collecting annual data information from their employers on earning, hours worked, and job roles. Our study is on-going but has found that someone’s wages tend to increase when they join firms that have been working with NPL. Furthermore, this increase in wages exceeds the increase in wages typically enjoyed by job switchers. The increase in wages for people joining an NPL firm also exceeds that of people joining a control group of similar firms that don’t work with NPL. Lastly, someone’s wage tends to decrease a little when they leave an NPL firm, suggesting that their skills are not fully transferable. The analysis is still on-going, but it’s currently believed that the wage premium might be around £4.2k.

As this analysis is empirical, there is not yet a settled understanding of what’s causing this increase (decrease) in wages that occurs when someone joins (leaves) a firm that works with NPL. However, a plausible explanation is based on the idea that some people possess certain technical skills and that these are highly prized by employers recruiting people for certain specific jobs. However, there may be a limited demand for such skills and so sometimes people with such skills work in jobs where a more generic skill-set is sufficient. These people tend to earn reasonable wages but are nonetheless underemployed because they could be more productive in other roles. (They are not using their full abilities.) Lastly, support from NPL may enable certain types of firm to expand and, in so doing, help to create jobs that require the specific technical skills that this group of people possess. In short, NPL may be helping to create or sustain roles that allow certain types of human capital to be properly employed.

8. DIRECT BENEFITS TO THE FIRMS THAT WORK WITH THE NTC

The following three pieces of information will now be combined so as to infer the effect on employment growth among supported firms: Firstly, the final three-years of the NTC programme will provide NPL with an additional £8m of resource spending. (This breaks downs as £4m for extra collaborative projects and £4m for delivering new training courses.) Secondly, it has been shown that an additional £1m of resource enables NPL to work with 10 extra firms. This implies that it costs about £100k to support an additional firm. Lastly, as mentioned in section 7.2, NPL has specific estimates of employment growth among supported firms, based on a recent econometric study by Frontier Economics.

This report finds that the expected impact on a supported firm amounts to around 20 additional employees 2 years after working with NPL. Therefore, the NTC can be expected to work with around 80 additional firms over the last three years of the project; which implies that the centre will support around 27 additional firms supported per year. (This comes from dividing the £8m of extra funding by the £100k cost of supporting a firm.) Furthermore, working with an additional 80 firms can be expected to have generated around 1,600 additional jobs 2 years after the end of the programme.

It has become traditional to talk about additional job-years rather than of jobs being created or saved. The idea is that one job running for one year is “one job-year”. If that job continues for another year, then its two “job-years.” This concept is meant to make it easier to talk about cumulative employment effects taking place over a number of years.

The next step is to find the effect of job-years for the firms that work with the NTC during the last three years of the programme. Firstly, suppose that NPL works with an additional 27 firms each year for three years. (The NTC programme is five years but it takes two years to build the facilities and set up the centre.) Let us number the three years during so that the first instance of support occurs in year ‘0’ and the last instance of support occurs in year ‘2’. Secondly, on average, each such instance of support generates 20 additional jobs. Lastly, there is a lag of around two years between receiving support and the new jobs being created. Based on these assumptions, there are an additional 540 job-years in year ‘2’ and an additional 1080 job-years in year ‘3’.

It is assumed that the jobs created by NPL’s direct support for innovation are associated with a supplying a new product. Based on the duration of a typical product life-cycle, this means that the direct benefits (employment growth among supported firms) are expected to last for 10 years. It can be shown that, a ten-year time horizon gives 11,340 additional job-years.

Since wages are the main component of value added, it follows that wages are a reasonable approximation to GVA and thus reasonable proxy for economic benefit. If one supposes that the people filling the additional jobs would have been unemployed, then an estimate of the economic benefit is the job-years multiplied by the wage rate. However, the type of jobs being created at firms working with NPL will largely go to people who won’t struggle to find a job (e.g. technicians and engineers). And, in the situation where the labour market is tight, the expansion of one firm is likely to come at the expense of other firms - both domestic and overseas. Due to the displacement of market share from one firm to another, the employment effects discussed above cannot really be treated net additional job-years.

However, the companies that engage with NPL tend to pay higher wages to joiners than firms in the control group of non-users. Ongoing research with economists from Innovate UK and Belmana Consulting suggest this figure might be £4,200. This is based on analysis of data from ASHE, which shows the change in wage that occurs when someone joins or leaves a NPL firm. In our current analysis we have used this estimate of the wage premium. The idea is that the new jobs created following support from NPL, generate opportunities for people with specific technical skills. Hence, people who were previously in less demanding jobs now get to use their full abilities, which creates value as people are employed more productively.

The wage premium is a reasonable measure of the economic benefit in terms of increased GVA. That is, the current analysis assumes that NPL helps to shift jobs in the direction of innovative firms who build human capital and retain staff by paying a wage premium. The following table, which presents the direct economic benefit, in nominal undiscounted terms, and allows us to get a sense of the value added by the NTC over a 10-year time horizon.

Wage Premium Analysis

Average wage premium per annum (£000s)	4.20
Total full-time-equivalent job years	11,340
Cumulative wage premium (£000s)	47,628

9. INDIRECT BENEFITS OR 'SPILOVERS'

The previous section discussed the direct benefits going to firms who work with NPL or use its services. However, the analysis also needs to account for various types of indirect benefit. As will be discussed, the benefits are hard to measure but can be estimated by scaling up the direct benefits.

9.1. KNOWLEDGE SPILLOVERS

The economic rationale for the existence of a publicly-funded organisation like NPL is that measurement R&D is subject to market failure. Indeed, the private investment needed to generate new measurement capabilities, will always be below the socially optimal level. This occurs because the benefits that measurement R&D generates will always spill over to firms who did not contribute, and this creates a strong incentive to free-ride[41]. The problem is particularly acute in the case of the R&D that the NPL undertakes, because advances in metrology tend to have applications across many sectors. It is this wide applicability that makes the development of these new tools and techniques particularly susceptible to free-riding. Consequently, it is argued that measurement should really be seen as a public *infratechnology*[42], that is, a technology that provides tools and techniques which can be widely applied across a number of sectors to enable further innovation. In short, NPL and its partners' scientific work generates a pool of knowledge that can be accessed and used by any firm. This fact carries a strong incentive to free ride, and thus, there is a clear need for public funding to compliment measurement R&D private spending.

9.2. PECUNIARY EXTERNALITIES

Indirect benefits exist in case where NPL generates benefits for firms that don't directly use its services and aren't even aware of its role. For example, suppose that NPL manages to extend the range of one of its calibration services, which enables the calibration labs who take traceability from them to pass on this extension of the range to their customers. Initially, only a few calibration labs might offer calibrations in this range which could allow them to charge a premium to firms who benefit from this new capability. However, as more calibration labs update the service they offer, this price premium will be eroded by competition and the full benefit of the new service will be passed on to the customers of the calibration labs. In the case of NPL*Time*®, intermediaries in the vanguard are companies providing fibre-based technical services to the finance industry, such as, Intercontinental Exchange (ICE). But in time, it's hoped that a broad network of intermediaries will allow NPL*Time*® allow the service to be made widely and cheaply available across multiple sectors of the economy.

41 (Arrow, 1962)
42 (Tassey, 2008)

9.3. CURRENT ASSUMPTIONS

A survey of users performed 2017 found that 38% of NPL's private sector users, that report an innovation, said the impact of their innovation has reach beyond direct users. These users claim that there are benefits going to partners, suppliers and customers that are not monetised. It is difficult to use this to infer the scale of these spillovers but it does provide evidence that such benefits exist.

At the aggregate level, R&D investment generates strong positive economic impacts. For private sector R&D investments, a study by Frontier Economics[43] found that existing literature estimates private rates of return to R&D investments of around 20-30%. Social returns, based on spill-over benefits from R&D, are typically 2 to 3 times larger than private returns. Therefore, our analysis estimates the indirect benefits by doubling the direct benefits, while applying a two-year time lag to allow time for the diffusion of new knowledge to take place.

43 (Frontier Economics, 2014)

10. ASSESSING VALUE FOR MONEY OF PUBLIC SPENDNG

This section quantifies the impact of the contribution of the NTC to the innovative segment of the UK timing and frequency market. The model is based on the Green Book's[44] established economic guidelines for assessing the economic impact of public programmes. The goal of the present analysis is to compute the Net Present Value (NPV) and the NPV-to-DEL ratio for the NTC. The NPV is calculated as the difference between the present value of streams of costs and benefits, which are obtained using a discount rate to convert all future deflated figures to values that can be compared across years. The assumptions made in this analysis are:

- NPV has been assessed over a 10-year horizon.
- Discounted figures have been computed using a 3.5% discount factor[45].
- Adjustments to inflation have been made using ONS deflators.
- A 5% return has been used to account for the opportunity cost of capital invested.
- A 14-year period[46] is used to account for the duration of the opportunity cost of capital invested.

10.1. PUBLIC AND PRIVATE COSTS OF THE PROJECT

The NTC will cost around £21m to establish, with most of this money going toward building four new atomic clocks. However, the analysis proceeds as if the NTC had already been built and the question now being asked is should government provide additional funding (resources spending at NPL and grants for firms) so that the NTC can support the development and commercialisation of new timing and synchronisation solutions.

The costs to both UK public and private sector of the additional innovation activity are:

- Exchequer costs to resource the NTC's innovation activities. (Collaborative projects and training programmes.)
- Direct private sector costs by those who pay for the NTC's services (e.g. training) or work on collaborative projects. As mentioned in section 5, the survey by Winning Moves[47] found that NPL's input typically accounts for about one-third of the resources that go into a firm's innovation project but that some of this is covered by grants from Innovate-UK.
- There is an opportunity costs of not allocating those private resources to other profitable activities. Using a 5% cost of capital, the loss from the foregone investments over 10 years is around £4m.

As mention in section 8, it is estimated that the NTC will support 80 UK-based companies over the course of three years. These companies will work on R&D projects that use the NTC's unique facilities, leading to additional private spending that, otherwise, would not have occurred. Considering both the public and private resources spent in those projects, the total expected real discounted cost is £26m. (Note that this includes the opportunity cost of the private spending.)

44 (HM Treasury, 2018)
45 (HM Treasury, 2018)
46 The duration of the perturbation is calculated as the time taken for the private investment to make back the principal invested plus any returns earned in the counterfactual situation of a non-sunk investment.
47 (Winning Moves, 2017)

10.2. MONETISED BENEFITS TO UK SOCIETY

The funding of the NTC project carries essentially two types of benefits:

Direct benefits flow to firms who engage with the NTC through their participation in collaborative projects or through the use training services. These benefits are assumed to incur a 2-year time lag before the benefit materialises in the form of employment growth. This assumes that any innovation needs some time to get implemented, that is, the firm's operations require an adaptation period.

Indirect benefits spill over to firms that did not engage with the NTC but share the same environment (e.g. market) as the supported firms. In this case, there is an additional 2-year time lag, so that it takes four years for the indirect benefits to materialise in the form of employment growth. This assumes that it takes two years for the knowledge acquired by NTC supported firms to flow to competitors, customers, or suppliers. (The idea is that over this two-year period some knowledgeable employees leave the supported firms and are then employed elsewhere.) Lastly, the NTC will promote **wide economic benefits** by establishing an infra-technology needed to underpin the emergence of disruptive new technologies, such as, 5G telecommunications and the adoption of autonomous vehicles.

10.3. FINAL RESULTS

In order to assess value for money, both the Net Present Value (NPV) and the NPV-to-DEL ratio must be computed. The following table summarizes the outcome of the NPV analysis:

NPV Analysis

DEL (£m) (d)	14
Economics Costs (g) (£m)	26
Total Economic Benefits (c) (£m)	83
Net Present Value (£m) (h=c-g)	57
Net Present Value/ Total Public Costs (h/d)	4.01
Net Present Value/ Economic Costs (h/g)	2.18

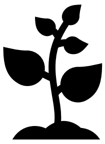
The NPV is calculated as the difference between the present value of streams of costs and benefits. The first two rows in the table constitute the present value of the costs of the project: a direct cost to the exchequer (DEL) of £14m that amounts to £26m once private sector costs are considered. The present value of the benefits is estimated at £ 83 million. Considering both figures, the net present value is computed as the difference of both. Lastly, the NPV-to-DEL ratio is obtained by dividing the net present value by DEL. This ratio shows that a net benefit of around £4 is expected for every pound invested by the public sector. If private sector resources and opportunity costs are taken into account, this net yield is well above a 2:1 ratio. (3:1 benefit to cost ratio.)

11. CONCLUSION

This paper outlines how the National Timing Centre (NTC) will support the growth of UK-based firms by promoting innovation across associated sectors. The NTC will provide access to specialist facilities to test the performance of new products and will build expertise through collaborative R&D projects and training services.

The analysis considers the setting up of the NTC as being equivalent to an expansion of NPL. Hence, NPL's evidence on the effect of its programmes has been used to predict the impact of the NTC; this evidence shows that:

Providing NPL with an additional £1 million per annum of funding will enable it to directly support an additional 10 UK companies.



Companies supported by NPL grow more rapidly than unsupported comparators - on average, supported companies have around 20 additional employees 2-3 years after working with NPL, when compared to a matched control group of similar unsupported ones.

Companies with a propensity to engage with NPL pay higher wages than the typical firm, because of the knowledge and experience needed to work with NPL. Ongoing research with economists from Innovate UK and Belmana Consulting suggest this figure might be £4.2k.

Using this information, the analysis finds an expected gross benefit of £83m, which leads to a net present value of £57m and a 4:1 NPV-to-DEL ratio, once investment costs are deducted over a ten-year appraisal horizon.

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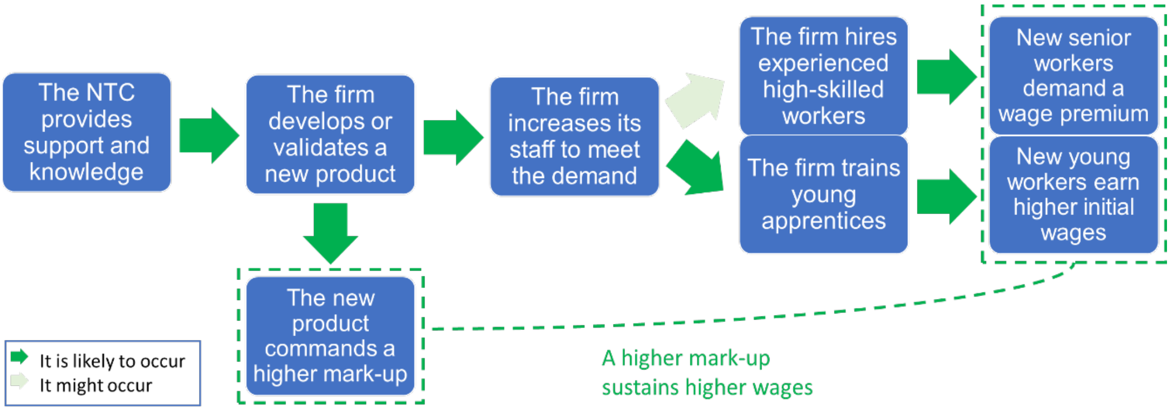
12. ANNEX: IMPACT MECHANISMS

This section explains how the NTC supports the growth in employment and wages among high-tech companies.

12.1. SHIFT IN DEMAND: THE SUCCESSFUL DEVELOPMENT OF A NEW PRODUCT

The development of new products directly increases the collaborating firm's sales by having something new or better to sell. The support and transfer of knowledge by the NTC can help to provide breakthrough or to validate the performance claimed by the seller. Hence, the firm is enabled to bring, either a fundamentally new product to the market, or one that performs better than those produced by its competitors. This will increase demand for their output and allow them to command a higher mark-up[48]. However, assuming that the firm operates efficiently, to be able to undertake the new production it will need to increase its staff[49]. Since high-tech firms are assumed to operate in a near to full employment environment, the increase in the number of workers at the firms supported by the NTC will come largely from training young apprentices. Hence, the collaboration with the NTC has a lasting effect on the career of young professionals who acquire cutting-edge skills and earn higher initial salaries[50] than they would otherwise have earned had they taken a different career path. In some cases, the firm may also need to hire experienced high-skilled workers, essentially from non-supported firms. To do so, a small wage premium is needed to encourage these high-skilled workers to move from those non-supported firms to the ones involved with the NTC[51]. In any case, these higher wages can be sustained due to the price premium commanded by the new products that the supported firms put on the market. This mechanism for growth is summarised by the following flow diagram:



It is possible to analyse what NPL already offers in terms of time services to get a sense of the possibilities of the NTC. Currently, NPL*Time*® already delivers a bespoke precise time signal directly traceable to Coordinated Universal Time (UTC) and independent of the Global Navigation Satellite System (GNSS) to the City. This service allows financial companies to comply with new EU legislation that requires timestamping to within 100 microseconds. Delivered through several commercial partners, the signal is the only means of ensuring confidence that trades comply with the new legislation without the need for further monitoring and calibration needs and costs. The NTC will bring this kind of time solution to many other industries that have already expressed their need for a similar commercial service.

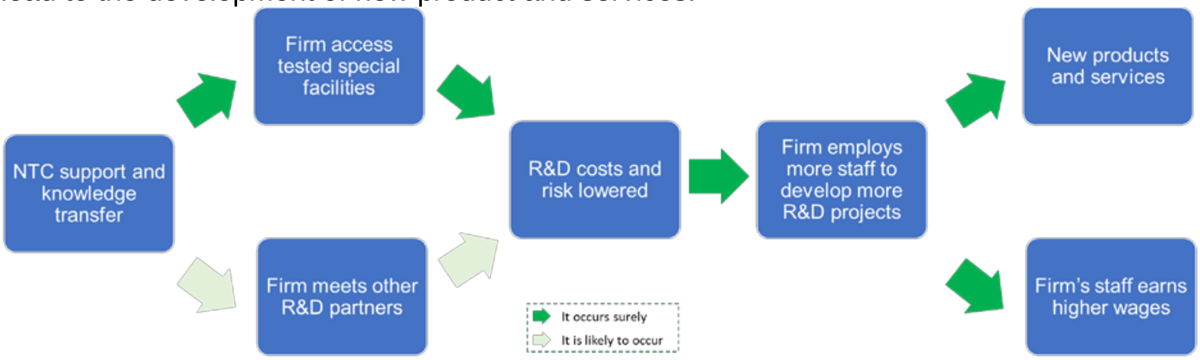
48 (Schumpeter, [1912] 1934)
49 (Marshall, 1890)
50 (Dearden, Reed, & Van Reenen, 2006)
51 (Becker, 1962) (Parsons, 1972)

12.2. POSITIVE SHIFT IN INVESTMENT DUE TO LOWERING THE COST OF INNOVATION ACTIVITIES

The NTC provides two major ways to promote investment within supported firms:

- It puts in place a testbed facility that provides direct support to R&D activities.
- It acts as an intermediary for different agents of the UK's time and frequency innovative segment to share collaborative projects.

Both effects mean that R&D becomes cheaper and less uncertain. This will increase the willingness to invest of the NTC supported firms. Hence, this support can be considered to act as a subsidy which will allow the supported firms to initiate projects that otherwise would not have been profitable. The outcome is an increase in the number of investment projects run by the company, and the staff to develop them. As in the two previous mechanisms, a small wage premium is needed to encourage these high-skilled workers to move from non-supported firms, to firms that collaborate with the NTC. Lastly, more R&D activities ultimately lead to the development of new product and services.



In its recent past, NPL has fostered innovation through this mechanism in a number of ways. Setting up special facilities where private firms can join efforts to test and develop new products is an optimal way to achieve success. As an example, the following case study by NPL's Quantum Metrology Institute can be considered. The goal of this group within NPL is to provide leading-edge measurements for verifying the performance of new quantum technologies. A recent application of this, concerns the novel technology of Quantum Key Distribution (QKD). Key exchange is at the heart of cryptography for secure communication. This distribution of keys using photons over an optical network can provide an extra layer of data security which is inherently future-proofed. *Toshiba Research Europe*, *BT*, *ADVA Optical Networking* and NPL performed the first demonstration of QKD and data encryption over a single field-installed fibre, with NPL providing traceable calibration of the QKD optical system. This showcased the technology and highlighted the importance of traceable measures for system verification.

13. ANNEX: INPUT-OUTPUT ANALYSIS FOR NPL'S GROUP

13.1. ABSTRACT

NPL has analysed how changes in funds received from BEIS affect its scientific staff, and how this feeds into changes in the number of UK-based firms that either pay for products and services, or collaborate with NPL in R&D projects. To do so, two fixed effects models have been developed to quantify the relation linking both NPL's number of scientific workers and the number of supported UK businesses, to the level of funds received from BEIS. The data used in this analysis is typically used for internal monitoring and agreed reporting metrics distributed to BEIS. It consists of annual data from 2010 to 2017 on:

- the level of funding received,
- the number of scientists and engineers,
- and the number of UK-based firms supported

for each of the 17 scientific groups that compose NPL.

The analysis finds that providing NPL with an additional £1 million per annum of resource funding, enables it to directly support at least 10 more UK companies. These additional companies will either become NPL paying customers or will engage in collaborative R&D projects.

13.2. THE PUBLIC FUNDING

The economic rationale for the existence of a publicly-funded organisation like NPL is that measurement R&D is subject to market failure. Indeed, the private investment needed to generate innovative measurement capabilities, will always be below the socially optimal level. This occurs because the benefits that measurement R&D generates will always spill over to firms who did not contribute, and this creates a strong incentive to free-ride (Arrow, 1962). The problem is particularly acute in the case of the R&D that the NPL undertakes, because advances in metrology tend to have applications across many sectors. It is this wide applicability that makes the development of these new tools and techniques particularly susceptible to free-riding. Consequently, it is argued that measurement should really be seen as a public infratechnology (Tassey, 2008), that is, a technology that provides tools and techniques which can be widely applied across a number of sectors to enable further innovation. In short, NPL and its partners' scientific work generates a pool of knowledge that can be accessed and used by any firm. This fact carries a strong incentive to free ride, and thus, there is a clear need for public funding to compliment measurement R&D private spending.

Another key argument to publicly support a specialist laboratory like NPL is that the kind of metrology research it conducts requires the setting up of large facilities. In such cases, the fixed costs could be so high that they exceed the private gains to any one company. Therefore, the facility would never be developed on the basis of individual private funds alone, despite the total benefits from the capability outweighing the cost.

Finally, there is an efficiency justification that supports the idea of a publicly funded metrology laboratory like NPL. Indeed, the high cost and difficulty of maintaining primary standards makes the calibration chain very efficient. NPL supplies a costly high-level instrument calibration service to a commercial laboratory, which then calibrates the instruments of a vast number of users without the need for the calibration laboratory to establish their own primary standard.

13.3. DATA

Data sources

NPL is organised in 17 scientific groups that specialised in different measurement related areas of expertise. These are groups of scientists and engineers who act collectively as a knowledge bank, in the sense that, although some may leave or eventually retire, the labour force remains considerably stable in general terms and therefore the stock of knowledge tends to grow with time.

The internal data utilised in this analysis is routinely collected by NPL administrative and strategy functions to serve monitoring purposes and to support NPL's management and board. This comprises data on NPL's workforce by scientific group and overall finances (particularly income), as well as, invoices to UK businesses and collaborative agreements with partners. Invoices' paying customers names have been uploaded to BVD FAME Database to identify distinct *Company Reference Number* and, thus, get the number of unique UK business that engage in with NPL.

Variables

The resulting dataset consists of a panel of 136 observations (17 groups and 8 years) containing the following variables:

- The number of UK-based firms supported by a given group in a certain year. Supported firms were those that either paid for products and services, or collaborated with NPL in R&D projects.
- The number of scientists and engineers who were working in a given group in a certain year.
- The level of funds from BEIS received by a given group in a certain year.

The following table summarises the variables used in this analysis:

Variable	Abbreviation
Number UK firms who paid for services or engage in R&D projects	*USERS*
Total full-time-employment scientific workers	*STAFF*
BEIS funding (£000s constant prices)	*FUNDS*
Number of paying customers (*USERS*) per FTE scientific workers (*STAFF*)	*users*
BEIS funding (*FUNDS*) per FTE scientific workers (*STAFF*)	*funds*

Throughout the rest of the document these variables will be referred by their respective abbreviations. Note that variables in level are abbreviated in capital letters whereas normalised by FTE workers are lowercased.

Summary statistics

Some basic summary statistics for the variables are shown in the following table:

Variable	Variation	Mean	Std. Dev.	Min	Max	Observations
	overall		33.3	0.0	136.0	N = 136
USERS	between	38.4	33.6	1.0	125.3	n = 17
	within		6.2	16.5	55.9	T = 8
	overall		1207.3	329.1	7695.8	N = 136
FUNDS	between	2489.9	1116.3	901.4	5409.8	n = 17
	within		525.4	1248.8	4775.9	T = 8
	overall		13.0	13.4	91.7	N = 136
STAFF	between	29.8	11.4	19.9	63.6	n = 17
	within		6.7	15.4	57.8	T = 8
	overall		1.1	0.0	5.2	N = 136
users	between	1.3	1.1	0.0	3.7	n = 17
	within		0.4	-0.1	2.8	T = 8
	overall		29.0	12.3	196.6	N = 136
funds	between	85.6	21.2	30.8	117.9	n = 17
	within		20.3	24.8	168.6	T = 8

The main features of the dataset are:

- It is a balanced panel, that is, no observation is missing for any group and year. This means that:
  - Any analysis conducted over this dataset will not suffer from an efficiency loss due to missing information.
  - There is no unobserved characteristic that must be controlled to account for attrition.
- Although there is a non-trivial variation *within* groups level variables, the dataset shows a more appreciable difference *between* the groups.
  - The fundamental source of this *between* variation comes from the internal process through which BEIS funds are split among the 17 scientific groups. Although the goal of this process is to allocate resources based on *anticipated demand*, in practice this is difficult to achieve, and thus, it introduces enough exogeneity to run the analysis.
  - However, it is not possible to perform an individual analysis for each of the groups because the number of observations is not enough to produce robust results.
- Once *USERS* and *FUNDS* are normalised by *STAFF*, the percentage of the *overall* variation coming from *between* the groups is reduced. This is because normalising by STAFF allows for comparisons to be made between groups of very different sizes.

13.4. MODEL

In order to develop a useful theoretical framework that accounts for NPL activity, two key factors need be considered regarding NPL:

- It is an organisation that acts as a vehicle to allocate efficiently the public funds needed to compliment private spending in measurement R&D.
- As a result of its R&D activities, NPL has developed commercially-viable products and services that cover partly for its costs.

Therefore, given that NPL is not a completely self-financing company, its ability to support UK businesses depends to a considerable extent on the public funds received from BEIS. Thus, strong relations between *FUNDS* and both *STAFF* and *USERS* are expected. This means that it is possible to find sensible conclusions despite the small scale of the panel (only 136 observations for 17 groups).

The analysis starts from the following linear relations:

$$\frac{v}{u} = \alpha_0 + \beta_0 \cdot \frac{w}{u} + \varepsilon_0 \qquad (1)$$

$$u = \alpha_1 + \beta_1 \cdot w + \varepsilon_1 \qquad (2)$$

Where the previously defined variables have been represented as letter for the sake of simplicity:

- $v(w, u(w))$ is the number of paying customers of the NPL group (*USERS*),
- $u(w)$ is the number of scientific workers of the NPL group (*STAFF*),
- w is the level of funding received by the NPL group (*FUNDS*),
- and $\varepsilon_i \sim (0, \sigma_{\varepsilon_i})$ with $i = 0,1$ is the error term in both expressions.

In (1), the error term is typically capturing macroeconomic shocks, *i.e.* technology and demand shocks. In (2) the error terms represent random changes in *STAFF* which cannot be explained by *FUNDS*; the retirement of senior scientists, long leaves of some employees, but especially hiring decisions by the group leaders beyond the funding they receive constitute the main sources of randomness.
Differentiating both sides of expression (1) and making use of the quotation rule, we get:

$$\Delta v \cdot u - v \cdot \Delta u = \beta_0 \cdot (\Delta w \cdot u - w \cdot \Delta u)$$

Finally, combining this result with (2), the following expression can be derived:

$$\frac{\Delta v}{\Delta w} = \beta_1 \cdot \frac{v}{u} + \beta_0 \cdot \left[1 - \beta_1 \cdot \frac{w}{u}\right] \qquad (3)$$

Therefore, the effect of *FUNDS* in *USERS* can be split into two different components that depend on the slopes β_0 and β_1.

13.5. ECONOMETRIC ANALYSIS

Effect of BEIS funding per scientific worker on the number of supported companies per scientific worker

In order to explore the effect of *funds* on *users* to compute β_0, two major facts have to be taken into account:

- Independent of the number of scientific workers, BEIS funding allows NPL to reach more companies by leveraging other financial resources and increasing its capital stock.
- NPL conducts a survey of its base of users that shows that approximately 60% of new customers decide to return the following year either to continue with the support programme initiated, or to demand new products and services. This trend evidences a clear inertia in the customer base of the NPL.

Considering these two facts, the following fixed effects model is used to explore the relation between *users* and *funds*:

$$\widetilde{\text{users}}_{i,t} = \gamma_0 + \delta_1 \cdot \widetilde{\text{users}}_{-i,t-1} + \delta_2 \cdot \widetilde{\text{funds}}_{i,t} + \eta_{i,t} \qquad (3)$$

Where the tilde accent in the dependent variable and the regressors stands for the demeaning *within* transformation, that is, $\widetilde{X_{i,t}} = X_{i,t} - \bar{X}_i = X_i - \frac{1}{T}\sum_{t=1}^{T} X_{i,t}$, and the term $\eta_{i,t}$ refers to the composite error term.

The results of the regression are given by output 1 included at the end of this annex[52]. The coefficient δ_2 represents the rate of change of *users* with respect to *funds*; in other words, it shows how the ability to support UK firms per scientist changes with respect the level of funding received per scientific staff. Note that this δ_2 coefficient is equivalent to the coefficient β_0 in the theoretical model[53]. The associated t-statistic shows that it is statistically significantly different than zero at the 99% level of confidence.

A link test[54] is run to check for misspecification in the model (output 2). The motivation behind the link test is the idea that if a regression is specified appropriately you should not be able to find additional independent variables. To test this, the link test regresses the dependent variable of the original regression against the original regression's prediction and the squared prediction. If the squared prediction regressor in the test regression is significant, there is evidence the model is misspecified.

Given that the coefficient for the squared prediction regressor is not statistically significantly different than zero, based on this test we can be confident that the specification is appropriate. Moreover, the coefficient of the prediction regressor is statistically significantly different that zero and close to one; this provides further assurance on this specification.

In other to provide further evidence of the correct specification of the model, the Ramsey Regression Equation Specification Error Test (RESET) (Ramsey, 1969) is conducted. This technique tests whether non-linear combinations of the fitted values have explanatory power over dependent variable. The intuition behind this test is that if non-linear combinations of the

52 All the STATA outputs mentioned in this section are included in the section STATA Outputs at the end of the document.

53 We stick to the short-term effect. The long-term effect coefficient given by $\delta_2/(1-\delta_1)$ is not considered.

54 The test implemented here is based on an idea of (Tukey, 1949), which was further described by (Pregibon, 1980)

regressors have any power in explaining the dependent variable, then the model omits relevant variables and may be better approximated by a non-linear functional form.

```
Ramsey RESET test using powers of the fitted values of FIRMS_FTE
       Ho:  model has no omitted variables
                  F(3, 91) =      6.17
                  Prob > F =      0.0007
```

The test clearly rejects the null hypothesis of no omitted variables. However, given that there are strong theoretical arguments to discard the idea that non-linear functional forms of the regressors have been omitted, a reasonable explanation for the failure of the test is the fact that the units of the analysis, the scientific groups, differ in nature. Indeed, some of them are more commercially focused whereas others are more science intense. Unfortunately, it is not possible to perform a single analysis for each scientific group due to the low number of observations.

Effect of BEIS funding on the number of scientific staff

The effect of *FUNDS* on *STAFF* can be analysed using the following fixed effects model:

$$\widetilde{\mathrm{STAFF}}_{i,t} = \gamma_0 + \delta_3 \cdot \widetilde{\mathrm{STAFF}}_{i,t-1} + \delta_4 \cdot \widetilde{\mathrm{FUNDS}}_{i,t} + \eta_{i,t} \qquad (4)$$

Where, as in the previous case, the tilde accent in the dependent variable and the regressors stands for the demeaning *within* transformation, and the term $\eta_{i,t}$ refers to the composite error term.

As in the previous regression a certain degree of inertia is expected due to the fact that NPL core workforce is stable.

Output 3 in the STATA Outputs section displays the estimate for δ_4, which represents the rate of change of *STAFF* with respect to *FUNDS.* In short, it shows that five additional scientific workers can be hired by the group when it receives £1m additional funding. Note that δ_4, which is equivalent to the coefficient β_1 in the theoretical model[55], is statistically significantly different than zero at the 99% level of confidence.

As in the previous model, a link test has been run (output 4). However, this time the coefficient for the squared prediction regressor is statistically significantly different than zero at the 95% level of confidence. This close fail of the link test can be explained by the fact that we are dealing with level variables in the model, and there are significant differences in group sizes. Nevertheless, due to the limited amount of data available, it is not possible to split the sample group size to address this issue.

The following table shows the results for the Ramsey test:

```
Ramsey RESET test using powers of the fitted values of FTE_TOTAL
       Ho:  model has no omitted variables
                  F(3, 91) =      2.87
                  Prob > F =      0.0406
```

The close fail can be once again explained by the heterogeneity of the groups.

55 Once again, only the short-term effect is considered.

Econometric issues

The previous econometric specifications deserve a few comments:

1) Many factors come into play when assessing how funds are assigned within NPL. It is a complex process involving the top management, the scientific group leaders and external expert oversight. Despite the fact that the goal of this process is to allocate resources based on *anticipated demand* to maximise value delivered to the UK economy, its difficult idiosyncrasy implies it is far from perfect. This means that although funds are not assigned in a complete random fashion, it is a highly imperfect process that introduces exogeneity in the analysis. If there were no policy respond imperfections because the allocation process could foresee perfectly future changes in demand for each group, full endogeneity would cause the previous analysis to be impractical. Therefore, the implicit assumption is that policy respond imperfections in the decision process carry sufficient variation to make the analysis possible.

2) There is a simultaneity issue when assessing the relation between *users* and *funds*, that is, the explanatory variable is jointly determined with the dependent variable. This is a result of the process for resource allocation within NPL. More funds surely feed into a greater ability to support UK firms; however, the more firms a group supports, the more funds it is expected to get. This leads an endogeneity issue and a simultaneity bias by which the explanatory variable is correlated with the error term. This is why to deal with this, the instrumental variable (fixed effects) specification is chosen.

3) To confirm that the specification of the model with a one-period lagged dependent variable as a regressor is indeed adequate, the static model with no lagged variables was estimated. The presence of a strong statistically significant serial correlation in the error term suggests that the proposed dynamic structure is appropriate. In other words, the presence of autocorrelation in the error term for the static model can be seen as clear sign of improper theoretical specification (Beck, 1985) (Hendry & Mizon, 1978) (Mizon, 1977).

4) Since the variables in the model are *observed means*, that is, both *users* and *funds* consist of its respective level variables normalised by *STAFF*, the regression should be weighted to account for the different sizes of each group. This technique is often used in macroeconometrics where is customary to work with panel data of countries. Observations for each country cannot be treated equivalently because countries differ in population. Weighting each observation is required to obtain sensible results. Hence, in this analysis an equivalent procedure has been adopted.

13.6. RESULTS

The effect of NMS funding on the number of UK-based companies that pay for services or engage in collaborative R&D is given by (3):

$$\frac{\Delta v}{\Delta w} = \beta_1 \cdot \frac{v}{u} + \beta_0 \cdot \left[1 - \beta_1 \cdot \frac{w}{u}\right]$$

Where v is the number of paying customers (*USERS*), u is the number of scientific workers (*STAFF*), w is the level of funding received (*FUNDS*), and β_0 and β_1 are the slopes estimated previously:

Parameter	Value
β_0	0.0068 firms/£k
β_1	0.0048 scientist/£k

The following table shows annualised values of the three variables for the period analysed:

Variable	Letter	Annualised Value
USERS	v	652 firms
FUNDS	w	£42.3 million
STAFF	u	506 scientists

Using these values in (3), we get:

$$\left(\frac{users}{funds}\right)' = 0.0048 \cdot \frac{652}{506} + 0.0068 \cdot \left[1 - 0.0048 \cdot \frac{42300}{506}\right] = 0.0103 \qquad (4)$$

Hence, since funding is given in thousands of pounds, this result shows that providing NPL with <u>an additional £1 million per annum of resource funding, enables it to directly support at least 10 more UK companies</u>. These additional companies will either become NPL paying customers or will engage in collaborative R&D projects.

13.7. STATA OUTPUTS

Output 1

```
. regress firms funds L.firms i.YEAR i.GROUP_ID [aweight = FTE_TOTAL], vce(robust)
(sum of wgt is 3,601.39777777778)

Linear regression                               Number of obs     =        119
                                                F(24, 94)         =      70.09
                                                Prob > F          =     0.0000
                                                R-squared         =     0.9084
                                                Root MSE          =     .36094
```

firms	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
funds	.0068233	.0024263	2.81	0.006	.0020058	.0116409
firms						
L1.	.2859645	.1195832	2.39	0.019	.0485291	.5233998
YEAR						
2012	.0116256	.1256568	0.09	0.926	-.237869	.2611202
2013	.0143819	.1175616	0.12	0.903	-.2190393	.2478031
2014	-.0870087	.0928222	-0.94	0.351	-.2713095	.097292
2015	-.0326733	.1004174	-0.33	0.746	-.2320545	.1667078
2016	.0127098	.1235519	0.10	0.918	-.2326053	.2580249
2017	-.1981002	.1041375	-1.90	0.060	-.4048676	.0086672
GROUP_ID						
2	1.275996	.4072076	3.13	0.002	.4674754	2.084516
3	1.211556	.2619097	4.63	0.000	.6915285	1.731584
4	.4420796	.1334377	3.31	0.001	.1771359	.7070232
5	.5450988	.1442251	3.78	0.000	.2587364	.8314612
6	.0960676	.0889866	1.08	0.283	-.0806174	.2727526
7	.9575888	.2183003	4.39	0.000	.5241484	1.391029
8	1.001996	.2055332	4.88	0.000	.5939049	1.410087
9	2.176081	.5322312	4.09	0.000	1.119324	3.232839
10	-.0155047	.138603	-0.11	0.911	-.2907043	.2596949
11	.8470184	.2221356	3.81	0.000	.4059629	1.288074
12	1.365431	.3361592	4.06	0.000	.6979793	2.032883
13	.9004146	.2609426	3.45	0.001	.3823069	1.418522
14	1.565979	.3071179	5.10	0.000	.9561896	2.175769
15	-.339723	.130386	-2.61	0.011	-.5986075	-.0808385
16	-.1908368	.0888637	-2.15	0.034	-.3672778	-.0143958
17	.1293318	.0836237	1.55	0.125	-.036705	.2953687
_cons	-.3135722	.196478	-1.60	0.114	-.7036838	.0765394

Output 2

```
. linktest
(sum of wgt is 3,601.39777777778)
```

Source	SS	df	MS
Model	121.464705	2	60.7323524
Residual	12.1735583	116	.104944468
Total	133.638263	118	1.13252765

```
Number of obs     =        119
F(2, 116)         =     578.71
Prob > F          =     0.0000
R-squared         =     0.9089
Adj R-squared     =     0.9073
Root MSE          =     .32395
```

firms	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
_hat	.9375691	.0805955	11.63	0.000	.7779395	1.097199
_hatsq	.0189917	.0228277	0.83	0.407	-.0262215	.0642049
_cons	.0293766	.05948	0.49	0.622	-.088431	.1471842

Output 3

```
. *Ouput 3
. reg STAFF FUNDS L.STAFF i.YEAR i.GROUP_ID, vce(robust)

Linear regression                               Number of obs     =        119
                                                F(24, 94)         =      41.17
                                                Prob > F          =     0.0000
                                                R-squared         =     0.8908
                                                Root MSE          =     4.9253
```

STAFF	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
FUNDS	.004819	.001515	3.18	0.002	.001811	.007827
STAFF						
L1.	.5286321	.1423023	3.71	0.000	.2460875	.8111768
YEAR						
2012	.2177662	1.560492	0.14	0.889	-2.880626	3.316159
2013	1.012106	1.336965	0.76	0.451	-1.642469	3.666681
2014	.0875837	1.678102	0.05	0.958	-3.244327	3.419494
2015	1.011554	1.495994	0.68	0.501	-1.958776	3.981884
2016	-.0509346	1.817021	-0.03	0.978	-3.658672	3.556803
2017	3.824584	1.664567	2.30	0.024	.5195483	7.12962
GROUP_ID						
2	.7604716	1.831319	0.42	0.679	-2.875655	4.396598
3	7.122045	2.61167	2.73	0.008	1.936514	12.30758
4	.772707	1.798789	0.43	0.668	-2.79883	4.344244
5	4.664362	5.283869	0.88	0.380	-5.826883	15.15561
6	3.571558	3.121797	1.14	0.255	-2.626843	9.76996
7	-.2900414	2.313528	-0.13	0.901	-4.883605	4.303522
8	5.270808	3.603963	1.46	0.147	-1.884945	12.42656
9	-5.929221	5.05181	-1.17	0.243	-15.95971	4.101266
10	-2.732305	2.376078	-1.15	0.253	-7.450064	1.985454
11	.9370208	2.742609	0.34	0.733	-4.508493	6.382534
12	-4.032191	2.276956	-1.77	0.080	-8.553141	.4887594
13	.4843865	2.23989	0.22	0.829	-3.962968	4.931741
14	-4.189619	2.176567	-1.92	0.057	-8.511245	.1320058
15	-2.831159	3.558386	-0.80	0.428	-9.896418	4.234101
16	2.212216	3.006577	0.74	0.464	-3.757413	8.181846
17	1.487048	2.186471	0.68	0.498	-2.854241	5.828336
_cons	1.662415	2.574788	0.65	0.520	-3.449887	6.774717

Output 4

```
. linktest
```

Source	SS	df	MS
Model	18673.9803	2	9336.99016
Residual	2205.63261	116	19.0140743
Total	20879.6129	118	176.945872

```
Number of obs     =        119
F(2, 116)         =     491.06
Prob > F          =     0.0000
R-squared         =     0.8944
Adj R-squared     =     0.8925
Root MSE          =     4.3605
```

STAFF	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
_hat	.7266646	.1415873	5.13	0.000	.446233	1.007096
_hatsq	.0033758	.0017035	1.98	0.050	1.82e-06	.0067499
_cons	4.65261	2.570647	1.81	0.073	-.4388815	9.744101