International Transport Forum

Managing the Transition to Driverless Road Freight Transport

Case-Specific Policy Analysis

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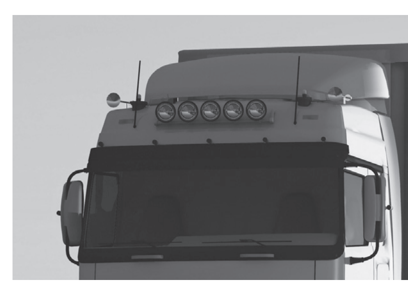

Case-Specific Policy Analysis

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Case-Specific Policy Analysis Reports

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Executive summary

What we did

This report explores how a transition to driverless trucks could happen. Reduced reliance on humans to move road freight offers many benefits. It also threatens to disrupt the careers and lives of millions of professional truck drivers. Based on different scenarios for the large-scale introduction of automated road freight transport, this study makes recommendations to help governments manage potential disruption and ensure a just transition for affected drivers.

Three leading transport-sector organisations joined the International Transport Forum for this project to assess benefits, costs and risks of a transition to driverless trucks. The International Road Transport Union, the International Transport Workers' Federation and the European Automobile Manufacturers Association contributed insights on driverless technology in the road freight sector as well as funds for the research.

What we found

Driverless trucks could be a regular presence on many roads within the next ten years. Self-driving trucks already operate in controlled environments like ports or mines, and trials on public roads are under way in many regions including the United States and the European Union. Manufacturers are investing heavily into truck-automation technology while many governments are actively reviewing their regulations to understand what changes would be required to allow self-driving vehicles on public roads.

Automated trucks would enable cost savings, lower emissions and safer roads. They could also address the emerging shortage of professional drivers faced by the haulage industry, particularly in Europe. Without driverless trucks, around 6.4 million truck drivers are projected to be needed across Europe and the United States (US) by 2030, yet fewer than 5.6 million are projected to be available and willing to work under current conditions. The majority of truckers are in the later stages of their careers, while few women and young men are choosing trucking as a profession.

The adoption of driverless trucks is likely to reduce demand for drivers at a faster rate than a supply shortage would emerge. Of the 6.4 million driver jobs in 2030, between 3.4 and 4.4 million would become redundant if driverless trucks are deployed quickly. Even accounting for prospective truck drivers being progressively dissuaded by the advent of driverless technology, over 2 million drivers across the US and Europe could be directly displaced by 2030 in some of the scenarios examined for this study.

Preparing now for potential negative social impacts of job losses will mitigate the risks in case such a rapid transition occurs. While truck drivers are typically flexible, self-reliant and able to concentrate for long periods, their relatively low education level and potential automation in other sectors puts them at a high risk of extended periods of unemployment. Support available to displaced workers in developed economies may prove to be inadequate given the potential speed and scale of job losses. Active management of the transition will likely be needed to smooth the introduction of driverless technology, avoid excessive hardship for truck drivers, and ensure the gains from the technology are fairly shared across society.

What we recommend

Continue driverless truck pilot projects to test vehicles, network technology and communications protocols

Governments, industry and researchers should continue to advance tests on public roads in designated corridors and areas for trialling vehicles, network technology and communications protocols. This way various technologies are able to be tested without committing to an individual company, standard or technology early in the development process, ensuring that expensive network-wide investments are not wasted or over-specified. This will help ensure societal benefits from automated road freight transport will be maximised.

Set international standards, road rules and vehicle regulations for self-driving trucks

Harmonisation of rules across countries is critical for maximising the gains from driverless truck technology. Common vehicle standards and operational rules would allow smooth cross-border movements of autonomous trucks and should be put in place at least at a continental level, preferably at the global level. The proactive approach of many governments to test permits and ad hoc exemptions to road rules allows different approaches to be tested in parallel which can speed up the maturing of the technology. However, such competition entails the risk of insufficient attention on the ultimate goal of harmonisation.

Establish a temporary transition advisory board for the trucking industry

Governments should establish a transition advisory board for the trucking industry to advise on labour issues associated with the introduction of driverless trucks. The board should be temporary and include representatives from labour unions, road freight businesses, vehicle manufacturers and government. It would support the government in choosing the right policy mix to ensure that costs, benefits and risks from automated road haulage are fairly distributed.

Consider a temporary permit system to manage the speed of adoption and to support a just transition for displaced drivers, while ensuring fair access to markets

Governments should consider a mechanism to shape the transition to driverless trucks. A permit system would offer influence over the speed of uptake as well as revenue to support displaced drivers. Where economy-wide unemployment support is considered inadequate, additional assistance could come in the form of targeted labour market programs to try to re-deploy drivers. It could also take the form of additional income replacement payments where alternative employment opportunities have also been reduced by automation. For reasons of fairness, funds for transition assistance should be generated by the main beneficiaries of the operation of driverless trucks. The sale of permits to operators experiencing operating cost reductions could be complemented by contributions of all road users who will benefit from improved safety. Careful design of the permit system would ensure that permits are used to manage the labour transition fairly and not as a proxy to limit the free movement of goods.

Introduction and motivation for the study

Technology in road freight

A wide range of technologies has been introduced into cars and trucks in recent decades. For example, anti-lock braking systems, which are now standard in new cars sold in the European Union (EU) and United States (US), have been shown to improve on-road stopping distances (NHTSA, 1999). In-vehicle navigation units have removed the need for drivers to consult paper maps. Together these and other developments have improved the safety and ease of driving and helped improve the labour productivity for the road freight industry.

More recently, technologies that can further support, and even take over some aspects of, the driving task have been made available in cars and trucks. Driver assistance systems currently deployed in new vehicles are capable of monitoring blind spots when changing lanes, automatically manoeuvring a vehicle into a parking space, and adapting the vehicle's speed to a safe distance from the vehicle in front (Frisoni et al., 2016). At the same time, driverless truck systems have been deployed on mine sites in Western Australia and at the Port of Rotterdam (Diss, 2015; Allen, 2015). Trucks are currently also being tested on the interstate highways of Nevada in the US, where the driver is only required to take control of the vehicle in an emergency or when changing lanes (Grobart, 2015).

Research and development in the automotive industry (and broader technology industry) is currently directed at technology that can take over even more aspects of the driving task. Although significant progress is still required before fully driverless operation on the open roads could be deployed, such technology is at least a realistic prospect in coming decades and therefore demands attention.

Motivation for the study

Many studies have explored the complex technological and regulatory issues associated with a wide variety of automated vehicle technologies, especially for private cars. However, fully driverless truck technology is a specific challenge with somewhat unique motivations and impacts. In particular, driverless trucks would have a highly disruptive impact on the lives and careers of current (and future) heavy vehicle drivers. So there is a clear need for an evidence base and a plan to manage disruptions to people's lives and livelihoods if and when driverless trucks are taken up. As trucking roles evolve, it will also be important that the industry can equip its people with the right skills.

Labour currently accounts for an estimated 35 to 45% of operating costs of road freight in Europe (Panteia, 2015). Further, restrictions on the time a driver can drive for over a given day or week limit the speed and reach of long-distance road freight, where individual drivers are allocated to each truck. At the same time, road freight operators can struggle to attract drivers to undertake such long-distance trips. Clearly the possibility of dramatically reducing labour input costs and relaxing the driving-time constraints on vehicle productivity would be of great interest to road freight businesses and their ultimate customers. More broadly, driverless truck technology offers the possibility for improved safety, fuel efficiency, asset utilisation and environmental performance. However, the timing and regulatory acceptance of driverless truck technology is still highly uncertain.

Scope and approach to study

This study aims to build on the extensive recent research into driverless vehicle technology in the particular areas of driverless road freight (on public roads) and the labour implications of applying such driverless technology.

The geographical scope of the study is limited to road freight in Europe and the US. This limit is only applied due to practical limitations on research resources available, as we recognise that significant progress in the field is being made in other jurisdictions and in other sectors, for example the automated trains and mining vehicles being applied in Australia.

The approach taken in this study was to review a broad range of literature, which was supplemented with consultation with industry project partners and quantitative analysis of road freight labour markets. Development and adoption of driverless trucks is necessarily subject to significant uncertainty so the analysis is based on realistic scenarios rather than deterministic approaches. The ultimate focus of the study is on labour issues: to understand the implications of driverless truck scenarios on the prospects for human drivers and hence to explore possible pragmatic pathways to a just transition towards this new technology.

The remainder report is structured as follows. The second chapter explores what is meant by driverless trucks and how they might be developed, applied and taken up by the various actors in society: businesses supplying the technology, road freight operators deploying the technology and governments who should decide if and on what terms the technology can be operated on open roads. The third chapter sets out possible scenarios for the timing and speed of the deployment of driverless trucks. The fourth chapter considers the implications of driverless technology scenarios for the employment of human drivers. The fifth chapter considers the employment opportunities available to human drivers displaced by the technology. The final chapter considers the policy implications: should government intervene in the market to speed up or slow down the adoption of driverless trucks, and should displaced drivers be given assistance to support them in their transition?

Towards driverless road freight

Defining driverless trucks

The field of intelligent transport systems is a minefield of acronyms and technological concepts, for some of which there is no full agreement on definitions (Frisoni et al., 2016). This section provides some clarity by defining key concepts and describing a potential operating environment for driverless trucks on public roads.

Concepts

This study's narrow focus is on technologies that support trucks operating without drivers means we mainly need to consider: the *automation* of dynamic driving tasks; reaching *fully automated* driving; and vehicle *connectivity*, though these concepts apply equally for all vehicles – trucks, buses and passenger cars.

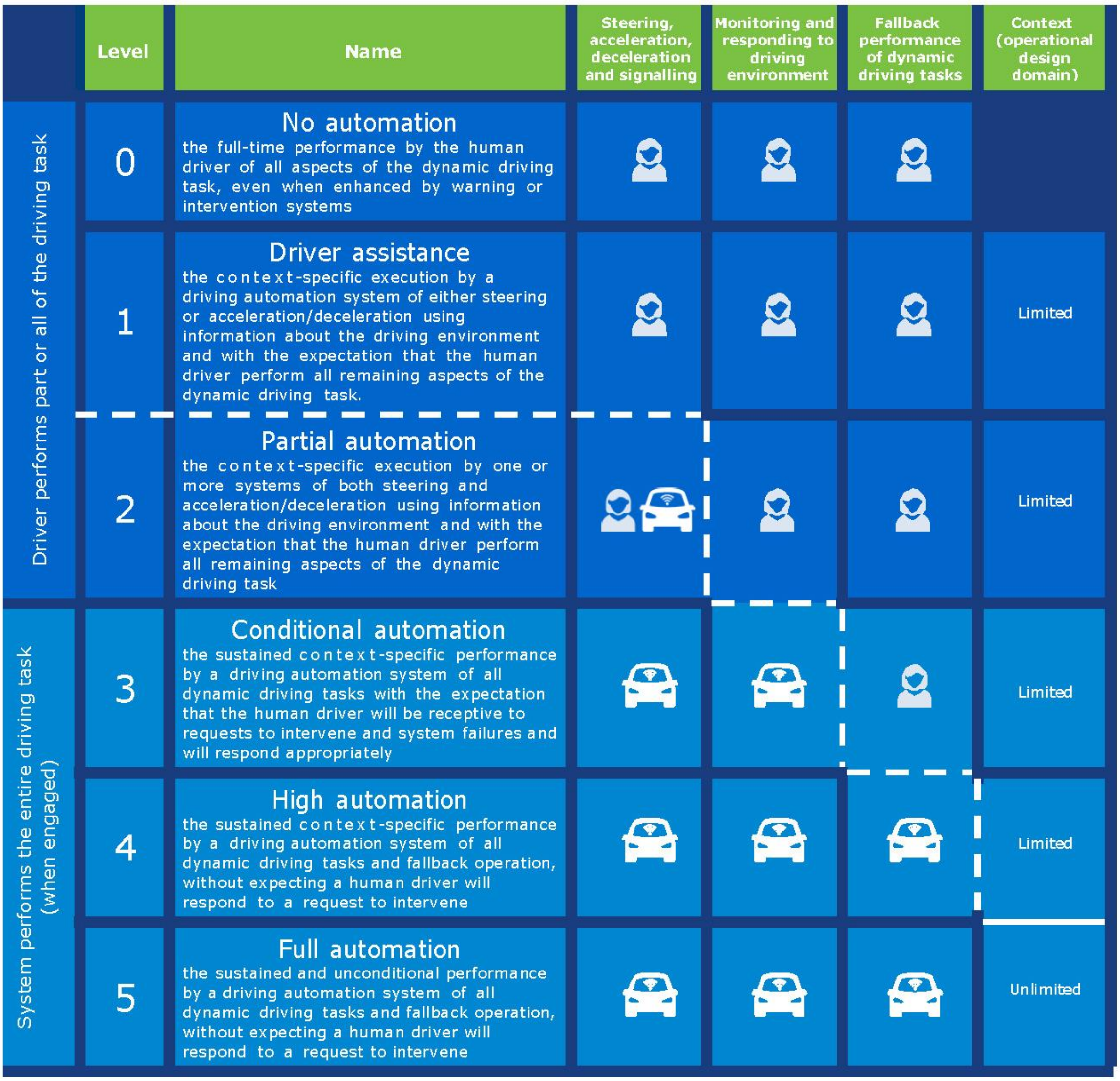
Automation of driving tasks means that they are undertaken by computer-based systems rather than a human driver. Automation can be described either in terms of automation features, e.g. "can a system automatically regulate a safe distance to the vehicle ahead?", or in terms of capabilities, e.g. "can a collection of systems conduct the overall driving task without human intervention?"

The AdaptIVe industry and EU research initiative takes the features approach and has developed a full conceptual framework that describes and names all automation building block features, such as parking assistance (Bartels et al., 2014). In contrast, SAE International (2014; 2016), an international association of engineers, developed a framework for describing the overall capabilities of vehicles. The widely accepted SAE framework identifies levels of automation from "no automation" (level 0) to "full automation' (level 5) based on the extent to which the major functions of the driving task are automated, as well as the contexts and situations in which a human driver is required to take control, i.e. the system's "operational design domain" (Figure 1).

Intermediate levels of automation (e.g. level 3) may require drivers to take control of the vehicle only very occasionally in the event of an emergency. In such a situation, it is possible that drivers would not tire as quickly as a driver that is undertaking most of the driving tasks. While it is technically possible that the length of driver shifts could be safely extended, project stakeholders were strongly of the view that the rules governing the length of shifts would not change in response to the availability and adoption of such "conditional automation" systems.

As such, only levels 4 and 5 are of direct interest to this study. All lower levels of automation will always require a human driver to be able to take control of the truck. There would be no significant labour implications unless the technology reaches a stage where drivers are not required to be on-board the truck. SAE levels 4 and 5 describe *fully automated* driving. Here a vehicle's on-board systems can collect and respond to sufficient external information to allow the vehicle to safely operate without human input. The key distinction between the two levels is that level 5 describes a set of systems that is able to automatically operate the vehicle in *any* situation (ITF, 2015). Level 4 is the most realistic target for investigations in this report: when the "full automation" threshold is crossed, it is likely to be for a specific set of contexts or domains, such as operating on motorways or in fine weather only. Different contexts for fully automated operations are described in the following section.

Figure 1. **Levels of driving automation: Who does what?**



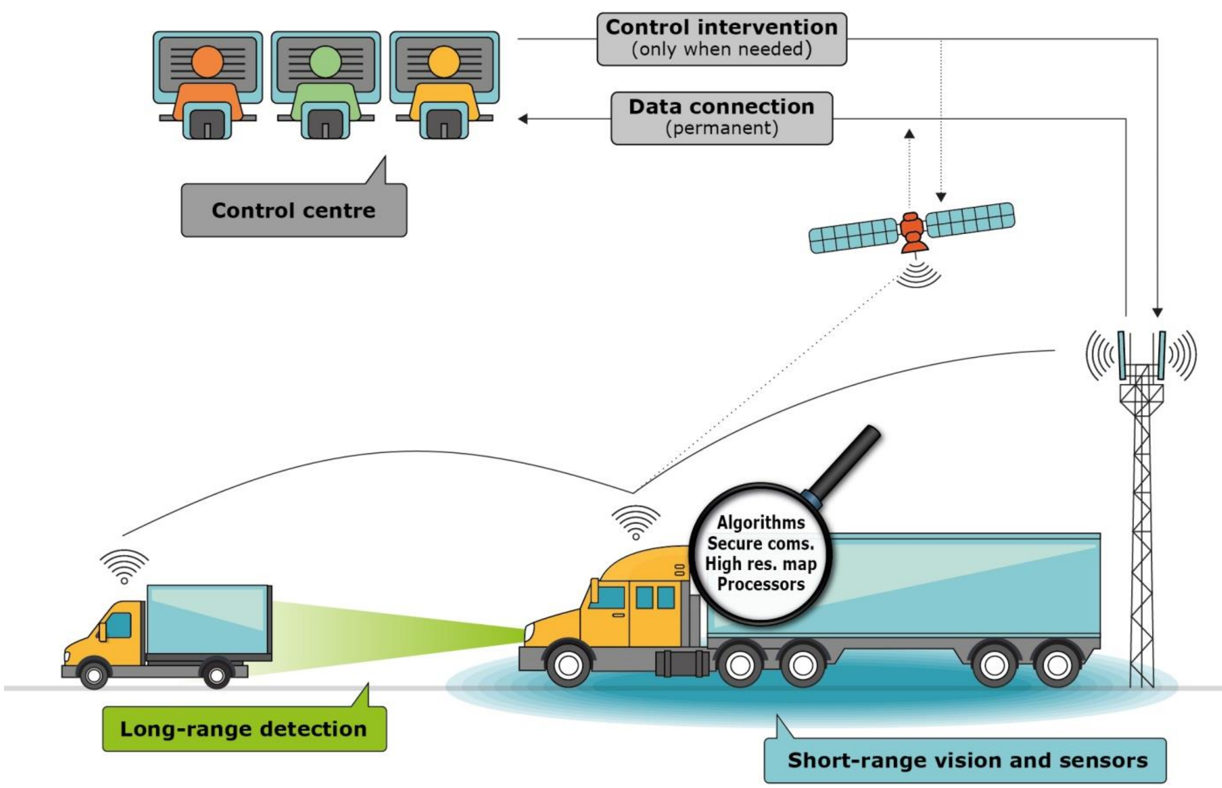
Source: Adapted from SAE (2016) and ITF (2015, p. 14).

One of the potentially critical determinants of whether a vehicle can operate automatically without a driver is *connectivity*. On-board systems of a fully automated vehicle can either perform driving tasks by acting *autonomously*, or by communicating with surrounding vehicles, hand-held devices such as smart phones or traffic infrastructure (ITF, 2015; Frisoni et al., 2016). Autonomous operations would have much lower supporting infrastructure requirements (and could operate without all vehicles on the road being connected) but would need higher order intelligence on-board the vehicle, since it would not be able to rely on real-time information transmitted from external information sources. Google is currently investigating cars that can operate autonomously (without a full-time connection to other vehicles or the internet), while other researchers consider a connected solution much more likely to prevail (Frisoni et al., 2016). Compared to a connected system, the autonomous system would be more resilient due to decentralised decision making and operations.

The driverless truck operating environment

There is no consensus yet on the configuration of hardware and software that will underpin fully automated driverless truck operation. This will ultimately be determined by the interplay of supply, demand and policy factors described below. Based on the current state of the technology, Figure 2 presents a simplified potential end state for the operating environment of driverless trucks. This operating environment considers a hybrid operating model where the trucks do not have hands-on or fall-back drivers within the cabin, but instead the fleet is connected to a pool of experienced remote drivers in a control centre who are able to intervene and remotely control a given vehicle in case of emergency. These remote drivers could be in place as a necessity (level 3 conditional automation) or as risk mitigation for higher levels of automation (level 4 or 5).

Figure 2. **Stylised driverless truck operating environment (with optional Control Centre)**



The three main components of a fully automated truck's potential operating environment are its on-board systems, supporting infrastructure and the (remote) control centre. As noted above, fully autonomous vehicles would require less supporting ICT infrastructure, but that puts much stronger emphasis on the on-board systems.

- On-board systems comprise (BCG, 2015):
  - sensors to observe the dynamic driving environment including the roadway, signage vehicles, other road users and obstacles
  - processors, operating system and algorithms to figure out how to respond to environment and send commands
  - actuators such as steering and brakes to implement commands
  - internet connection to receive dynamic “around the bend” information on driving environment (where available) as well as periodic software updates
  - detailed maps of the static driving environment.
- Infrastructure comprises:
  - roadway, signage and signals that govern the physical operating environment for the vehicle
  - information and communications technology outside the vehicle, including mobile and/or satellite connectivity. Unless vehicles are operating autonomously, this network would need to cover the entire route or driverless operating domain.
- Control centres could comprise:
  - monitoring system to check performance, location and situation of the vehicle fleet
  - (possible) control system to enable manual over-ride of on-board systems
  - (possible) remote driver(s) to operate control systems if manual over-ride of on-board systems is desired.

Potential applications for driverless trucks

Before we consider how, when and why fully autonomous trucks might become available, we first explore how and where the technology might be applied by the road freight industry.

Contexts

For fully autonomous vehicles, context is everything. Systems are already available and legally operating in relatively undemanding domains: from controlled and carefully-mapped mine sites to low-speed airport personal transit pods running on closed guideways.

The ITF Corporate Partnership Board (2015) suggests that there are five critical dimensions that collectively define the context in which driverless operations may be achieved:

1. Geographic areas – this covers different jurisdictional borders, as well as distinctions between private and public roadways, and urban versus rural settings.
2. Roadway types – ease of automation will vary widely among road surfaces (from loose gravel to asphalt), presence of lane markings, number of lanes, quality of signage, road layout (e.g. grade separation, signalisation, or roundabouts).

3. Traffic conditions – safety and ease of automation will vary widely with different maximum speeds, traffic volumes, traffic mixes (especially whether pedestrians and cyclists are present).
4. Weather conditions – heavy rain, fog or snow affect traction and visibility that can make automation more difficult than in clear weather.
5. Incidents – human drivers are able to understand and respond to a very wide range of events that occur while driving (e.g. braking if a ball emerges from behind parked cars in a suburban street since they would understand there is a high risk that a child may come running after it). It would be difficult to fully program into software since the possibilities for such rare and complex real events are nearly endless.

To achieve driverless operations, vehicles will need to cover a very high proportion of conceivable traffic conditions, weather conditions and incidents to satisfy regulators. For most contexts other than closed areas at low speed, there is still a great deal of progress needed to reach this stage. However, progress across these dimensions will not be uniform across geography (since conditions and regulations will differ across countries and states) and road types (since some roads have distinctly easier conditions for automated functions to deal with). The operational design domain will, at least initially, be limited.

For the purposes of this study, we simplify the diversity down to two overall contexts where the possibility of operating driverless trucks is profoundly different: long-distance interurban freight and urban freight.[1] Long-distance interurban freight is assumed to generally travel on mostly grade-separated rural and regional routes where interaction with pedestrians and cyclists is generally very limited. From a safety perspective, fatigue and speeding are major contributors to heavy vehicle crashes for long distance trips, so the motivation for automation of this task would be particularly strong. In contrast, urban freight covers travel within towns and cities where there is much greater variation in the traffic mix and road types, including navigating traffic signals, pedestrian crossings, roundabouts, diverse signage, driveways, etc. Discussions with freight industry stakeholders suggest that automation on long-distance motorway routes was likely to be dramatically more achievable in the medium term than for (full speed) freight movements in urban areas (see following section).

Platooning

Much of the progress towards truck automation in recent years has been made by connecting and co-ordinating platoons of closely spaced vehicles (see Box 1). Platooning involves a lead truck whose human driver navigates traffic, with a number of trailing vehicles automatically undertaking the steering and braking required to maintain a safe (mostly fixed) distance between the vehicle in front (ITF, 2015). Tests of platooning have generally been undertaken on motorways.

While there are certainly possibilities for platooning to reduce crashes, fuel and labour costs of a given set of trips, for this study the main interest is in the possibility of driverless operation of trucks. However, current legislation in all jurisdictions requires that a human driver is present in any vehicle, even if it is a trailing vehicle in a platoon. In other words, platooning by itself will not enable driverless operation (for the trailing vehicles); all of the technical and legislative hurdles required for any kind of driverless operation will also be required of driverless platooning specifically.[2] If these hurdles were cleared, driverless platooning would offer a very appealing application of driverless truck technology, and may see the emergence of new forms of collaboration across truck operators, such as scheduled platooning or a platooning service provider (Janssen et al., 2015).

Box 1. **Case study: European Truck Platooning Challenge**

During its presidency of the EU, the Netherlands organised the European Truck Platooning Challenge. The aim was to promote the implementation of truck platooning in cross-border road freight transport on the European scale. This was seen as necessary so as to reduce the risk of countries creating a patchwork of rules and regulations, which ultimately could hinder manufacturers and road users from investing in automated and connected vehicles. It included a cross-border demonstration event with participation of six brands of automated trucks – DAF Trucks, Daimler Trucks, Iveco, MAN Truck & Bus, Scania and Volvo Group. The automated trucks of the various brands drove in platoons on public roads from various European locations to the Netherlands (Figure 3).

Figure 3. **Truck platoon trial in Europe**

Source: https://www.eutruckplatooning.com

Control centres

No driving system can ever be 100% safe, whether humans or computerised systems are in charge. Nevertheless, in well-defined situations such as on motorways, automation technology may soon get to a point where computerised systems can safely and autonomously handle driving tasks at least as well as humans. However, there is no clear-cut crash performance that would satisfy the safety concerns of regulators or general road users for operation without a driver in the cabin. In in terms of the SAE framework, it is not obvious where the legal line will be drawn between level 3 (where a human driver will be needed) and level 4 (where a human driver is not technically required). This real and perceived issue may be solved by regulators setting a specific risk-based rule that prospective systems could need to demonstrate to be accredited for driverless operation. Alternatively, the current approach proposed by the National Highway Traffic Safety Administration (NHTSA, 2016a) is to allow vehicle manufacturers to develop their own methodology for demonstrating safety outcomes, including the metrics to demonstrate safety performance. Even under this point, a decision will need to be made on the acceptable level of crash performance of driverless systems once applications begin being assessed.

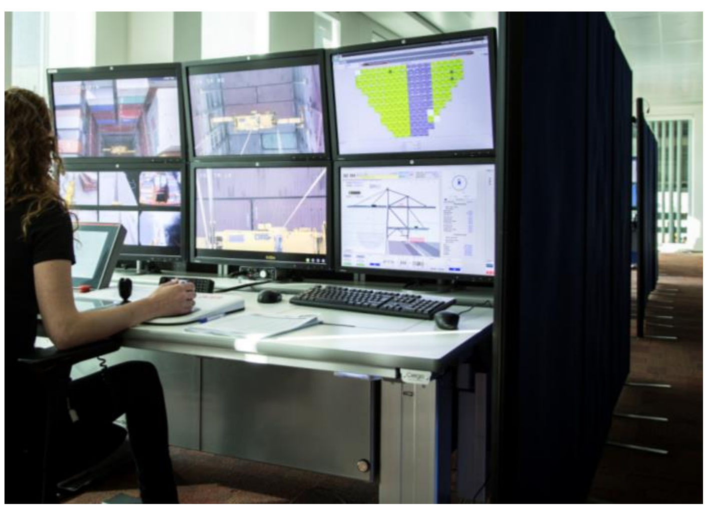
An intermediate solution to the crash performance issue could be to allow fall-back performance of driving tasks to be allocated to drivers in a remote control centre rather than within the cabin. This kind of approach is used for the operation of low-speed driverless WEpod minibuses in the Netherlands and the driverless mining vehicles in Australia's northwest that are controlled in a centre 1 200 kilometres away (Somers and Weeratunga, 2015). If such an approach was implemented for trucks on motorways, drivers would be taken out of cabins and a much lower number of drivers would be on hand in the control centre to take control of a vehicle if an incident arose that the computerised system could not handle.

Box 2. **Case study: Automation at the Port of Rotterdam**

The Port of Rotterdam is the largest port in Europe and one of the largest in the world. As trade volumes and the scale of operations at the port expanded over the decades, various terminals have been automated since 1993, when the ECT terminal was automated. In this terminal, the cranes used to stack containers in the yard and the vehicles used to transport containers between the yard and quay are all automated. These automated processes are supervised in a remote control centre. Some have argued that a shortage of vehicle drivers, a desire to reduce the influence of unions, and the need to increase productivity to process larger ships have motivated this push towards terminal automation (Stojaspal, 2016; Keefe, 2015).

A new element to port automation was added in the Rotterdam World Gateway (RWG) and APM terminals at the Maasvlakte 2 of the Port of Rotterdam, operational since 2015. In these terminals the ship-to-shore cranes are monitored and operated by "remote crane operators" from an air-conditioned office using computer screens and joysticks (Figure 4; Economist, 2016a). This does not represent additional automation as it has only meant relocating crane drivers physically from a crane to an office, though some experts have speculated that remote crane drivers might in the future be able to handle two cranes at the same time. To date, both Maasvlakte 2 terminals have been unable to achieve the same berth productivity as the other container terminals in Rotterdam still operating with conventional ship-to-shore crane operators.

Figure 4. **A remote control centre for operating containter terminal cranes**



Source: Rotterdam World Gateway.

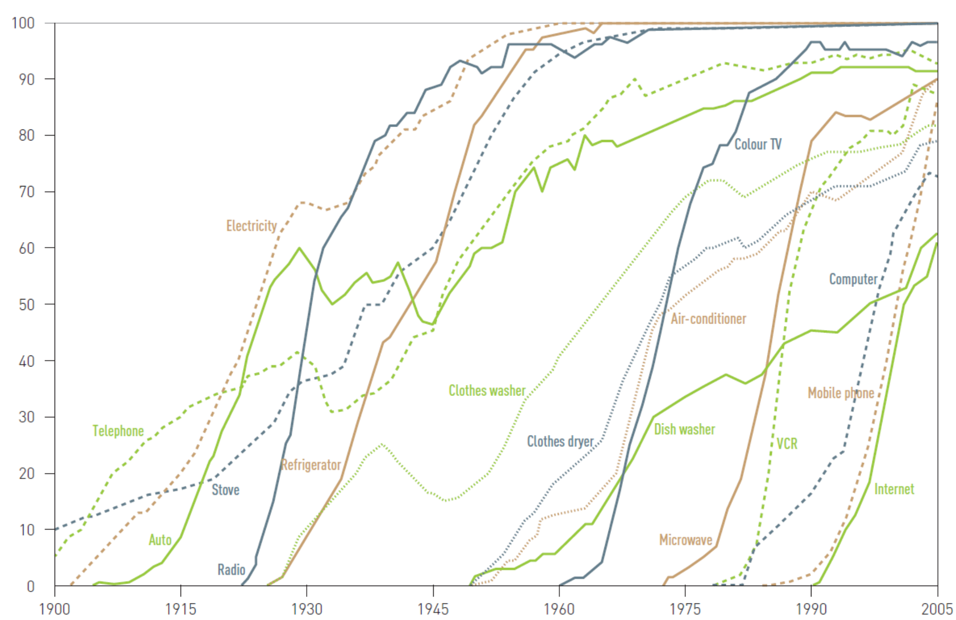
The control centre model could blur the hard distinction between SAE levels 3 and 4, since technically a human driver would still be available to take control at short notice. At either level, the control centre model for "driverless" operation could dramatically reduce the labour requirement for the driving task. The extent of the reduction depends on the ratio of drivers to trucks on the road. This ratio in turn would depend on the risk aversion of the regulator or operator and the degree of correlation across incidents. If regulators were more risk averse and/or if incidents tended to happen all at once (e.g. during a snow-storm or a system-wide software failure), then more drivers would be needed in the control centre for a given operating fleet. But it is conceivable that the concept could be introduced at a relatively high ratio (say 1 to 3) and then, based on empirical data from the frequency and simultaneity of calls to the human remote drivers in its own operation, could receive regulatory approval for gradually lowering the ratio.

The control centre model for motorway operations appears to be a feasible early application of high automation truck technology. The potential labour cost savings from such a remote control centre model would be attractive to road freight operators, while the fall-back availability of drivers could allay public and regulatory concerns about purely driverless technology (discussed further in the next section). The remote control centre model has been used in various automated container terminals, following the example of the Port of Rotterdam (Box 2).

Building blocks of driverless trucks availability and adoption

The successful adoption of any new or innovative technology usually follows a certain pattern: uptake is initially slow, but at some point the product takes off rapidly, spreading through the market before ultimately levelling out at a high level of penetration. This can best be characterised by an S-shape or sigmoid function. While the speed of adoption may differ, the trajectory for a diverse set of technologies all broadly follows this S-pattern (Figure 5). Also of note is that the adoption of a technology generally does not reach 100% market penetration, because competing technologies are available or because the technology is not considered universally essential.

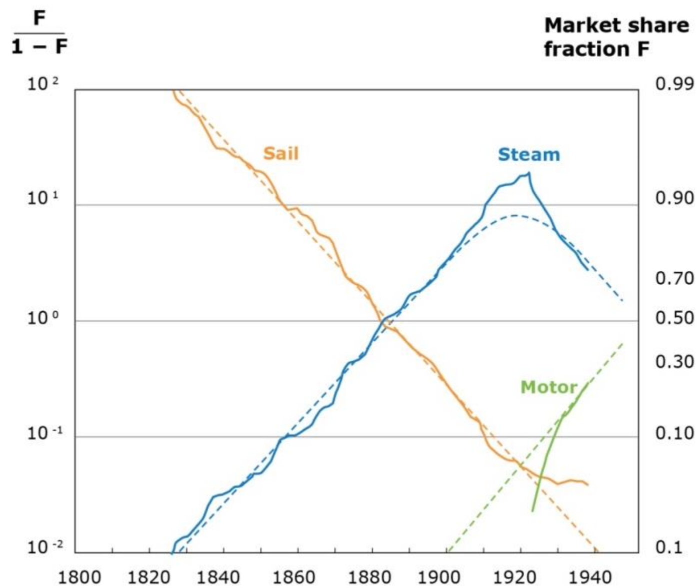
Figure 5. **Technology adoption curves for modern innovations among US households (% of total)**



Source: State Government of Victoria (2013, p. 18, Figure 8).

Innovation adoption rates can differ across sectors of the economy, but also depend on the characteristics of the specific technologies. For example, investment costs can be substantial in the maritime sector, so it can take 100 years until the adoption reaches its maximum, while adoption of new consumer good technologies can be a lot faster (Figure 5). In the transport sector, the dramatic changes in maritime transport over the 125 years leading up to the Second World War provides a vivid example of the transmission of a new technology and the ultimate limits to adoption over time as new technologies emerge (Figure 6).

Figure 6. **Share of gross tonnage in the UK's commercial fleet prior to World War 2 (logarithmic scale)**



Source: Adapted from Grubler (1990, p.87).

From the perspective of the innovators (e.g. vehicle manufacturers), three main types of factors influence the rate of adoption of a new technology: supply, demand and policy (Horbach, 2008; Erzurumlu and Erzurumlu, 2013; Triguero et al., 2013). In the following sections, the outlook for each of these supporting factors is considered for the case of driverless road freight.

Supply side: Technological progress and supply

The most obvious requirement for adoption of driverless technology is demonstrating its technical feasibility. The remaining technical hurdles to driverless trucks cannot be overcome without well-funded research and development (R&D). In recent years, there has been deep and sustained R&D spending in the field of automated and driverless vehicle technology. The global spending on R&D activities in 2015 by the automotive industry was estimated by PwC (2015a) at USD 109 billion, including USD 47 billion in Europe and USD 18.5 billion in North America. While not all of this spending will be on automation technology, a significant proportion would be in this field (Frisoni et al., 2016). At the same time, public sector organisations and academia have also been heavily engaged in supporting and undertaking R&D.

The stakes are high in the race to develop driverless vehicles. Worldwide, around 90 million vehicles are produced and sold annually, including over 23 million new commercial vehicles (OICA, 2015). For the incumbents, the risks of not being one of the first to market are profound: their domestic and regional markets could be swamped by an international rival; or the entire incumbent pool risks being disrupted by a new entrant. Yet at the same time, there are reasons to resist the new technology: investments in large plants producing conventional vehicles may need to be re-valued or re-configured, while fewer fully driverless vehicles would be required to service any given freight demand. For the disruptors, there is a massive potential to enter a previously untapped business, but also the opportunity to exploit synergies with their own core businesses. For example, Google would be able to obtain extremely rich data on consumer preferences and activities that could be useful in targeted advertising, while Uber would be able to dramatically expand demand for its services if driver costs were eliminated.

The risks and payoffs from driverless vehicles are broadly reflected in the two development paths explored by the incumbents and potential disruptors. The incumbents (vehicle manufacturers and automotive suppliers) are generally[3] following a strategy of incremental automation, expanding the number of driving tasks that can be automated. This strategy has been characterised as the "something everywhere" approach since they would provide support to drivers, wherever they were (ITF, 2015). In contrast, the disruptors (primarily information technology companies) are seeking to bypass partly automated vehicles to produce fully driverless systems. This strategy is the "everything somewhere" approach since such driverless vehicles will at least initially be constrained to specific operating contexts, such as defined routes or low operating speeds.

Even if the technical challenges to fully driverless systems had already been overcome, driverless vehicles could still not be legally operated on public roads under current laws in the US and EU.[4] To convince law-makers to accommodate driverless systems within the road rules, driverless technologies will need to be tested and their safety performance characteristics demonstrated. Crash liability will need to pass from the driver of the vehicle to the manufacturer and/or systems provider. And new approaches to vehicle regulation may be required to assess roadworthiness of driverless vehicles in a way that takes full advantage of the proliferation of new sensor data that will be generated in testing and operation (ITF, 2016a). Overall, the legal pathway towards the legal accommodation of these trucks in the market is not clear-cut and is likely to vary from jurisdiction to jurisdiction. Further dialogue at the national and international level will help to develop and harmonise performance thresholds for innovators to work towards.

A further supply issue is whether vehicle manufacturers would be able to meet the demand for these vehicles initially, if technical and legal obstacles were overcome. It is likely that, in the short-term at least, production constraints would emerge while plants shift from prototype production to full-scale commercialisation. The cost advantages expected to be offered by driverless operations compared to conventional trucks could result in some competition issues emerging in the period immediately after driverless trucks are available on the market. The extent of (and concern about) supply constraints would depend on the speed and depth of adoption of driverless trucks, as well as the approach taken by manufacturers in the lead-up to fully driverless operations. For example, Tesla's current approach is to install all the hardware required for driverless operation in their existing new vehicles; once driverless operations are technically and legally possible, the rollout will be via a software update rather than a vehicle replacement.

Demand side: Road freight industry motivation

The demand for any new product is driven by its cost relative to the benefits that its characteristics bring to the prospective purchaser. The "purchaser" of driverless trucks could be any number of actors in road freight supply chain: third-party logistics firms, large hauliers, large "in-house" freight users, or even the vehicle manufacturers themselves. So the motivations of these businesses are critical in determining the demand for driverless road freight vehicles.

The incremental cost of fully automated trucks to the purchaser is not yet known as it will depend on the balance of supply and demand when the supply breakthrough is made. Project stakeholders argued that the incremental manufacturing costs above the existing new truck technology would be small relative to the overall cost of a truck, perhaps less than 5%. In the short term, any supply constraints might mean that driverless trucks sell at a considerable premium above their production costs. Over the medium to longer term, fully driverless trucks could be cheaper to produce than the traditional “manned” vehicles, for example, because a sleeping unit would not be required for the long-haul vehicles.

Operational and transition cost implications for road freight businesses adopting driverless truck technology could be significant. Operationally, there will be a need for additional expenditure of information and communications technology systems and systems maintenance. In transition, there will be some retraining costs for retained staff whose jobs will change, and payment of redundancy entitlements for staff that are not retained. The broader social costs from displacing drivers from their jobs will be discussed in the final chapter.

Other costs of adoption of driverless truck technology are less tangible. Automation of a job generally requires some simplifying and restructuring of tasks to remove elements where computerised systems are inferior to humans (Frey and Osborne, 2017). The exact nature of task restructuring for automation truck driving is not yet known since it may depend on the contexts in which driverless trucks are applied. For example, if long-distance motorway operation were possible, while urban operations were not, there would be some costs associated with reorganising supply chains (or driver shifts) around new hubs located at the city limits on motorways. Further reorganisation may be required that would also involve costs, such as consignors and consignees having to upgrade their receipt or shipping systems to interact with a truck’s computer systems rather than a human.

The benefits road freight operators get from the use of fully automated driverless technologies will also depend on the range of contexts the technology is applied in. This study focuses on the labour savings to road freight operators (and, in later chapters, the associated challenges this brings to drivers themselves), but there are several other benefits to operators that will flow from the application of fully automated trucks (Box 3). The operating cost reductions are likely to be significantly higher in long-distance freight where drivers will account for a greater share of the cost base than in urban freight. Overall, operating cost reductions for long-distance freight in the order of 30% are possible under driverless operation.

The adoption speed, subject to availability of technologies, production capacity and acceptability to regulators, will strongly depend on the costs and benefits that the technology brings. For the road freight vehicle purchase decision to be made, the associated cost savings and range improvements are very significant. Some road haulage companies will likely be quick to take up a marginal increase of the capital costs to achieve a substantial decrease in labour costs. Competitors would likely need to quickly respond to the operating cost advantages from the early mover by also investing in driverless vehicles. This could lead to fast, possibly even disruptive, adoption of driverless technologies in road freight transport.

Box 3. **Potential operating cost reductions with driverless trucks**

Adoption of driverless trucks would have profound implications for road freight operations and costs. Though this study does not to seek to provide forecasts of cost savings, some indication is useful to understand the business imperative for the development and adoption of such technology. Furthermore, this looks only at the on-going operating cost savings after transition costs (such as capital purchase and redundancy payments to former drivers).

Though some drivers operate for relatively poor remuneration, labour costs still account for 35 to 45% of the costs in the road haulage sector in Europe (Panteia, 2015). Similarly, in the US, driver wages and benefits account for an estimated 35% of marginal (per mile) costs of freight operations (Torrey and Murray, 2015). Of course not all of these labour costs would be eliminated by the adoption of driverless operations, as some driving and non-driving tasks would likely remain. However, even if half of these costs could be avoided through the introduction of driverless trucks to some supply chains, operating costs could be nearly 20% lower. Furthermore, road freight operators are facing a shortage of suitable drivers in the US and Europe, which puts upward pressure on driver wages and operating costs (see "The potential scale of truck driver job losses" section; Costello and Suarez, 2015; Samek Lodovici et al., 2009). This issue is particularly acute in the long-distance segment where long periods away from home and the potential for boredom do not offer an attractive employment proposition.

Fuel efficiency is expected to improve as braking and acceleration commands are optimised (e.g. adaptive cruise control) and improved aerodynamic performance is achieved (platooning). Estimates of the fuel savings for automated functions are in the order of 4 to 10% for automated "eco-driving" of non-platooned trucks and 6 to 10% for partly manually driven platooned trucks (NRC, 2013; Lammert et al., 2014). The combined effect of full automation and platooning could exceed 10%, though most of these gains are possible without driverless operations per se. In the EU, ERTICO and the European Automobile Manufacturers' Association (ACEA) have initiated a new project that is exploring the fuel and emissions impacts of automated vehicle functions for commercial vehicles "ITS4CV" (Intelligent Transport Systems for Commercial Vehicles).

The number of hours in a day that a human driver can operate a truck is limited by both physiological abilities and government safety regulations such as Regulation (EC) No 561/2006 in the EU. Particularly in long-distance trucking, the constraints on shift lengths mean that vehicles can be sitting idle for a significant proportion of the day (unless operating as a driving team). The introduction of driverless truck technology would remove this major constraint and potentially enable much more intensive use of the vehicle fleet (depending on other regulations, such as night-time operating curfews in urban areas). The extended hours of operation of vehicles would bring substantial cost savings as a given task could be done with a smaller fleet. The extent of the reduction in fleet would depend on the context but for long-distance tasks a reduction in the order of 50% is plausible. The actual cost savings might be relatively small since the fleet would require more frequent maintenance and replacement, and there may be some incremental costs to equip vehicles with driverless technology (Morgan Stanley, 2013).

Perhaps more than 90% of road crashes in Europe and the US are due to human factors (Frisoni et al., 2016; Singh, 2015). So there is the ambition and expectation that widespread adoption of automated vehicles would reduce the number of crashes, deaths and injuries on the roads, particularly as some specific crash causes should be eliminated altogether (e.g. falling asleep or driving under the influence of drugs). However, it is very difficult to know what the actual crash performance of automated systems will be since new crash types could emerge, and other new insurance risks may involve serious costs (e.g. hacking or theft of "unattended" cargo). In any case, if and when an improved crash (and overall insurable cost) performance of driverless vehicles can be demonstrated to insurance companies, premiums can be expected to significantly decrease (AXA, 2015).[5]

Taken together, the above analysis suggests that a reduction in operating cost from adopting driverless trucks is possible in the order of 30% compared with today's costs. Morgan Stanley (2013) estimates a potential savings to the (overall) US road freight industry of USD 168 billion annually. Beyond the unit cost reduction, the extension in the daily range of a freight vehicle would significantly improve the delivery times offered by long-distance road freight. This degree of cost-quality improvement explains industry's strong interest in the technology, in spite of the many challenges that still remain and the R&D costs required to resolve them.

The adoption of driverless truck technology can be expected to be faster than the equivalent adoption for passenger cars due to the different incentives (Morgan Stanley, 2013). With freight, the value of the mobility comes from moving the cargo for its customers. For passenger transport, the value of the mobility in most cases comes from moving the driver (and any passengers). Driverless passenger transport therefore improves only the enjoyment or time productivity of the (former) driver's trip – except in the case of buses and taxis (whether paid taxis or unpaid parents ferrying kids around) where the driver's trip may be saved altogether. In contrast to the case of driverless trucks where the person's trip can be eliminated, the incentive for adopting driverless private passenger cars is therefore somewhat weaker.[6]

The fast adoption of driverless technologies will be further helped by the relatively low asset value in road transport (in comparison with other transport modes) and short asset life. In developed economies, the operating life of a truck is in the order of 3-10 years, depending on the company strategy and its market segment. After the end of the lifetime of a truck, a choice is made for a replacement, and subject to sufficient return on investment, a truck with a higher level of automation could be chosen. Given the expected cost savings, it might be that in some cases early replacement of the fleet would be justified, thus speeding up the overall adoption.

Policy influences: Regulatory accommodation

A potential barrier, both for the development and implementation of the driverless vehicles, is the current legislation prohibiting the use of driverless vehicles on public roads. Since businesses are unlikely to invest in development of costly technologies that cannot be brought to the market, the current R&D boom in the sector implies that the vehicle producers expect the legislation to change and their driverless vehicles to be able to satisfy the upcoming requirements. On the contrary, it is possible that some new entrants may seek to deploy technologies before they are explicitly legalised. This approach has been seen in the deployment of unmanned aerial vehicles (drones) and services from some transport network companies such as Uber and Lyft.

At a fundamental level, the regulatory situation is consistent around the world: "driverless" testing is allowed, but actual driverless operation is not legal. In the US states of California, Michigan, Florida, Nevada, Arizona, North Dakota, Tennessee, and the District of Columbia have allowed public road testing of driverless vehicles. There is nearly always a requirement to have a person behind the wheel to intervene in case it was needed. In Japan the tests are carried out, but driverless operation is not allowed. In Europe currently only the Netherlands has legislation that specifically allows large-scale tests with self-driving passenger cars and trucks, with fully driverless operation potentially allowed in specific testing circumstances (Ministry of Infrastructure and the Environment, 2015). The "Declaration of Amsterdam: Cooperation in the Field of Connected and Automated Driving" (2016) showed a commitment from EU policy makers and the transport industry to work on rules and regulations that will allow autonomous vehicles to be used on the European roads. The aim is to support innovation and come up with harmonised legislation for the deployment of interoperable connected and automated vehicles by 2019. NHTSA (2016a) aims to accelerate the safe roll-out of driverless vehicles in the US.

Legislation to accommodate driverless vehicles on public roads will require the general public to broadly accept the technology. Likely barriers to public acceptance include safety, employment and environmental impacts. Even if the rate of crashes associated with driverless vehicles proved to be lower than conventional vehicles, such crashes could receive much greater press attention. The result could give members of the public a disproportionate perception of the risk of driverless technology. (This presumes that people are attempting to make a rational assessment of risk, when in reality road users may instinctively prefer to have a driver available in the cabin "just in case".)[7] The loss of jobs associated with driverless vehicles being implemented could provide a sticking point with the public. Similarly, the potential for demand increases associated with lower-cost road freight could raise environmental concerns. From previous innovation cases in road freight, such as the operation of larger and heavier vehicles, it is clear that lobbying from competing modes of transport that fear loss of relative competitiveness will be encountered.[8]

The regulation for accommodating driverless vehicles will need to take into account the urge of some parts of the road freight industry to transition to driverless freight transport, but also the concerns of labour interests, the general public and competing industries. It will need to provide policy solutions that balance the interests of these stakeholders. The legislative efforts should take into account the need of harmonised legislation across borders to enable the use of driverless vehicles in international transport.

Scenarios for uptake of driverless trucks

The previous section explored the various building blocks that will govern if, how and when driverless trucks will come to market and be adopted by the road freight industry. What is clear from this discussion is a strong enthusiasm and willingness to rapidly pursue the technology among policymakers and industry. However, it is also evident that there are many ways that progress can be delayed or even derailed indefinitely. The remaining technology challenges are significant, while at the same time the legal transformation required to reconsider crash liability and general safety should not be underestimated. The activities of interest groups seeking to influence public opinion and lawmakers could also play a significant role in the availability and uptake of driverless trucks.

Recent predictions of timetables for adoption

Decisions about the development of technology and its supporting legal framework must be made in spite of the inherent interconnectedness and uncertainty of the future for driverless vehicles. While automated, connected and driverless vehicles have been extensively discussed and researched in recent years, the inherent challenges to reaching driverless operation have deterred most researchers from making firm predictions about timelines. Fewer studies still have commented specifically on the potential timeframe for driverless truck availability and uptake.

A small number of researchers and organisations have bravely made predictions about the availability and uptake of driverless vehicles, including trucks. A selection is included here:

- Frisoni et al. (2016) argue that there is potential for drivers to legally rest in trailing vehicles in platoons in the next 10 to 20 years. However, fully independent driverless operation (whether in platoons or not) is not predicted before about 2035.
- Underwood (2014) surveyed self-identified experts attending a conference to collate timeline predictions for a range of automation technologies applied in different contexts. Among the 220 respondents the median prediction was that SAE level 4 technologies (hence potentially driverless) would be in operation on US freeways by 2020; three-quarters of respondents predicted this would occur between 2018 and 2024. A majority of experts responded that driverless trailing vehicles in platoons would commence between 2025 and 2035.
- KPMG (2015) interviewed vehicle manufacturers and found that most expected fully autonomous vehicles would not appear until after 2025. The report argued that only 4% of passenger vehicles would be equipped with SAE level 4 or 5 technology in 2025. This production share was forecast to ramp up to 25% in 2030, though the share of fleet with this technology will be much lower as the new technology gradually enters the vehicle stock.
- PwC (2015b) expect that fully autonomous long-range driving at highway speeds will emerge between 2020 and 2025, but that this technology will come with manual override until at least 2025. By 2030 vehicles are expected to be sold without steering wheels and so would be legally operated fully autonomously.
- As part of the European Truck Platooning Challenge 2016 (under the Dutch Government and the Conference of European Directors of Roads), Dutch research organisation TNO

argued that by 2025 “highly” automated (SAE level 4) platoon operations will be possible across all European motorways.

- ITF (2015) sets out an indicative pathway towards driverless truck availability. This pathway indicates that Highway Autopilot (a level 4 system that only needs a driver to activate the system) could be available before 2030, with full automation (“self-driving trucks”) placed on the pathway at around 2030 but notes that “no consensus exists as to when such systems will become commercially available” (ITF, 2015, p. 24). ERTRAC (2015) offers a very similar timeline for commercial vehicles, though the timings are slightly earlier than the ITF study (around 2022 for level 4 on highways, and around 2028 for level 5).

More recently a number of industry announcements suggest the feasibility of an earlier availability of driverless vehicle technology than previous analyses have predicted. For example:

- In mid-2016, Uber acquired Otto, a small firm that has been testing an “interstate autopilot” system that allows drivers to sleep in their cabins while the truck is in motion. In October 2016, an Otto truck undertook an on-road test (albeit in light traffic, with good weather and under police supervision) with a driver in the cabin, but not at the steering wheel during the highway portion of the trip (Newcomer and Webb, 2016).
- A number of autonomous taxis have also been tested on public streets (though currently with fall-back human drivers in place) (Uber in Pittsburgh and nuTonomy in Singapore).
- Tesla continues to undertake “public beta” on-road testing despite incidents, and its new business plan includes driverless vehicles. Tesla CEO argues that “worldwide regulatory approval will require something on the order of (10 billion km). Current fleet learning is happening at just over (5 million km) per day” (Tesla, 2016), which suggests a timeframe of end-2021 even if their on-road fleet doesn’t grow.
- Ford has announced that it is setting up production facilities to allow it to mass market driverless cars by 2021. These vehicles are set to be fully driverless, with no steering wheel or pedals (Campbell and Weldmeir, 2016).

Alternative scenarios developed for this study

Based on a review of the available studies, industry announcements and consultation with project stakeholders, the ITF has formed four scenarios that describe possible timeframes for the deployment and uptake of driverless truck technology over the next 20 years. Clearly a definitive statement of future timeframes is not possible at this point in the technology and policy-development process, but a transparent and realistic set of scenarios is needed for the analysis of labour impacts in the remainder of this study.

Baseline scenario

This scenario describes a situation where there is no expansion of the operations of driverless trucks in the medium term. Their only applications continue in closed environments at ports and mines, but they are never legalised on public roads. This scenario could arise because one of the many requirements identified in the previous section is not met within the next 20 years. For example, the technology may not be able to identify all potential hazards; or road users may strongly resist sharing the road with driverless vehicles; or crash liability issues may not be adequately resolved.

Conservative adoption scenario

In the Conservative adoption scenario, driverless trucks do become available, but their treatment by legislators is cautious and potentially divergent among neighbouring jurisdictions. The technology expands from closed environments onto public roads, but only gradually, for example, spreading from low-traffic motorways in progressive jurisdictions, and only slowly being allowed to operate in more challenging contexts in a wider number of states and countries. In this case, the supply and policy side factors only provide a limited or gradual accommodation of the demand for the technology. For cross-border carriers, the motivation to adopt technology that is allowed on only one side of the border might be quite low. For others, such as those whose operations are mostly within jurisdictions that allow the technology, the adoption would be expected to be rapid. Other factors may result in a relatively slow roll-out of driverless technology, for instance, if supply shortages emerge in the early years of legalisation then adoption will be constrained. Alternatively, industrial disputes may inhibit the uptake of the technology.

Regulated adoption scenario

In the Regulated adoption scenario, regulatory impediments are resolved relatively quickly, supply constraints are resolved either through dynamic local industries or international imports, and importantly, successful transition plans are implemented that smooth industrial tensions and allay public perception concerns. The entire road freight industry quickly takes up the newly available technology when it is available to avoid being undercut by early adopting competitors. Use applications begin with long-distance freight on motorways, but gradual penetration occurs in urban areas in later part of the 20-year horizon.

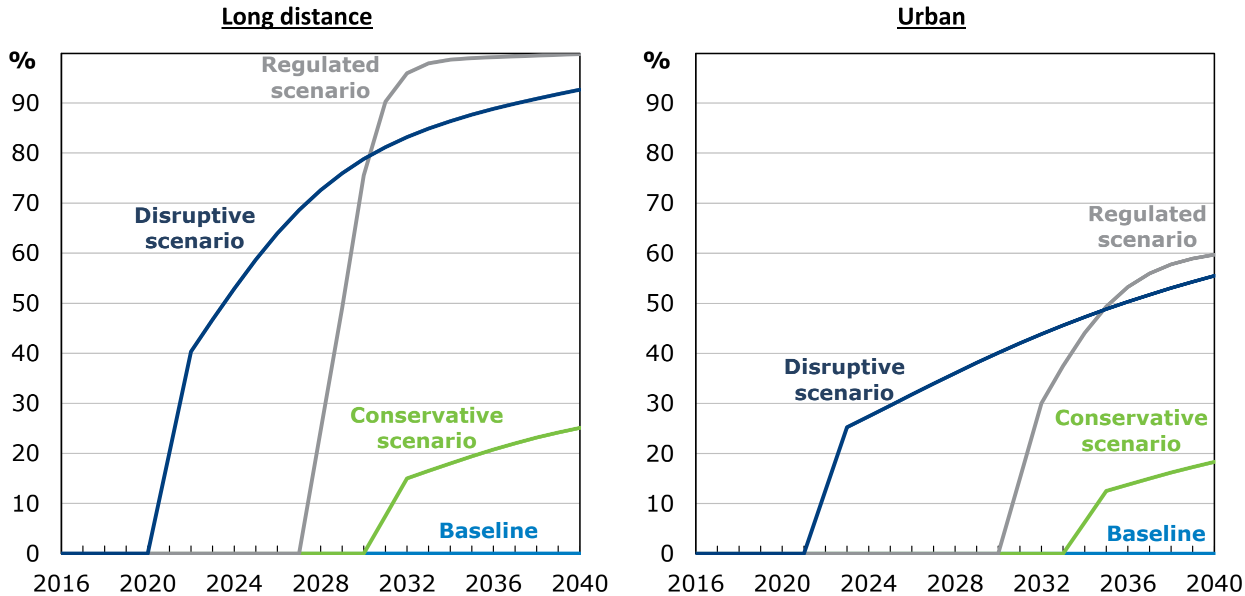
Disruptive adoption scenario

In the Disruptive adoption scenario, technology is brought to market by early moving players, perhaps before all regulatory issues have been resolved. In this scenario, some jurisdictions actively restrict the application of the technology, while others implicitly or explicitly allow it. The variable application of implementation of transition plan and public information campaigns mean that industrial tensions and public fears vary significantly from jurisdiction to jurisdiction.

Summary of scenarios

The four scenarios developed for this study are not probabilistic forecasts for the future of driverless trucks, but instead indicate possible pathways (Figure 7). Scenarios are distinguished by the degree to which existing and future road freight transport would be undertaken using driverless trucks. The Baseline scenario is for zero adoption of driverless trucks on public roads in the next 20 years. The Conservative scenario assumes that driverless technology is slowly introduced from 2030 onwards, initially in a few long-distance markets, and (from 2033) a few cities in Europe and the US. The Regulated scenario assumes that driverless technology is allowed on all long-distance routes from 2028 and in cities from 2030. In long-distance freight the technology is ubiquitous within three to five years, whereas in cities the take-up is less strong. The Disruptive scenario assumes that driverless technology is rolled out on only half long-distance routes from 2021 (and progressively expanded) and similarly in cities from 2022.

Figure 7. **Scenarios for roll-out and adoption of driverless trucks on long-distance routes and in urban areas**



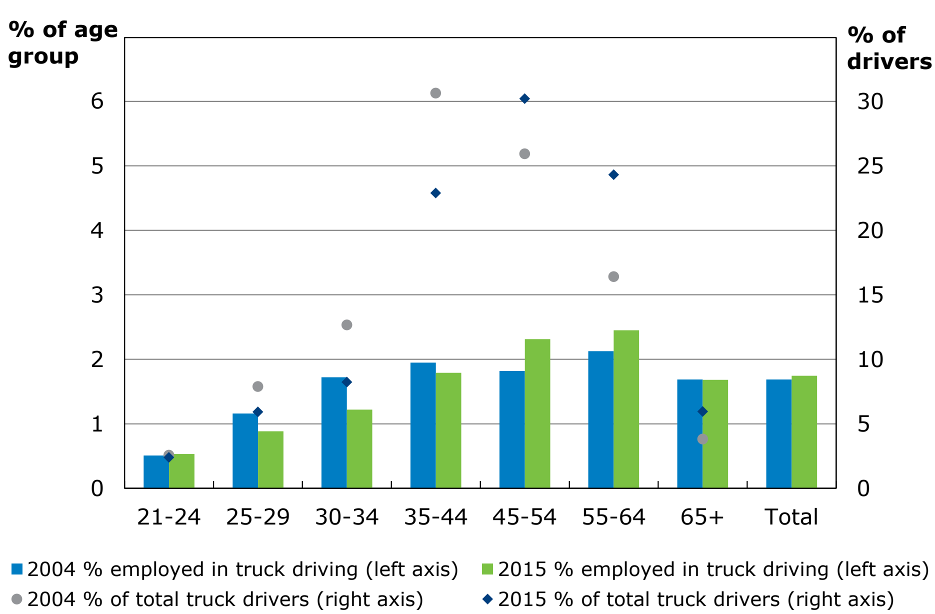
The potential scale of truck driver job losses

The remainder of this report focuses on the potential impact of automated road freight on current and future truck drivers. This section sets out estimates of the number of truck drivers whose jobs would be lost at different points in the future under the driverless truck adoption scenarios developed in the previous chapter. This exercise is challenging for a number of reasons. Primarily there is great uncertainty about the evolution of the number of qualified individuals seeking employment or employed as truck drivers. Equally the future demand for truck drivers (with and without driverless technology) is not known with any certainty. Before addressing these challenges, the truck driver labour force is first defined and described.

Truck driver labour force snapshot

Heavy truck driving is a major employment occupation in the US and Europe. In Europe around 3.2 million were employed as heavy truck drivers in 2015, which represents 1.5% of the employed population. (Europe is defined here as the 27 European Union countries as of 2014, plus Norway and Iceland). In the US around 2.4 million people or 1.7% of the employed population are estimated to drive heavy trucks. Employment in truck driving has been somewhat volatile in the past decade; the European market is still around 300 000 jobs below its peak level in 2008. In the US, truck driver employment only began to recover in 2014, and for the first time in 2015 more people had jobs than before the crisis. The approach to developing these employment data series is set out in Annex 1.

Figure 8. **US male truck drivers as share of the male employed population and distribution by age**

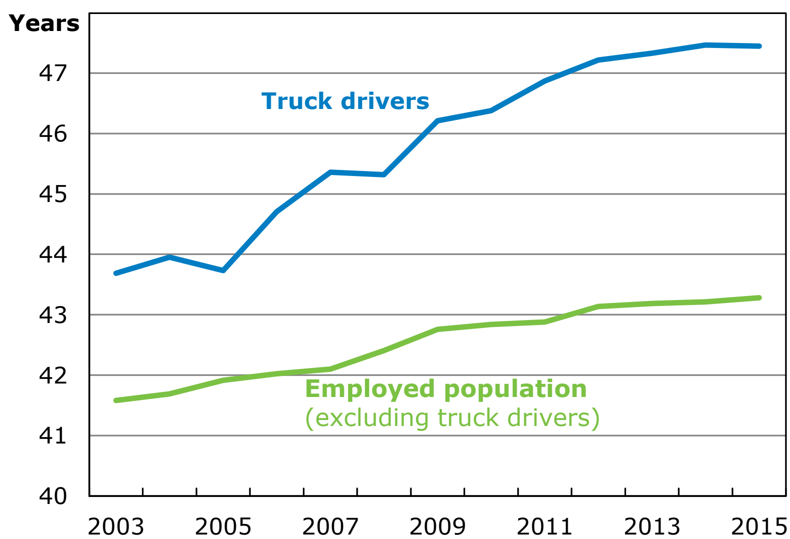


Note: "Truck drivers" covers people employed in the truck transportation industry either as "driver/sales workers and truck drivers" or self-employed, i.e. excludes in-house trucking in other sectors.
Source: Bureau of Labor Statistics (2016) Current Population Survey.

Heavy truck driving in the US and Europe is primarily undertaken by men aged between 40 and 60 years of age. The occupation struggles to attract women and young people. Less than 4% of American truck drivers are women, and in Europe, the figure is less than 2%. In the US, around 2.5% of employed males between the age of 45 and 64 were driving heavy trucks in 2015, yet for males aged 21 to 30 the share was less than 1% (Figure 8). In Europe the pattern is very similar.

The already limited age diversity of truck drivers is worsening. In the past decade, the share of each age group engaged in heavy truck driving has fallen except for the 45 to 64 year age group. Heavy truck drivers are therefore getting older on average. In 2015, the US average truck driver was 47.5 years old – more than four years older than the average worker. (Available evidence suggests this is also a feature in Europe though it is not possible to estimate the average working ages there as the public data is too aggregated.) Furthermore, the ageing of the truck driving workforce is happening even faster than for the workforce in general (Figure 9).

Figure 9. **Average age of US male truck drivers and the rest of the male employed population**



Source: Bureau of Labor Statistics (2016) Current Population Survey.

Future supply of truck drivers

Predicting the future supply of truck drivers is fraught with conceptual challenges. People have some freedom to choose their job based on their preferences, their expected incomes, and how compatible their skills and education are with the job's requirements. And from the perspective of employers, if more labour is required, raising wages or improving conditions will be effective in increasing the number and quality of applicants. So it is not appropriate to consider supply and demand for labour in any given sector completely separately.

Nevertheless, for the purposes of this study the exercise of projecting the supply of truck drivers is simplified as only two things are of central interest: First, how many people in the future will choose to be drivers if the current trends on the relative attractiveness of the occupation do not change? And, second, how might this number change in response to the introduction of driverless technology?

Baseline projections of truck driver supply

To address the first part of the exercise, a baseline scenario is developed using a simple three-part approach that aligns with the methodology of Global Insight (2005) in their work for the American Trucking Association (Box 4). The supply of heavy truck drivers projected in this study for the Baseline scenario (without driverless trucks) is dominated by the overall labour force trends in each region: in the US, truck driver supply is projected to increase from 2.4 million to 2.8 million in 2040, while in Europe, a decline from 3.2 million to 2.8 million is projected (Figure 10).

Box 4. **Approach to projecting baseline truck driver supply**

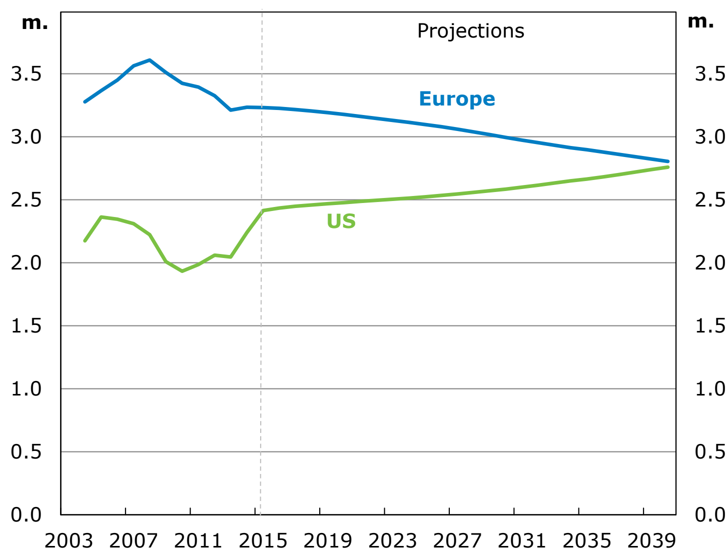
The first component of this approach is the official demographic projections of the US and Europe, which set out the number of people in each gender and age group in future years due to births, deaths and net migration. (Only the trends in the male population are considered due to their overwhelming majority in heavy-truck-driving employment.) The overall trends for working age population are highly divergent between the US and Europe. The US has been projected to have a continuing expansion of its labour force, in part due to an expected continuation of net inward migration (United Nations, 2015). In contrast, the large post-war generation group in Europe heading towards retirement age are not being replaced by sufficiently large younger cohorts, so Europe's labour force is projected to decline in coming decades.

The second component of the baseline projections of truck driver supply is a projection of the percentage of each age group among males that will work as a truck driver. The simplest assumption would be that the current shares persist indefinitely. However, the previous section highlighted that in recent decades younger age groups are less likely to drive trucks than the same age groups a decade earlier (and the reverse has been true for 45-64 year-olds). For example, in the US, a decade ago 1.5% of 25 to 34 year old male workers were heavy truck drivers, and now the figure is just under 1.0%. In Europe the equivalent shares have decreased from 2.7% to 2.0%. To conservatively account for these trends in preferences, a dampened time trend is introduced to the shares of future working age populations that will enter the truck driving occupation. The percentage point reductions in shares observed in the previous decade have been projected and spread over the 25-year period to 2040.

The final component is to scale up results from the male population of truck drivers to the overall supply figure (under the assumption that the share of females driving trucks does not change through time). For the US, the total projections also need to be factored up to account for in-house heavy vehicle drivers in non-transport sectors (e.g. retailers who directly employ drivers) since we only have detailed age-based datasets for people directly employed in the truck transportation industry.

Source: Adapted from Global Insight (2005).

Figure 10. **Baseline projections of heavy truck driver supply**



Note: Europe is defined as EU 27, plus Norway and Iceland (excludes Switzerland).
Source: ITF calculations based on labour statistics from the Bureau of Labor Statistics (2016a) Current Population Survey and Eurostat (2016a) European Labour Force Surveys, and on population projections from the US Census Bureau (2016), OECD (2016a) and Eurostat (2016b).

Driver supply projections under technology adoption scenarios

Truck driver supply projections that account for people's reactions to driverless truck technology adoption will clearly be hypothetical. It's not possible to know how each future potential truck driver will respond to the different technology scenarios, or how quickly they will do so. What can be assumed though is that potential new entrants, rather than established drivers, would be the first and most likely to be dissuaded from truck driving.

The individuals driving trucks are not the same from year to year (though many will continue from one year to the next). Some people will retire, others find a different job or are laid off; and on the other side, new people will enter the occupation, either as their first job or a mid-career change. Unfortunately, there are no statistics gathered at the level of individual people to give a clear picture of the "churn" that is hidden underneath the headline occupation employment number.

Some clues are available about the entries and exits from the truck driving occupation from analysing the evolution of employment data by age group. For instance, if the number of drivers aged 35-44 was the same as the number of drivers aged 25-34 a decade ago, it could be inferred that either: (a) all of these drivers had remained in the job for the past ten years, or (b) that the number of people in that cohort who left the job were exactly matched by the number of new entrants in the cohort. This example shows that net entrants or exits from an age cohort can be observed, but not the gross numbers of "leavers", "entrants" and "stayers".

Even at the level of age cohorts a great deal of churn of truck drivers is projected over the course of a decade. For example, in the US for the truck drivers from the age cohort highlighted above (who were 25-34 year-olds in 2015), over the space of a decade their numbers in the occupation are projected to double (Table 1). In other words, at least 136 000 people born between 1980 and 1989 will become new truck drivers by 2025. This underestimates the true number, since it is almost certain that some of the 136 000 people in that cohort driving trucks in 2015 will have left the occupation. This approach shows how older age cohorts tend to start leaving the occupation (in net terms) once they get into their 50s.

Table 1. **Cohort analysis of male heavy truck drivers in the US* and Europe**

US	**2015**		**2025 (projected)**		**10-year change**
Cohort born	**Age**	**Employment**	**Age**	**Employment**	**Employment**
After 1993			21-29	97 205	97 205
1990-93	21-24	37 372	30-34	101 864	64 491
1980-89	25-34	211 266	35-44	346 981	135 714
1970-79	35-44	345 598	45-54	410 634	65 036
1960-69	45-54	460 848	55-64	351 007	-109 841
1950-59	55-64	410 634	65+	117 715	-252 722
Before 1950	65+	91 219			-91 219
Europe	**2015**		**2025 (projected)**		**10-year change**
Cohort born	**Age**	**Employment**	**Age**	**Employment**	**Employment**
After 1996			18-24	78 822	78 822
1990-96	18-24	96 301	25-34	397 598	301 297
1980-89	25-34	526 601	35-44	862 508	335 907
1970-79	35-44	942 557	45-54	1 065 429	122 872
1960-69	45-54	1 060 286	55-64	693 564	-366 722
1950-59	55-64	605 077			-605 077

Note: *US figures only include people employed in the truck transportation industry either as "driver/sales workers and truck drivers" or self-employed, i.e. excludes in-house trucking in other sectors.
Source: ITF calculations based on labour statistics from the Bureau of Labor Statistics (2016a) Current Population Survey and Eurostat (2016a) European Labour Force Surveys, and on population projections from the US Census Bureau (2016), OECD (2016a) and Eurostat (2016b).

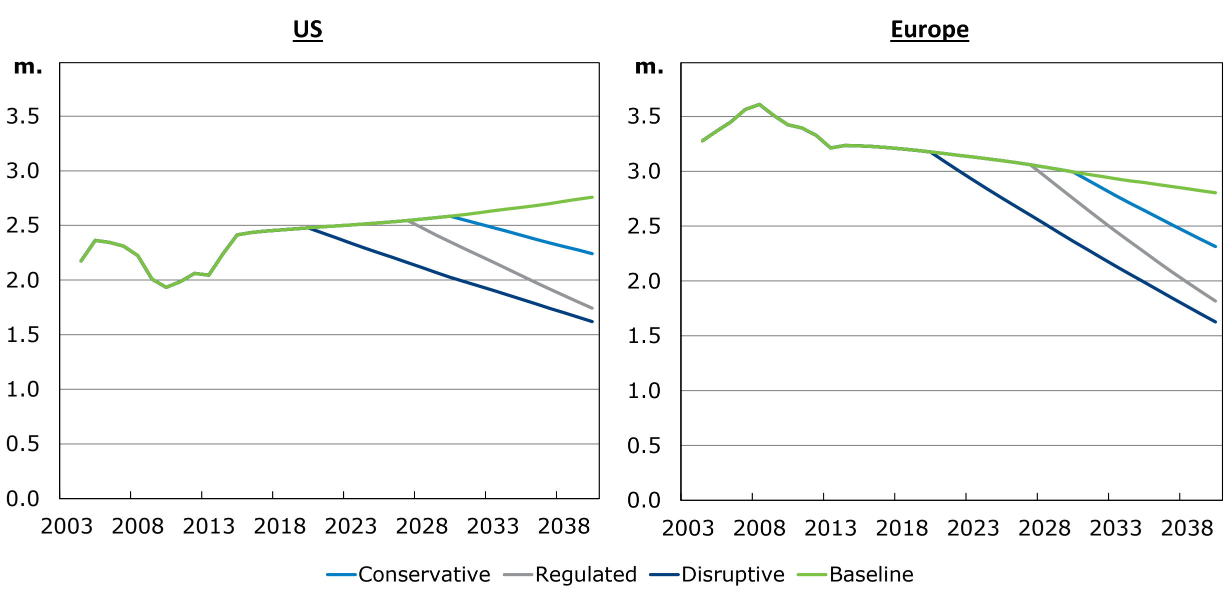
This analysis of cohorts is used to establish conservative estimates of the number of new entrants to truck driving in any given future year. (In any given year, the total driver numbers can be decomposed into the previous year's *total* plus *gross new entrants* or minus *gross leavers*). If labour market participants are assumed to be somewhat informed about industry trends and technologies, new entrants in any given year are subject to being dissuaded from becoming drivers based on the introduction of driverless technology. A complex decision model for technology responses could no doubt be developed, but this is not the central focus of this study. Instead, a very simple approach is applied: from the year driverless technology is first introduced in long-distance freight, a percentage of would-be new entrants to truck driving are assumed to be dissuaded from the occupation each year. Dissuaded entrants do not become part of the supply of truck drivers.

Faster technology adoption profiles are assumed to be associated with a greater proportion of would-be new entrants being dissuaded from truck driving supply (Table 2). The effect of dissuading would-be entrants is cumulative. With sustained and increasing adoption of driverless trucks, the supply of drivers decreases as older cohorts gradually leave; as drivers age, they are not replaced by as many new entrants as would have been the case in the Baseline scenario (Figure 11). This effect is even more pronounced in Europe where the Baseline scenario includes decreasing labour supply. By 2040, the labour supply in the Regulated and Disruptive scenarios are around half of what was projected in the Baseline scenario.

Table 2. **Assumed labour supply responses to driverless truck technology adoption scenarios**

Scenario	First year of adoption	Proportion of would-be new entrants dissuaded
Baseline	None	0%
Conservative adoption	2031	50%
Regulated adoption	2028	80%
Disruptive adoption	2021	65%

Figure 11. **Projections of future supply of heavy truck drivers under driverless adoption scenarios**



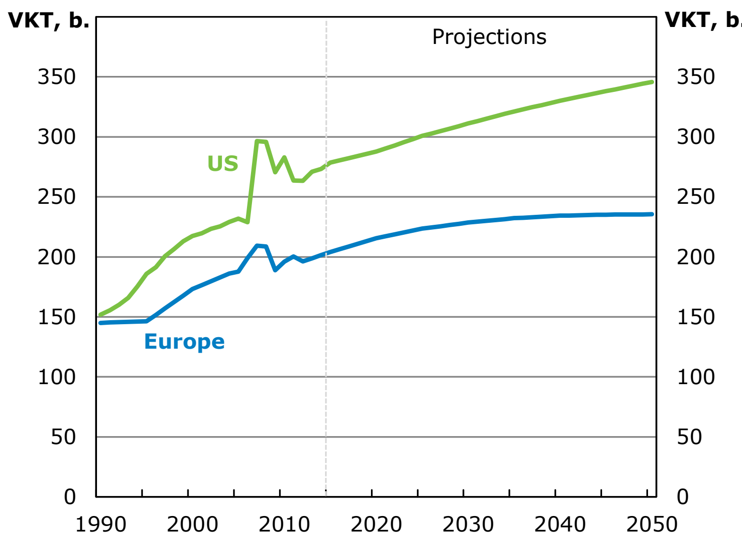
Source: ITF calculations based on labour statistics from the Bureau of Labor Statistics (2016a) Current Population Survey and Eurostat (2016a) European Labour Force Surveys, and on population projections from the US Census Bureau (2016), OECD (2016a) and Eurostat (2016b).

Future demand for truck drivers

The future demand for truck drivers will depend critically on how soon businesses take up driverless truck technology. Most obviously, the greater the penetration of driverless technology, the lower the number of drivers required for a given freight task. However, the operating cost reductions and longer daily range of driverless trucks are likely to increase the demand for road freight generally, even for parts of the supply chain that are assumed not yet to be automated (e.g. “last mile” urban deliveries). This study considers only the first of these influences, so it is likely to somewhat overestimate the potential fall in overall demand for truck drivers in a given driverless truck adoption scenario.

Nationwide heavy commercial vehicle kilometres travelled (vkt) series are available from the International Energy Agency's Mobility Model at five-year increments for the period 1975-2050 (IEA, 2016). Shorter annual time series are also available for recent years for the US and Europe; and the two sources have been combined to preserve the future (and past) growth rates projected by the IEA. The series show generally increasing freight demand in the coming decades for the US, though broadly flat for Europe. In the case of the US, the strong projected growth represents a rebound from the fall that occurred during the years of the global slowdown of 2007-2012 (Figure 12).

Figure 12. **Heavy commercial vehicle road freight demand (billion vehicle kilometres travelled)**

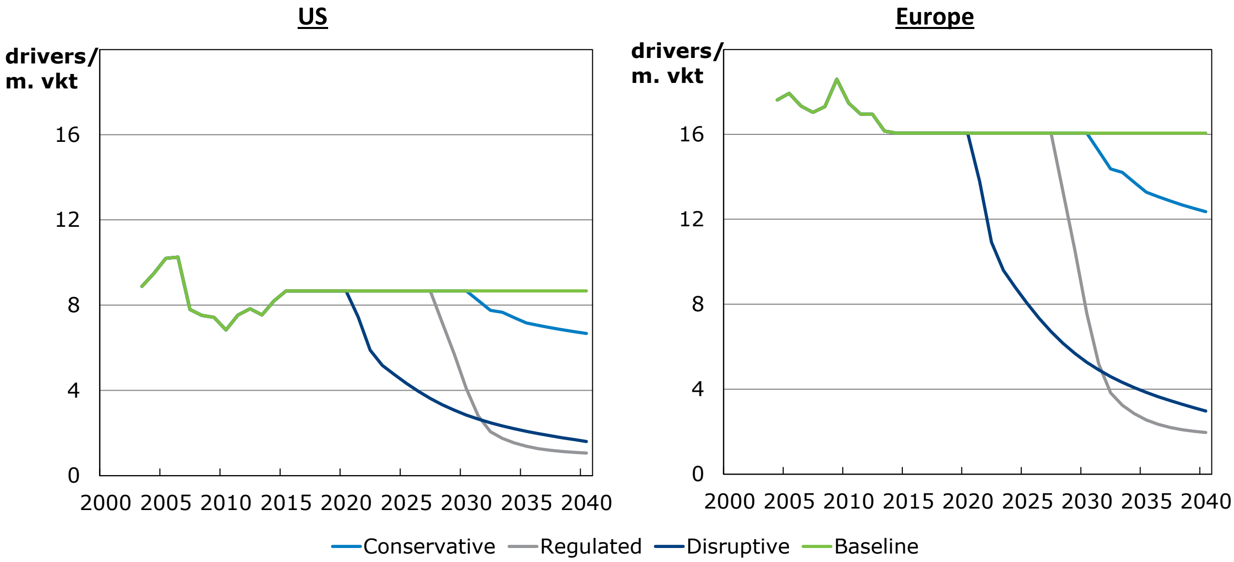


Note: Europe is defined as EU 27, plus Norway (excludes Switzerland and Iceland). In the US heavy commercial vehicles are defined as combination trucks, in Europe they are vehicles with maximum permissible laden weight greater than 30.1 tonnes. Series have been back-cast to align with IEA projection levels.
Source: ITF calculations based on US Bureau of Transport Statistics (2016), Eurostat (2016c), IEA (2016).

Historical vkt series are paired with the truck driver employment figures derived above for the US and Europe to estimate a baseline "driver intensity" ratio of drivers per million truck kilometres. For the US, the average figure in the past decade was 8.1 (i.e. 123 000 kilometres per driver per year), and for Europe it was 17 drivers per million vkt.[9] Future driver intensity in the Baseline scenario (without driverless trucks) is assumed to be constant until 2040. In the other scenarios, the market penetration of driverless technology (Figure 7) directly scales down the driver intensity of each truck vkt (Figure 13).

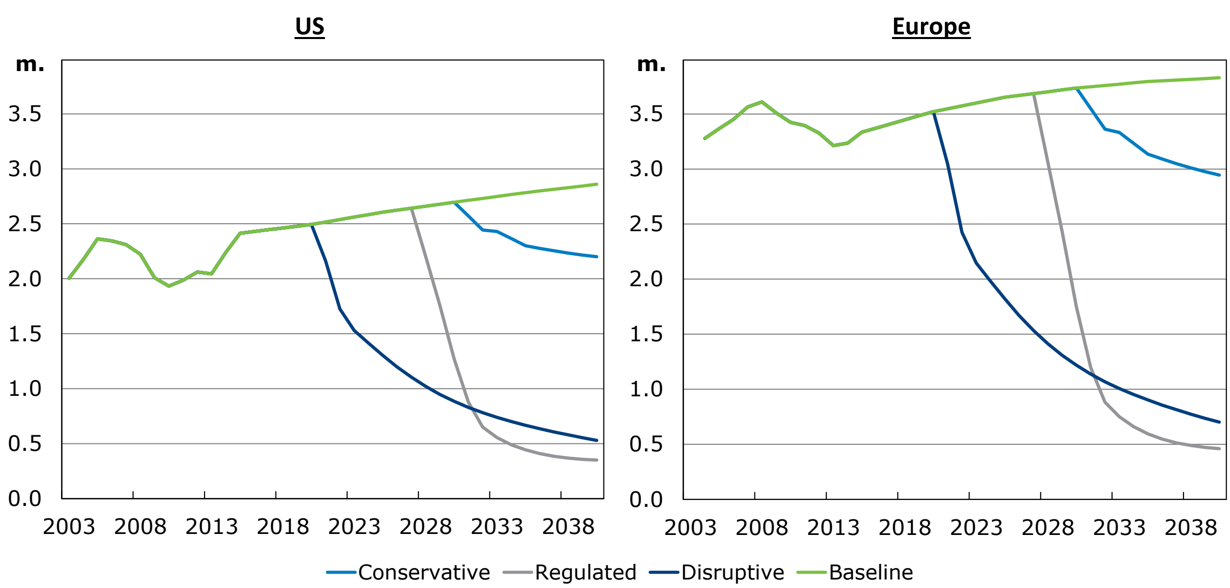
Future driver demand is projected by multiplying the driver intensity projections for each of the driverless trucks scenarios by the baseline projection of freight demand. As expected, the two more rapid driverless truck adoption scenarios are associated with a dramatic reduction in the future demand for truck drivers (Figure 14). In both scenarios in Europe and the US, demand for drivers falls to just 1 million by the early 2030s. In the Conservative adoption scenario, demand for drivers begins to decline in the early 2030s and by the end of the decade is projected to come back to levels around those observed in recent years.

Figure 13. **Projected drivers per million vkt of heavy truck freight under driverless adoption scenarios**



Source: ITF calculations based on labour statistics from the Bureau of Labor Statistics (2016a) Current Population Survey and Eurostat (2016a) European Labour Force Surveys, and on US Bureau of Transport Statistics (2016), Eurostat (2016c), IEA (2016).

Figure 14. **Projections of demand for heavy truck drivers under driverless adoption scenarios**

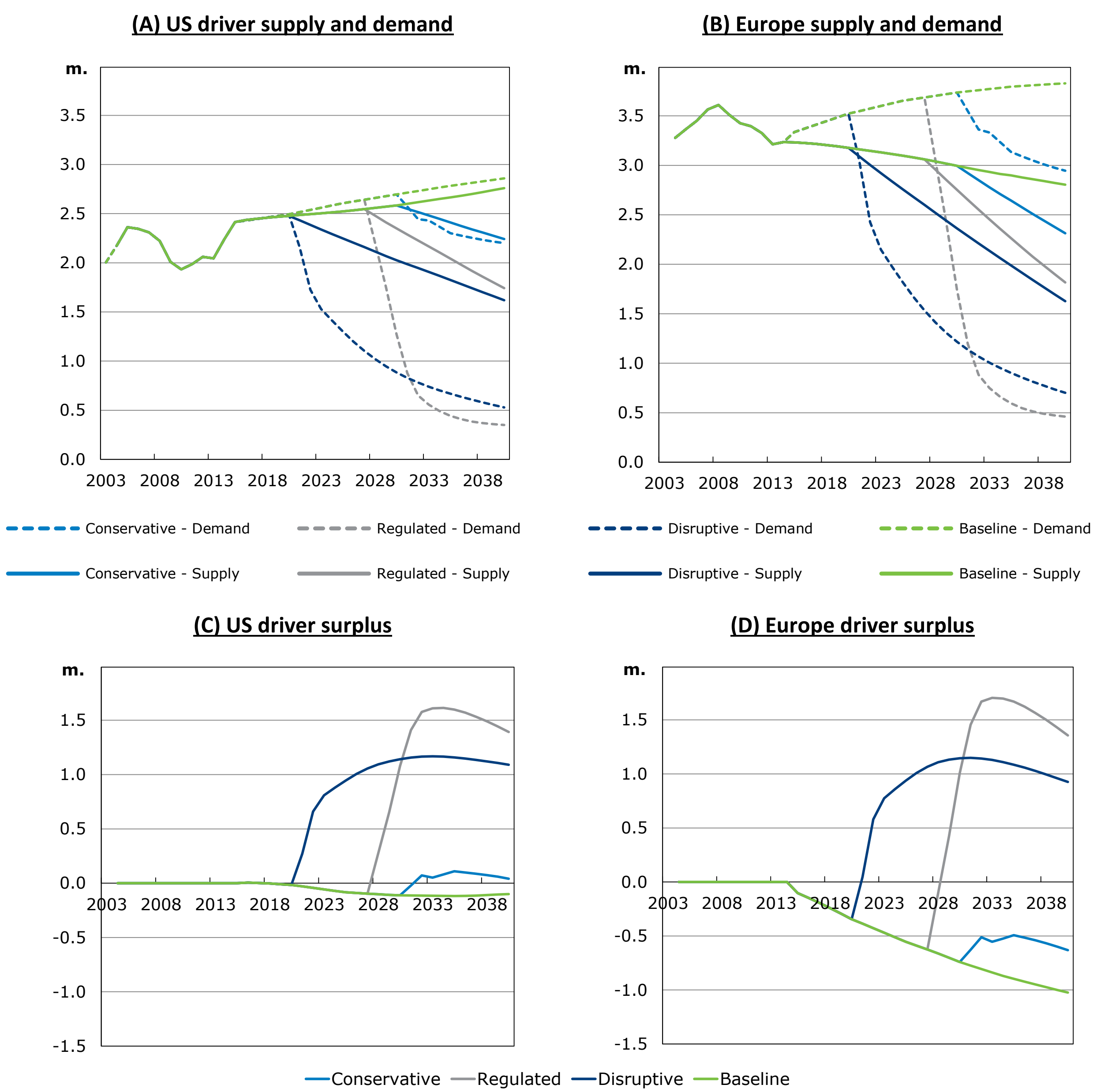


Source: ITF calculations based on US Bureau of Transport Statistics (2016), Eurostat (2016), IEA (2016).

Estimates of the future driver job losses

The critical issue for this study is how the supply and demand projections compare. A divergence between these series suggests that in a given scenario a driver shortage or surplus will emerge, if other factors (e.g. driver pay and conditions) remain comparable to today's situation.

Figure 15. **Heavy truck driver supply and demand projections under driverless truck adoption scenarios**



Industry analysts have regularly identified driver shortages in the road freight industry, particularly in the long-distance sector (Costello and Suarez, 2015; Samek Lodovici et al., 2009). The approach of this study is designed to test for future imbalances in truck driver supply and demand, rather than directly evaluating past or present arguments about driver shortages. However, the adverse demographic trends in Europe underpinning these supply projections suggest the likelihood of a significant and growing driver shortage in future decades under the Baseline scenario (the green lines in panel B of Figure 15). In the US (panel A), there is some evidence of an emerging driver shortage, though in that case the results are sensitive to parameter choices (especially the future driver intensity).

The emergence of significant driver shortages, particularly in Europe, suggests the possibility of a neat resolution. The introduction of driverless technology may be fulfilling demand for road freight for which there are not enough willing human drivers to undertake. Without driverless trucks, around 6.4 million truck drivers are projected to be needed across Europe and the United States (US) by 2030, yet fewer than 5.6 million are projected to be available and willing to work under current conditions.

The driver supply and demand projections assembled instead suggest that in the Regulated and Disruptive scenarios the adoption of driverless trucks is likely to reduce demand for drivers at a faster rate than a supply shortage would emerge. The labour demand projections in panels A and B of Figure 15 suggest that of the 6.4 million potential driver jobs in 2030, between 3.4 and 4.4 million would become redundant if driverless trucks are deployed quickly. The scale of potential future jobs losses in these scenarios is shown in panels C and D of Figure 15. Even accounting for adverse demographic trends and prospective truck drivers being progressively dissuaded by the advent of driverless technology, over 2 million drivers across the US and Europe could be directly displaced by 2030 in the two fast-deployment scenarios. The projections also demonstrate that if the adoption of driverless technology is slow enough, there is a possibility that the neat resolution occurs. In Europe, the projections suggest that a driver shortage would persist even with the introduction of driverless trucks in the Conservative scenario.

The labour projections for the Regulated and Disruptive scenarios suggest three alternative conclusions. First, these scenarios could imply that driverless trucks will be adopted “too quickly” for the labour market to react and adjust. Second, labour market participants may be reacting “too slowly” to a fundamental change in future job opportunities in the sector. Or finally, that the assumed reactions of the road freight operators and labour markets are all reasonable: the result is that there will be a large number of jobs lost in both the US and European road freight sectors. The next section considers the implications of the third perspective, and in particular: what options will the newly unemployed future truck drivers have to find jobs in other occupations and sectors if these scenarios are realised? The final section considers possible policy responses to address all three perspectives.

Future employment opportunities and challenges for displaced truck drivers

This section explores the types of future jobs that are relevant for displaced truck drivers in an economy that may be applying computer-based systems to a wide array of tasks previously performed by humans. This "high automation" context may prove challenging for drivers and people in other occupations to find suitable alternative jobs. Three main types of jobs are considered: remaining and new jobs in the trucking sector, remaining jobs in other sectors and new jobs in other sectors. The remainder of this section considers how well-placed drivers are to take advantage of future job opportunities based on their experience, education and skills.

Origins of automation

Driverless vehicles may be feasible in the near future, not because driving is an easy task, but rather because sustained rapid development of computing power, telecommunications technology and software over the past century have dramatically improved the abilities of computing systems. These advances may soon be applied in nearly every corner of the economy to dramatically change the structure of developed and developing economies alike.

Nordhaus (2007; 2015) estimates that, on average, since the era of manual computers the cost of undertaking computations has decreased at the staggering rate of 53% per annum. This progress accelerated after the 1970s when the oft-cited "Moore's law" held that the number of transistors that could be incorporated in a given size microchip would double approximately every two years (Takahashi, 2005). This dramatically expanded processing power has enabled computer scientists to develop and quickly execute computer code to undertake a wide set of tasks and functions automatically.

In the past, it has been primarily "routine" tasks, such as book-keeping, that were automated since these lend themselves to clear-cut and logical rules (Autor, 2015). More recently, powerful computers are being increasingly applied to abstract or creative tasks that are quite easily and naturally performed by humans, but that are not easily codified. Such tasks, including the driving of vehicles or recognising faces, are being effectively computerised by "machine learning" or "artificial intelligence" rather than by writing longer, more detailed code (Frey and Osborne, 2017). Machine learning involves "training" computers to make human-like inferences (e.g. these two different images show the same person's face) without either the computer or the human needing to fully describe the logical steps involved (The Economist, 2016b; Ford, 2015). Similarly impressive developments in robotics, sensors and communications are expanding the physical range of movement and operations for machines beyond simple repetitive actions of early assembly-line robots.

The long-run trend towards cheaper computing power has predictably resulted in many firms looking to try and switch people for computers and robots (Nordhaus, 2007) as well as looking for opportunities to augment the productivity of people with such systems (Davenport and Kirby, 2016). Scientists, engineers and entrepreneurs continue to explore opportunities to exploit the new possibilities opened up by the rapidly improving technology. Applying such automation technology will create wholly new jobs, improve the productivity and comfort of existing jobs, and importantly it will also remove the need for some jobs altogether. The threats (and the opportunities) faced by the truck driving profession are shared by many.

Automation and future jobs in the trucking sector

Previous sections have outlined the potentially high degree of automation of truck driving that could occur in the coming decades. None of the scenarios developed for this study imply that all truck driving jobs will disappear. What is clear though is that automation of the truck driving task will result in a transformation of the industry, including the nature and number of jobs available within it.

The total number of remaining truck driving jobs in the US in 2030 was estimated in the previous section as between 0.9 million and 1.3 million in the two strong adoption scenarios, which would be less than half the number of jobs projected without driverless technology. In Europe, the equivalent figures are 1.2 million and 1.7 million. These estimates are based on adoption of a driverless fleet for a percentage of the projected freight task. Such an approach does not account for the competitive response to such a large improvement in the operating cost of road freight, suggesting the actual number of remaining jobs could be higher than these estimates (Box 5).

Fully automating a job requires that all tasks undertaken by a human can be satisfactorily performed by a computer system or reallocated to another job. For example, computer systems that control truck motion and navigation would not be sufficient to automate a truck driver's role if a human driver was still required for re-fuelling and communicating with shippers and consignees. Job automation can therefore be seen as a challenge to (1) identify all tasks in a job, (2) identify, develop and apply systems that can do tasks at least as well as humans, and (3) re-structure jobs to re-assign any tasks that humans are still better at doing (Frey and Osborne, 2017). The case for automating any particular job will therefore depend on the mix of tasks that make up any given job. Tasks that are difficult to automate which are either critical to the role or occupy a large part of each day in that role may limit the ability or motivation to automate the job. Further, *potential automation* does not mean that jobs will actually be lost, since the substitution of labour for machines needs to be profitable as well as technically possible (Autor et al., 2003; Arntz et al., 2016).

Earlier in the report urban truck driving jobs were argued to be more likely to persist than long-distance driving on motorways due to their different legislative and physical environments. However, the different mix of tasks contained in urban freight driver jobs and long-distance ones is likely to further emphasise the different driverless truck adoption profiles between these segments. Whereas drivers on long-distance routes may spend an entire work day focused on core driving tasks, in urban areas other tasks become much more prominent, such as route choice, communication with shippers and consignees, theft deterrence, as well as loading and unloading. In an urban freight context not all of these tasks will be easy or desirable to automate (or reallocate to other people), which dampens the adoption of driverless technology in this area compared with long-distance freight.

The task-bundle considerations emphasise that future road freight jobs are likely to be more urban and also more multi-dimensional than the average truck driving job today. Particularly since the same forces for change that are expected to automate many long-distance truck driving jobs are also likely to encourage job automation and task re-allocation elsewhere in the industry. A possible outcome is that if automation of the driving task is achieved, some of the freed up time could be used to do some of the previously "back office" tasks in the cabin of the truck. This kind of task re-bundling could create opportunities to preserve some "driver" jobs that may otherwise be subject to automation. This "augmentation" approach is consistent with evidence that adoption of computer systems leads to reorganisation of jobs to increase the complexity of human tasks and to increase the complementarity between human tasks and those of the machines (Autor, 2015; Arntz et al., 2016). Together, these factors could help make the truck driving profession more geographically stable (with less time away from friends and family), and therefore more appealing as a career to new labour market entrants and women than is currently the case for long-distance trucking. At the same time, these expanded job descriptions may be off-putting for late-career drivers.

Box 5. **Potential "rebound" in road freight demand and driver employment**

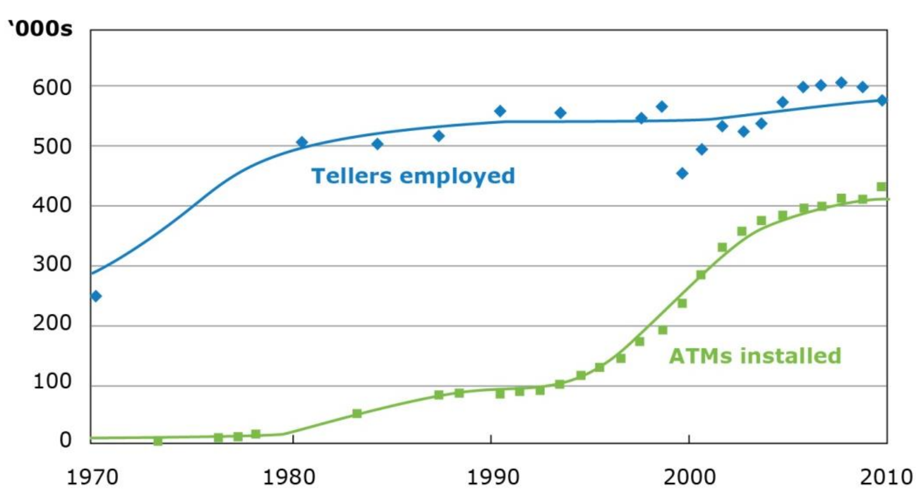
Box 3 identified potential operating cost reductions in the order of 30% for road freight operators. At the same time, trucks operating without a driver could undertake long-distance freight much more quickly without working hour limitations, substantially increasing a truck's daily range. Together, these would have significant effects on demand, not just for road freight, but potentially for freight overall.

Road freight currently accounts for nearly half of the tonne kilometres undertaken in the EU and US (EU, 2015). Road freight's success in specific market segments over alternative modes like shipping and rail can be more to do with reliability, distance and network reach rather than price and speed (Dionori et al., 2015). Nevertheless, an improvement of the scale considered here would mean that other parts of the freight market could be more strongly contested by road, unless competing modes are able to exploit the possibilities of automation to find comparable cost savings.

Significant overall reductions in the cost of freight – and an extended daily range – could lead to the adoption of more transport-intensive production models (e.g. decentralisation and increased specialisation). This increased demand for road freight could result in an expansion of demand for labour inputs in the sector (and elsewhere in the economy). Detailed modelling would be required to understand the net impacts on road freight demand (particularly in the presence of carbon dioxide emissions pricing) and employment. For example, the increase in road freight demand spurred by automation in the long-distance segment could result in greater demand for human drivers in urban areas and an increase in off-peak road freight.

A recent example of this type of feedback was in retail banking when automatic teller machines (ATMs) were introduced to undertake some of the functions of human tellers. Bessen (2015) examined employment and branch data in US retail banking and found that the operating cost reductions derived from having ATMs and fewer staff per branch encouraged banks to open more branches. Total retail banking employment stayed steady over the period in which 400 000 ATMs were rolled out.

Figure 16. **ATMs and teller employment in US retail banking**



Source: Bessen (2015, p. 17).

Beyond the truck cabin, there are likely to be new jobs emerging in a future high-automation trucking industry. Particularly during the transition period, there will be a strong need for software engineers and other maintenance workers to install and maintain new technologies in trucks and back-offices. New business models and supply chain configurations, spurred by the application of driverless technologies in trucking, are likely to also generate jobs in the industry. For example, if remote control rooms are installed for fall-back driving performance or other fleet monitoring tasks there will be some demand for skilled and experienced drivers. Such jobs would also be more comfortable and geographically stable than the current situation for long-distance drivers.

Current jobs outside trucking less likely to be threatened by automation

There is agreement among researchers that many, but certainly not all, current jobs are at some risk of automation in coming decades. Researchers differ in views about how far technologies can advance into currently human-dominated tasks. There is also disagreement on the appropriate methodology for estimating the extent of overall job automation that will occur.

A central debate in the literature of job automation is about the extent to which a single job title masks major differences in the mix of tasks undertaken by people in the occupation. At one extreme, Frey and Osborne (2017) assume that there is no variation within an occupation; for example, all salespeople perform the same set of tasks. Under this approach, they estimate that many whole occupations are subject to “high risks” of automation in the next 15 or so years (covering around 47% of employment in the US).

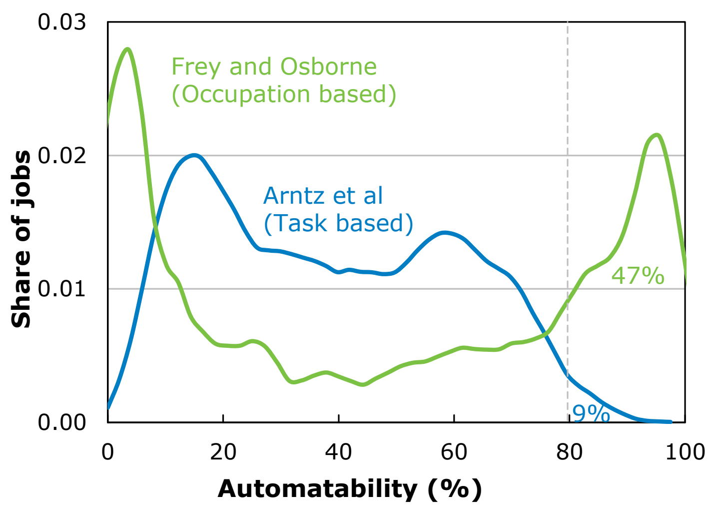
Arntz et al. (2016) argue that there is significant variation in tasks undertaken within each occupation. For example, some salespeople offer a highly tailored customer service, whereas others simply scan barcodes and process payments. The contended implication of this alternative approach is that a far smaller proportion of jobs can be automated (around 9% in the US), even with similar technologies considered by Frey and Osborne (Figure 17). Autor (2015) reaches a similar conclusion by arguing that unbundling tasks within jobs will be difficult without a material drop in quality. A preference for humans to undertake some technically “automatable” jobs is therefore likely to persist. For example, many people value the face-to-face contact with salespeople, even if this aspect of the job is not strictly one of the tasks defined in job automation studies (Verint, 2016).

At this point in time it is impossible to know which set of predictions about automation of jobs in other sectors will prevail. As with driverless trucks, technology availability (supply), customer interest (demand) and public acceptance and regulation (policy) all need to come together before new technologies can be applied (see section “Towards driverless road freight”). However, it is reasonable to expect that if these factors come together for driverless truck technology, they are likely to come together in other sectors over a broadly similar timeframe. That is, if either the Disruptive or Regulated adoption scenarios developed for driverless trucks is realised, it would likely coincide with a greater degree of job automation elsewhere in the economy. This means that in the scenarios where large numbers of drivers lose their jobs, the prospect that many people in other sectors are likely to be losing their jobs at the same time has to be taken seriously also.

So which of today’s jobs are most likely to be spared in an automated future? Even Frey and Osborne (2017), who estimate that a relatively high share of jobs could be automated, still find that at least a third of current US employment is in jobs that are at low risk of automation. Sectors where jobs appear most unsuited to automation are education, legal, community service, arts, healthcare, management, finance, computer science and supervisory roles in all industries. These include jobs such as counsellors, social workers, health aides, police officers, fire fighters, cleaners and pest controllers.

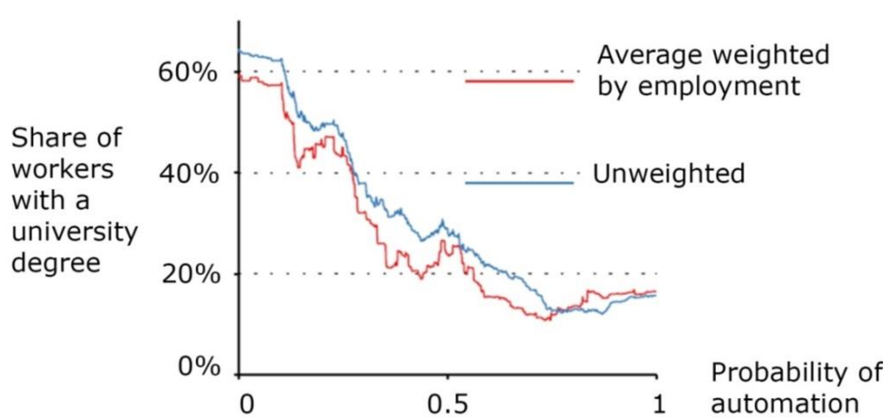
Researchers who are more sceptical about job automation concerns allow for an even broader range of sectors where employment will persist. For example, Autor (2015) identifies skilled trades (such as plumbers, builders, electricians and automotive technicians), medical support occupations as well as relatively low-skilled "manual" jobs (such as food preparation, food service, cleaning, and security) as all being unlikely to be automated in the coming decades.

Figure 17. **Distribution of automatability in the US (proportion of employment at risk)**



Source: Adapted from Arntz et al. (2016, p. 15).

Figure 18. **Prevalence of university degrees in a job and the job's estimated probability of automation**



Source: Adapted from Frey and Osborne (2017, Figure 4, p. 268).

In a high-automation future, Frey and Osborne (2017, p. 40) suggest generalist jobs that require "knowledge of human heuristics and specialist occupations involving the development of novel ideas and artifacts" will be the most resilient to automation. These jobs are currently disproportionately done by people with high levels of formal education (Figure 18). By contrast, the skilled trades and manual jobs that Autor (2015) argues will also resist automation in coming decades have somewhat lower formal education requirements. He argues that jobs combining "routine technical tasks with the set of non-routine tasks in which workers hold comparative advantage: interpersonal interaction, flexibility, adaptability, and problem solving" (Autor, 2015, p. 27), suggesting that communications and "thinking on the go" will be more important than formal education for a significant share of remaining jobs.

New jobs in a context of automation

Automation will transform the production processes for existing goods and services, reducing the number of workers required to produce any given output. However, there will also be some new jobs that emerge due to the expansion in demand (as for bank tellers, see Box 5) and from wholly new products emerging. From the perspective of truck drivers displaced by driverless technology in the future, the important questions are: what will these newly created future jobs be? And will these new jobs be suitable for me? (The final section picks up the broader issue of whether there will be enough jobs).

Recent labour market experience can provide a few ideas of what kinds of new jobs may emerge in the future. Official employment databases evolve as new jobs are created. Lin (2011) examined the employment growth in modern US cities within Census occupation codes that were created in the 1980s and 1990s and found that most new jobs were in new technologies or in new types of personal services. Similarly, the US Government-sponsored O*NET database of job classifications cites around 150 new and emerging job titles that have been added in the 2010 version, either because they have been newly created or because they have become more prominent in the labour market (Table 3). New titles broadly cover sustainability, personal services and technology.

Table 3. **New and emerging jobs in the US**

Field	Examples
Sustainability	Energy Auditors, Green Marketers, Recycling and Reclamation Workers
Personal services	Distance Learning Coordinators, Patient Representatives, Baristas
Health and well-being	Fitness and Wellness Coordinators, Art Therapists, Midwives
Computing and communications	Computer Systems Engineers/Architects, Web Administrators, Robotics Engineers
Advanced transport	Freight Forwarders, Transport Planners, Logistics Analysts, Supply Chain Managers

Source: Adapted from O*NET (2010).

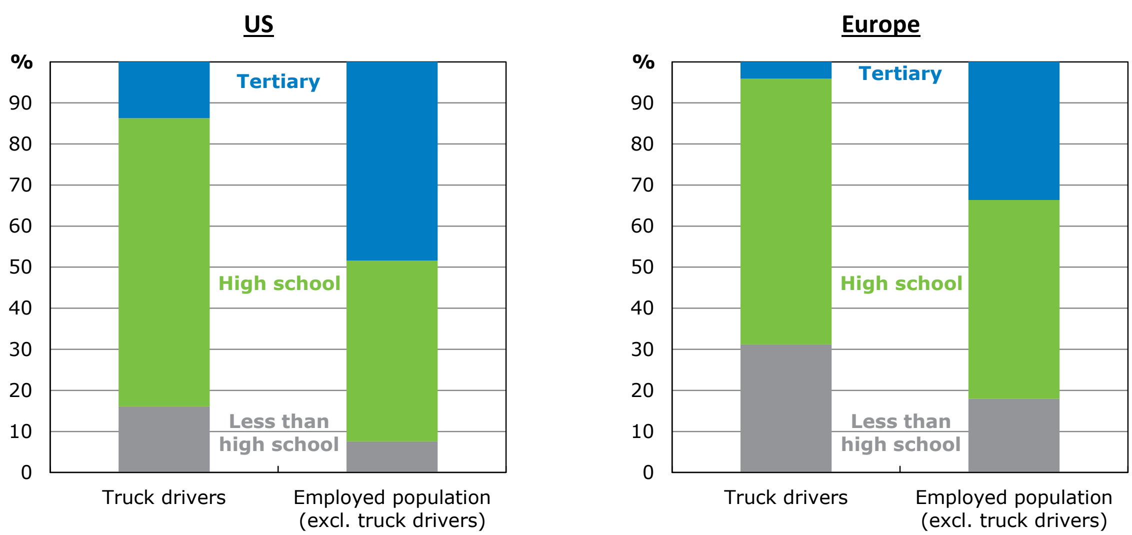
The professional network site LinkedIn also provides evidence on newly emerging jobs through the job titles used frequently today that were barely used five years earlier. These new job titles also cluster among technology (App Developer, Social Media Intern/Digital Marketing, Data Scientist/Big Data Architect, User Interface/Experience Designer, Cloud Services Specialist) and new personal services (Zumba Instructor, Beachbody Coach) (Murthy, 2014).

Readiness of truck drivers for alternative jobs in the future

Are dislocated drivers well placed to take advantage of the new jobs being created (and those that remain) in a high-automation future? In the future, remaining job opportunities could be disproportionately in high-education occupations, i.e. those where a high proportion of employees have a university degree (Frey and Osborne, 2017, see Figure 18). New job areas appear also to be somewhat skewed towards high-education sectors (e.g. Table 3). However, within some of these areas, especially in sustainability, health and personal services, there are likely to be activities that require human interaction more than high education levels.

Truck drivers are at a disadvantage in terms of formal education levels compared with the average person in other occupations as relatively few truck drivers have a university degree (Figure 19). However, a relatively large share of truck drivers have completed high school (70% in the US and 60% in Europe), so overall the average level of formal education of truck drivers is lower than that of the rest of the employed population. A trend towards "over-qualification" for traditionally lower-education jobs suggests the education gap could become even more problematic for displaced truck drivers in the future (Hogarth and Wilson, 2015).

Figure 19. **Educational attainment distribution for truck drivers in US and Europe, 2015**

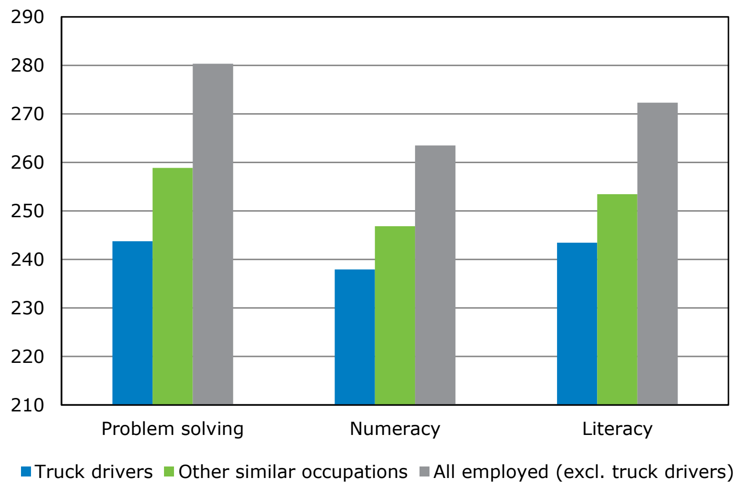


Note: Truck drivers here are people aged 21+ employed in the truck transportation industry either as "driver/sales workers and truck drivers" or self-employed, i.e. excludes in-house trucking in other sectors for the US.
Source: ITF calculations based on labour statistics from the Bureau of Labor Statistics (2016a) Current Population Survey and Eurostat (2016a) European Labour Force Surveys.

A worker's skills and ability to perform a given set of tasks depend not only on their level of formal education. There are several factors, such as innate aptitudes, on-the-job training, work experience, which contribute to job suitability. Measuring the actual skills of truck drivers would help in more appropriately assessing the suitability of truck drivers compared to the rest of the currently employed population who may be competing for future jobs. The OECD's Programme for International Assessment of Adults Competencies (PIAAC) survey provides one approach to measuring skills. PIAAC attempts to measure the abilities of people in each occupation to process information in technology-rich environments. The survey scores (out of 500) a respondent's literacy, numeracy and problem-solving proficiency at tasks of increasing complexity.

PIAAC data for a selection of European countries and the US suggests that the proficiency of truck drivers is lower than that of the rest of the employed population, particularly in problem solving (Figure **20**). Even if the comparison is restricted to occupations that the O*NET database identifies as being related to truck driving (due to similar tasks or skills needed), a proficiency shortfall persists. This adds further weight to the suggestions that truck drivers would be at a disadvantage to the rest of the employed population when seeking alternative jobs with a strong information-processing components. However, there are many skill types that are not well covered by the PIAAC survey, since it essentially focuses on "white collar" skills.

Figure 20. **Heavy truck driver proficiency at information processing in the US and Europe, 2012**



Notes: Scores out of 500, weighted average of data for the US, Cyprus[1], Czech Republic, England and Northern Ireland, Estonia, France, Greece, Ireland, Italy, Lithuania, the Netherlands, Flanders (Belgium), Poland, Slovak Republic, Slovenia, Spain, and Sweden. Other similar occupations are calculated as a simple average of scores of respondents from "earthmoving and related plant operators", "civil engineering labourers", "car, taxi and van drivers" and "locomotive engine drivers".
Source: OECD (2016b).

Based on available evidence, truck drivers appear to be somewhat behind their peers in any future "race" for new or remaining jobs. However, without objective evidence on their relative proficiency against skills relevant to their occupation (i.e. those applied outside an office) it is difficult to make a comprehensive assessment of their competitiveness for these jobs.

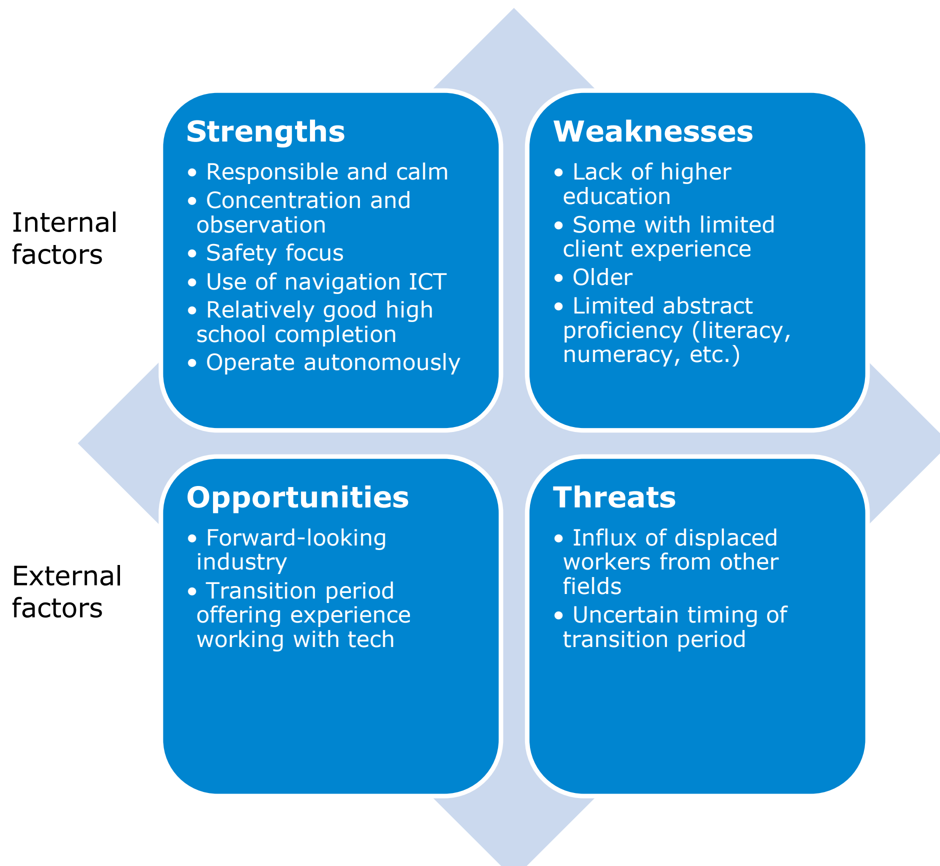
A more qualitative approach applied in this study is of truck drivers' strengths, weaknesses, opportunities and threats (SWOT) relative to other candidates for future jobs. This SWOT analysis considers positives and negatives for displaced truck drivers that are due to the characteristics of the drivers (internal factors) and those that are due to external factors. For example, drivers have strong abilities to concentrate and resolve issues by themselves (Figure 21). These abilities could be very valuable for security surveillance and monitoring, for example overseeing the applications of computer and robotic systems in future production processes. In contrast, the lack of customer interaction in long-distance trucking may mean that drivers are not developing the face-to-face skills that are valued in the growing personal services industries. In terms of the external environment, the gradual progression of the automated driving technology will give drivers practical experience that could be transferred to other roles working with highly automated systems. Driverless (long-distance) trucking may be an early case of automation in the forthcoming "wave", which is likely to be both a challenge (with less experience to learn from in other sectors) and an opportunity (more time to retrain and seek out new opportunities relative to other displaced workers).

[1] Note by Turkey
The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Creek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue".

Note by all the European Union Member States of the OECD and the European Union
The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey the information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

The SWOT analysis is necessarily simplified. It does not account for the diversity that will exist within the group of displaced truck drivers. There will be some drivers who are young, with high levels of education and skills – their opportunities for redeployment will clearly be very different from the average driver summarised above. Yet at this stage it is clear that there will be a significant number of older and less educated drivers who would face major challenges in re-deployment in the economy.

Figure 21. **Strengths, weaknesses, opportunities and threats for displaced truck drivers**



Policy considerations

The previous sections have considered the likelihood, timing and implications for adoption of driverless road freight vehicles. The analysis has taken the perspectives of the major actors individually: the technical automation challenges for vehicle manufacturers, the business motivations for automation, and the scale of potential job losses for truck drivers. By contrast, this chapter tries to balance these perspectives to give a societal point of view. It considers what roles there may be for government to help manage the transition to driverless technology in road freight.

This section first highlights the positive aspects of driverless road freight from a societal point of view and suggests ways in which governments may facilitate the introduction of the technology. The second part of the chapter focuses on the challenges facing displaced truck drivers and discusses options for governments to mitigate adverse impacts so that the gains from the technology can be shared fairly.

Social motivations for introducing driverless road freight vehicles

The section "Towards driverless road freight" described the business motivations for adopting driverless road freight. There are clearly significant potential advantages from labour, fuel and insurance cost savings as well as the ability to use fleet more intensively in a given day in long-distance tasks (Box 3). As business is part of the community, these savings contribute to profits that are ultimately distributed to individual shareholders. However, these cost savings will also partly be passed through to consumers in the form of lower prices for transported final and intermediate goods. A given income will be able to purchase a greater quantity of goods, working to improve standards of living, for instance through more affordable food, electronics and medicines.

Even more important than cost of living savings is the potential to save human lives through a reduction in vehicle crashes. Around 1.25 million people are killed, and 20 to 50 million people are seriously injured, on the world's roads each year, including both passenger and freight travel (WHO, 2015). In Europe around 26 000 were killed and 1.4 million injured in 2015; and in the US around 35 000 people were killed and over 2.4 million were seriously injured (ITF, 2016d and 2016e; European Commission, 2016). In the US, large trucks accounted for 8% of all vehicles involved in fatal crashes in 2015 (NHTSA, 2017). These road crashes result in major emotional and financial costs to society. In recognition of these serious costs, the United Nations Sustainable Development Goals has a target to reduce global road fatalities and serious injuries 50% by 2020, compared to 2010 levels. Further, ITF member countries have begun to focus on a vision to dramatically reduce road deaths, ultimately to the point where there are zero deaths (ITF, 2016b). Yet increasing motorisation in many low- and middle-income countries suggests further increases in the number of road fatalities and serious injuries may occur in the coming years. And recent years have seen a reversal of long-run trends of declining road deaths in several developed countries (ITF, 2016c). By eliminating human driver error, risk-taking behaviour and fatigue, the introduction of automated driving could help reverse these adverse safety trends (NHTSA, 2016a). The clear caveat to this is that the technology has yet to be proven, especially the safety performance when operating automated vehicles in "mixed" traffic with human drivers.

Driverless trucks also offer the possibility of reducing the energy required to perform a given freight task. Through more efficient braking and acceleration as well as lower wind resistance when operating in platoons (Box 2), automation offers the possibility of directly reducing local air pollution as well as freight transport’s contribution to climate change. This conclusion rests heavily on the extent of the demand “rebound” experienced as a result of the lower freight costs (Box 5). Nevertheless, automation could speed the uptake of emerging low-carbon energy sources, such as electric propulsion, by driving the consolidation of vehicle purchasing (especially in passenger vehicles) (Walker and Johnson, 2016). If it contributes to decarbonisation of propulsion, the net impact of automation on climate change could be neutral or even positive.

Potential measures to facilitate the introduction of driverless road freight vehicles

The broad areas where government could facilitate the introduction of driverless vehicles are in physical infrastructure and in setting the regulatory environment. Particularly for the testing phase, many governments and other organisations have been very active in both areas.

The infrastructure requirements for full automation of driving functions are not yet clear-cut (section “Towards driverless road freight”). The need for 5G mobile internet connectivity between vehicles along the full corridor is not yet certain. Further, specific applications such as platooning and remote control centre operations are also likely to have additional infrastructure requirements. For instance, platooning may require longer motorway entry and exit ramps than are currently in place (Janssen et al., 2015).

Uncertainty about the final infrastructure requirements means there is a risk that expensive network-wide investments could be wasted or over-specified. One way to respond to this uncertainty is to develop a high level of connectivity and road asset quality on a small selection of test corridors. Governments can either directly provide or designate “testbed” corridors. The Cooperative Intelligent Transport Systems initiative (C-ITS) coordinates the connected vehicle activities of three national governments (Austria, Germany and the Netherlands), industry research groups and vehicles manufacturers. The initiative provides the hard and soft infrastructure to test connected vehicles and information sharing on a specific motorway corridor between Vienna and Rotterdam. In the US, 10 different sites have been specifically designated as “proving grounds” for the testing of vehicle automation technology (DOT, 2017). The US sites are a mix of government, university and private initiatives.

Under the focused testbed investment approach to infrastructure, various ITS technologies are able to be tested without committing to an individual company, standard or technology too early in the development process. It also allows governments to collect data to assess the safety and performance of new technology under different configurations. Ultimately this data could be used as basis for determining the minimum requirements (e.g. whether 5G connectivity is required) and for regulating the use of the technology beyond the testing phase. It also allows new technologies to be demonstrated “on the road” and hence to build public trust and political support.

Based on the above, the recommendation is to c*ontinue driverless truck pilot projects to trial vehicles, network technology and communications protocols*.

As is the case with infrastructure, the transition from testing phase to “in market” operation is also critical for rules and regulations governing the use of automated driving technology. Governments in many jurisdictions have proactively introduced laws and provided permits for the testing of automated vehicles (Frisoni et al., 2016). In part this reflects a desire for jurisdictions to attract or retain the economic activity associated with vehicle manufacturing and advanced research and development.

This willingness of governments to provide on-road access to immature technology should speed its development by allowing many different approaches to be tested in parallel. However, there is a real risk that the competition among jurisdictions for the testing activities means that insufficient attention is being paid to the harmonisation of the ultimate in-market rules that will be put in place once technology has been proven. Such harmonisation – ideally at world level, but at least at a continental level – is critical for ensuring smooth cross-border freight movements. Different regulations could result in cross-border freight operators needing multiple on-board systems in vehicles, or even the need to have human drivers on-board for whole trips. A lack of harmonisation in standards and approaches would therefore raise the costs of adopting the technology and hence limit the benefits from, and uptake of, vehicle automation.

With this in mind, the second recommendation of this report is to *set international standards, road rules and vehicle regulations for self-driving trucks*.

Broader challenges facing displaced truck drivers and other labour force participants

A large number of truck drivers are expected to be displaced from their jobs if driverless technology develops and is introduced quickly in the coming decade or so (see “The potential scale of truck driver job losses). This is true in spite of the purported shortage of skilled drivers to undertake the current and future road freight task. The details differ according to scenarios, but within the space of three to seven years of driverless trucks being introduced over a million drivers could be directly made unemployed in both the US and Europe (Figure 15).

The previous section narrowly focused on the alternative employment opportunities for displaced truck drivers. The situation of other people potentially displaced by automation (notably people in other driving professions such as taxi driving) was considered there only insofar as it affected the employment prospects of former truck drivers. This section considers the collective situation of people whose jobs are threatened by automation and the broader economic context in which job automation may occur.

The conventional argument is that displaced workers in any given industry will find alternative employment through the expansion of activity in new and existing industries. However, there are several reasons described below as to why this argument may not provide comfort for truck drivers and others in the high-automation scenarios:

- the high costs associated with losing a job
- the risk that this time is different, i.e. that a low employment future is possible, at least temporarily, because automation may occur in many sectors of the economy
- the emerging economic context means that job losses may result in higher social costs than previously.

High costs of job loss

There are long-lasting social and financial costs on individuals from losing a job involuntarily, e.g. due to a factory closure or downsizing. On average, displaced workers tend to experience long periods of unemployment, particularly during recessions (Brand, 2015). The duration of unemployment tends to be longer for less-educated and older workers, and if there are many concurrent job losses elsewhere in the industry or regional economy generally (Quintini and Venn, 2013; Productivity Commission, 2014). The most immediate impact of job loss is the loss of earned income (Feldstein, 1978). But the loss of income tends to persist even once people do find new jobs: “wage scarring” means that people displaced from a job earn less than their continuously employed peers, even more than a decade after their initial job loss (Brand, 2015; Quintini and Venn, 2013). In part this wage scarring reflects the stigma associated with a period of unemployment, but also the lower quality of jobs that displaced workers are subsequently hired for (more part-time and less job authority) (Podgursky and Swaim, 1987; Sullivan and von Wachter, 2009).

The earnings loss for an average displaced worker is estimated at 20% of total lifetime earnings (Brand and von Wachter, 2013). The personal economic costs for people losing jobs are worse for older and less-educated workers – especially if similar workers are also displaced or if the economy is in recession (Brand, 2015; Productivity Commission, 2014). This suggests that the lifetime impact on the earnings of truck drivers, who are older and less educated than the workforce average, would likely exceed 20% of their lifetime earnings.

The loss of a job represents a stressful life event beyond the impact of the lost income resulting in non-financial social costs borne by the individual, their family and the community. Job loss disturbs a person’s status, daily routine, relationships and ability to demonstrate competence, and as such can be associated with social stigma, shame and anxiety (Newman, 1988). The incidence of reported symptoms of depression and anxiety are 15 to 30% higher among displaced workers than non-displaced workers (Brand, 2015).

Job loss can also adversely affect physical well-being. Job loss is associated with worsening physical health, more hospital visits, and higher incidence of suicide (Brand, 2015; Productivity Commission, 2014). Sullivan and von Wachter (2009) analyse the mortality of displaced male workers who had previously worked in the same job for more than three years. They find a 50–100% higher risk of death during the years immediately following job loss compared to non-displaced peers. Also, life expectancy is 1.0-1.5 years shorter for those displaced in middle age, but there is little effect for those nearing retirement age, suggesting physical impacts of job losses can be to some extent mitigated if they fall disproportionately on older workers.

The mental and physical impacts of job loss are estimated to have a greater combined impact on well-being than the financial costs from lost income. Helliwell and Huang (2014) estimate that such non-financial factors decrease the average person’s well-being two to seven times more than the does their lost income from losing their job.

The costs of job loss extend beyond the individual to the family and the broader community. Job loss puts strain on marriages and also future educational attainment of children, particularly where a father’s job is lost, except in the case of single mothers where the negative impacts are also large (Brand, 2015). Even members of the community who keep their jobs are adversely affected by people losing their jobs. In part this is because displaced workers are less likely to participate in community activities (Brand, 2015) but also because workers start fearing their own job’s security. Helliwell and Huang (2014) estimate that the non-financial well-being effects of a job loss on the community are 1.6 to 5.6 times higher than the impact on the individual’s well-being.

The academic literature gives some insight into the personal and financial hardships that are often not fully taken into account in consideration of policy or business decisions involving job losses. These considerations are particularly important to consider in light of the analysis in the previous section that finds that truck drivers are potentially at a skills, age and education disadvantage when considering the jobs that will emerge in the future. There is a risk that former truck drivers will have a particularly protracted and hence costly period of unemployment if their jobs are automated.

Risks of a low employment future

The application of expanding computing power is certain to eliminate and re-define many of today's jobs and occupations. Automation will transform production processes, reducing the number of workers required to produce any given output. What is less obvious is the types and numbers of new jobs that will emerge in a high-automation future: will there be new jobs be due to the expansion in demand as there were for displaced bank tellers, or from wholly new products emerging?

Concerns for widespread technological unemployment go back perhaps half a millennium. In the 16th century, Queen Elizabeth I fretted that a newly developed stocking-knitting machine would result in widespread unemployment in England and Ireland (Acemoglu and Robinson, 2012). In one sense, these concerns are well founded: past periods of major technological change (combined with movements of some parts of production to developing countries) did dramatically reduce the number of people employed in agriculture and manufacturing in the US and Europe. For example, manufacturing now makes up less than 10% of employment in the UK, whereas for at least 130 years prior to the 1970s, it accounted for 30 to 40% of jobs. A similar transformation happened in the previous century in the agricultural sector, to the point where now less than 1% of UK jobs are in this sector (PwC, 2016).

Historically though, job losses from mechanisation, automation and changes in the employment mix have not resulted in permanent reductions in the total number of jobs. Instead, the long-run trend has been one of job creation. Millions of new service sector jobs have emerged to replace those lost in manufacturing and agriculture in the developed world. However, researchers are divided on whether such past technological disruption of jobs is a good guide to the future. For example, in a 2014 survey, 1 896 experts were almost perfectly divided between optimists and pessimists on the net impacts of automation technology on total jobs (Pew, 2014).

The pessimistic view on the impact of future automation and total employment suggests that "this time is different". As computers become more powerful, they are increasingly able to replicate or exceed human capabilities in some tasks, so humans could become "superseded" in the production process (e.g. Ford, 2015; Brynjolfsson and McAfee, 2014). The reduction in work could be a positive development if it results in a widespread increase in leisure time and living standards (Keynes, 1930). Ford (2015) is much more pessimistic, suggesting that automation would concentrate incomes (and hence purchasing power) in the hands of the owners of the machines, leading to a collapse in consumption (since a single rich person is not going to purchase 1 000 televisions) and hence the economic system. Though this is an extreme conclusion, it highlights that a relatively strong redistribution of incomes and wealth from the rich to the poor may be required to avoid worsening inequality, particularly as the economy is restructured. OECD member countries in recent decades have instead seen rising income inequality, suggesting a reversal in the trend would require a major policy shift (OECD, 2015).

The optimistic view on the impact of future automation and total employment instead suggests that automation will be gradual and/or the rate of job creation in expanding sectors will broadly match the rate of job destruction (e.g. Autor, 2015). In other words, this time won't be substantially different to previous waves of technological change: new products, services and jobs will emerge to replace those from truck driving and other areas where automation reduces employment. There is some evidence in the UK that more jobs are being created than lost to automation, and that the majority of new jobs are in occupations that are expected to be hard to automate (Allum, 2017). Under this view the "job destruction" analysis of Frey and Osborne (2017) and others is one-sided. A more complete picture of the future needs to account for microeconomic and macroeconomic factors that will affect outcomes beyond the automation possibilities offered by technology.

As described above, firm-level microeconomic motivations to adopt new technologies in place of labour will clearly influence the extent that humans are replaced by machines. For instance: how easily can production processes be adapted? How costly is the technology relative to the savings made? Will the customers perceive a drop in quality if computers substitute for humans? Together, such "demand side" motivations were assessed for driverless truck technologies in the second section of this report and will be considered by any firm looking to automate jobs. Employment sectors such as sales, food service and even semi-skilled trades have a large customer interaction component so the adoption of computer systems will be sensitive to customer preferences for human interaction. In contrast, road freight is an intermediate input to other goods with limited direct customer interaction, particularly in long-distance segments. So demand for automated production is less likely to be constrained by customer perceptions about human versus machine service delivery. Arguably road freight could be one of the earlier sectors to overcome customer wariness about automation (if not the wariness of other drivers sharing the road).

Macroeconomic factors will also dictate the overall employment outcomes from future automation. Arntz et al. (2016) set out three types of feedback that could create new jobs:

- Computer jobs – Producing and maintaining automated systems will require some labour, thus creating some new jobs.
- Extra production jobs – Businesses will adopt new labour-saving technologies because they improve price or quality competitiveness. If successful, these businesses will attract new demand and expand production, therefore potentially rebalancing its demand for labour (Box 5).
- Extra consumption jobs – Labour productivity (output per worker) will improve when new machines complement workers. This is expected to increase disposable income by increasing wages, employment or both. This extra income should expand demand for new and existing goods and services that will further boost employment.

The balance of these demand feedbacks against the job-destruction potential of existing and emerging technologies is still subject to considerable uncertainty. A low-employment future remains a possibility in spite of these caveats.

Difficult economic context

The gap between the rich and poor has widened in recent decades (OECD, 2008; 2011; 2015). For example, in OECD member countries, the richest 10% of the population today earn 9.6 times the income of the poorest 10%, yet in the 1980s, this ratio stood at just 7:1 (OECD, 2015). There have also been difficulties in middle parts of the income distribution with the loss of many "middle class" manufacturing jobs in developed economies. OECD analysis suggests that inequality can harm both social cohesion and the development of human capital through education. Both result in a drag on economic growth.

Part of the explanation for the rise in income inequality has been the rise in non-standard work (contract work, part-time work, and more recently the growth in platform-based on-demand work), which is associated with higher incidences of household poverty (OECD, 2015). Many of the stable, full-benefits, full-time manufacturing jobs of the post-war decades have been replaced by less secure forms of employment.

Economists and other researchers debate the extent to which automation has contributed to the rise in income inequality in recent decades (Stern, 2016; Atkinson, 2015; Ford, 2015). Technology and new "winner takes all" business models can also contribute to higher income shares going to those on the upper end of the income scales (Ross, 2016). However, more conventional economic policy settings (especially on welfare and taxation) and institutional settings (such as union membership levels) also play major roles (Atkinson, 2015).

The OECD has also recently embarked on a multi-disciplinary research project to investigate the future of work. Even before this research is completed, it is clear that the economic and labour market context that displaced 40-50 year-old truck drivers would face will be very different from the one they faced when they first entered the workforce 20 to 40 years earlier. There may be few full-time salaried jobs available to them; instead work may be either on short contracts or via a diverse portfolio of activities in the on-demand economy. Ultimately remuneration may be lower and/or more variable from week to week. This potential future is certainly a concern for potentially displaced workers in all industries. And even the business community is gradually confronting the potential societal implications of the technologically advanced on-demand economy. For example, Klaus Schwab, Founder and Executive Chairman of the World Economic Forum, has recently wondered:

> Is this the beginning of a new and flexible work revolution that will empower any individual who has an internet connection and that will eliminate the shortage of skills? Or will it trigger the onset of an inexorable race to the bottom in a world of unregulated virtual sweatshops? If the result is the latter – a world of the precariat, a social class of workers who move from task to task to make ends meet while suffering a loss of labour rights, bargaining rights and job security – would this create a potent source of social unrest and political instability? (Schwab, 2016, pp. 48-49)

Strategies for mitigating adverse labour impacts in the transition to driverless road freight

The previous sub-section should give policy makers some motivation to carefully consider the speed of introduction of driverless trucks and the measures in place to support this transition. There are clearly risks to the livelihoods and well-being of current and future drivers if they are displaced by driverless technology. At one extreme, policy makers could consider withdrawing support for the rollout of the technology. This would place the interests of drivers ahead of the safety and cost efficiency imperatives outlined earlier in the chapter. Alternatively, policy makers could continue to pursue the active support of the development, testing and rapid rollout of driverless truck technology. This approach would play down the risks to displaced drivers in pursuit of the safety and efficiency gains from driverless technology. A more balanced approach would proactively pursue the gains from the new technology but try to ensure these gains are shared fairly through society.

In contemplating the introduction of driverless trucks into the market, it is essential that policy makers consider the trade-off between the benefits of the technology (primarily safety and cost efficiency) against the costs of the associated job losses. The rate and extent of job losses depends on how soon driverless trucks are available and adopted in the market, which are currently both highly uncertain. And the costs of the job losses will depend on the degree of support available to people who are unemployed or underemployed, since this support can mitigate the financial and social costs of unemployment (Productivity Commission, 2014).

Governments need not be passive participants in the development and adoption of these technologies. Governments could actively intervene in the market to re-balance outcomes in favour of one group over another. Interventions could take the form of two distinct and complementary strategies: influencing the speed of uptake of driverless technology (and hence job losses) and ensuring adequate support is available to those drivers who are displaced.

Before selecting which policy tools to deploy, governments must first decide on the balance between the two strategies for managing the labour transition. This balance is likely to be highly uncertain and values based. Different societies would likely make different choices than their neighbours, and each society would likely make different choices across time. Some societies would be highly risk averse to job losses, so would prefer to slow the rate of adoption. Others may focus more on creativity and economic dynamism, and so would prefer to rapidly adopt new technology and emphasise re-deployment or support for displaced workers. As the transition progresses, more evidence will be gathered about the industry's desired rate of adoption of the technology, the technology's impacts on driver employment and the costs of job loss on those displaced.

A temporary transitional body could advise national governments on the choice of strategies to manage this transition towards driverless trucks. A balance of perspectives would be required to appropriately advise on costs and benefits of the technology at a point in time. The membership of the group should therefore draw from diverse members of the industry, including representatives from labour (drivers and union representatives), road freight businesses, vehicle manufacturers and government. The proposed advisory body would make periodic recommendations to government about the nature of the trade-off between the benefits of driverless trucks and their social costs in terms of driver displacement. It could also advise on industry-specific support for displaced labour discussed below.

Because of these elements, the recommendation is to *establish a temporary transition advisory board for the trucking industry.*

Proposals for the labour transition to driverless road freight

Specific policy proposals to deliver on labour transition strategies are considered here under three broad categories: a permit system to influence the speed of adoption, economy-wide support, and industry-specific support.

Permit system to influence the speed of adoption of driverless trucks and job losses

Active government intervention to influence the timing and number of involuntary job losses is legitimate. Slowing down the adoption of driverless trucks once they are technically ready for use in the market can be justified partly because private innovations are often built on the accumulation of publicly funded research, and also because social costs should not be ignored (Atkinson, 2015). Microsoft co-founder Bill Gates has argued for such an approach for labour-saving robots: "at a time when people are saying that the arrival of that robot is a net loss [for jobs] because of displacement, you ought to be willing to… even slow down the speed of that adoption somewhat" (Delaney, 2017). The European Parliament (2017) recently considered issues relating to automation, including research ethics, liability and employment impacts, though a proposal to consider charges on owners of labour-saving robots was defeated.

In the case of driverless trucks, the sheer number of drivers and the speed of their potential disruption suggest that the social risks of a "hands off" transition may be too great. Under the Regulated and Disruptive adoption scenarios job losses are projected at between 300 000 and 500 000 each year in both the US and Europe in the first few years the technology is introduced (see "The potential scale of truck driver job losses).

To influence the speed of adoption, governments could require road freight operators to purchase a permit to operate in driverless mode on roads in their jurisdiction. This permit would give professional road users the right to operate a suitably capable truck in driverless mode for say 10 000 vehicle kilometres in a given year. It is assumed that these permits would be enforced under the general monitoring arrangement that is likely to be in place for the use of driverless vehicles.

Two main alternative approaches could be considered for managing the distribution of the permits. The first is a Pigouvian tax where the permit price is set up front. The second approach is a cap-and-trade system. In this alternative, a fixed number of permits for the jurisdiction could be auctioned to the highest bidders, with these permits being tradable in a secondary market (Box 6). The permit scheme would have two impacts: it would reduce the demand for driverless operation and it would raise revenue. In principle, it could even be possible to introduce driverless trucks at a rate that did not result in any job losses at all. This could be the case particularly in Europe where the emerging driver shortage suggests that a significant share of the road freight task will go unfulfilled at the current wages and conditions if driverless trucks were not deployed.

Box 6. **Alternative permit approaches – tax versus cap and trade**

The difference between the two permit sub-options is the choice that policy makers would need to make each year. The policy makers would need either to decide the appropriate level of the permit charge (Pigouvian tax) or the number of permits to issue (cap and trade).

A Pigouvian upfront charge should be based on the "external" social cost that the technology brings but would not otherwise be included in the costs of use. In this case, driverless trucks would be associated with social impacts of job losses. Although some estimates were outlined in the previous section, these are not tailored to each jurisdiction or the specific re-employment prospects of truck drivers. An alternative basis for setting the charge is on the basis of road freight operators' willingness to pay, i.e. by estimating the cost savings they would make by implementing driverless trucks. The closer the charge is set to the actual cost savings, the lower the uptake would be, and hence the slower the displacement of drivers.

The cap-and-trade approach avoids the need to estimate the external social costs or truck cost savings upfront. Instead, the government could estimate the number of permits to issue in their jurisdiction in a given year and then sell them at auction. In the context of an emerging driver shortage, the number of permits could grow each year without causing large job losses.

Economy-wide support for the un(der)employed

Under the strategy of supporting workers displaced by technology, the natural starting point is the existing economy. The existing economy offers support either through job creation discussed above, or through current or future government safety net policies. The nature of the safety net varies significantly across jurisdictions and evolves through time, so a detailed review is not proposed here. In general, social safety net support takes the form of unemployment benefits (cash transfers), other benefits that are provided to low-income households (such as child benefits), as well as free or subsidised health and education.

Many of the unemployment and low-income support programs were designed in an era when economies offered close to full employment with jobs being largely stable full-time positions with benefits such as health insurance included. Support can therefore be time-limited in the expectation that a new full-time job will be found in the space of a few weeks or months. In spite of (and because of) structurally higher levels of unemployment and underemployment in recent decades, several developed economies have made these programs less generous and subject to means testing. Together these changes have contributed to the worsening in inequality described above (OECD, 2011; Atkinson, 2015).

A second potential issue with current support systems is that they are not well equipped to deal with more variable incomes associated with the on-demand economy. People with a portfolio of tasks, and hence a variable income, can face high marginal tax rates (as they pay income tax and benefits are withdrawn under means testing) and high costs of complying with welfare system processes. The result may be that people are discouraged from working and can get stuck in a "poverty trap" (Atkinson, 2015). In response, several authors have made some radical policy proposals. Chief among these suggestions is the universal basic income (UBI) and its variants, which would offer an income safety net regardless of employment status (Box 7).

Box 7. **Universal income proposals**

Technology writer Martin Ford (2015), former labour unionist Andy Stern (2016) and many others have proposed a universal basic income (UBI) as the centrepiece of their proposed reform packages to address the impacts of automation. A UBI would involve paying all citizens a small regular income regardless of how much they earned, though the UBI and all earned income would be subject to income tax. Many existing social benefits would be withdrawn to avoid the issue of high marginal tax rates and to make the scheme affordable. While the scheme has had diverse support through time (including conservative economist Friedrich Hayek and civil rights leader Martin Luther King Jr.), the idea is still only on the edge of mainstream policy debate in most countries. For example, a major-party presidential candidate took the policy to the 2017 national election in France, while a referendum on a UBI proposal was defeated in Switzerland in 2016.

A number of writers looking to tackle the economy-wide challenges discussed here have concluded that a UBI is not the best solution. One argument is that it dulls the incentive to work (Byrnjolfsson and McAfee, 2014). A second argument is that a very high average tax rate would be required to fund even a modest universal income (Atkinson, 2015; Tobin, 1970). A third argument is that if truly universal, it would mean making payments to high-income earners and having to inefficiently take this straight back through taxation.

In spite of reservations, implementing one of several UBI variants is still seen by many authors as a crucial reform. Atkinson (2015) proposes a participation income, paid to all residents in a jurisdiction who are making a social contribution. This contribution is very broadly defined, including any form of paid employment, active job search, caring or volunteer work. This approach could work in tandem with existing means-tested programs, since this participation income would be included in eligibility calculations and hence dramatically reduce recourse to these complementary programs. A further variant, proposed by Byrnjolfsson and McAfee (2014), is for a negative income tax, which pays a percentage income supplement to people below a minimum earning threshold. This approach resolves the third complaint with the universal basic income since high-income earners would be well above the minimum earning threshold. Atkinson also argues that the implementation or expansion of an earned-income tax credit would be useful income supplement to low-income earners who worked (rather than receiving returns on assets).

Other potential tax and transfer reforms could include (Atkinson, 2015; Ford, 2015):

- making the income tax system more progressive (increasing marginal tax rates payable by high-income earners)
- reducing exemptions and exclusions received by businesses and high-income earners
- moving away from payroll taxes (which put labour-intensive businesses at a disadvantage and hence encourage automation) towards wealth and capital taxes
- developing a global tax system to ensure high-income and high-wealth individuals and businesses are not able to "shop around" for low tax rates to avoid taxation.

These policy proposals, including the UBI and its variants, are clearly highly contentious and (especially in the case of global taxation) unlikely to be implemented any time soon in the US and Europe. Nevertheless, they provide useful information about the direction of reform that governments could pursue to tackle the risk of a low-work or high-inequality society.

Education and training are typically at the top of most economists' lists of recommendations to ensure people are employable. For example, Australia's Productivity Commission (2014) argues that training in basic skills (literacy and numeracy) is an effective way to ensure low-skilled displaced workers are able to be re-employed. Though Ford (2015) argues that the returns from more university education have been falling in recent decades and suggests that as automation (and offshoring) reaches high-skill professions this trend will continue. Therefore, Byrnjolfsson and McAfee (2014) emphasise improving teaching standards for school-age education to help deal with the threat of automation, while Ford (2015) focuses on vocational training opportunities.

Beyond the tax, transfers and education systems, a range of economy-wide policy settings can support people who become unemployed. These include (OECD, 2005):

- Active labour market programs – measures in place to help people move from one job to another, including those requiring re-location. Measures include job-search assistance, counselling, training, and moving allowances.
- Labour market flexibility – ensuring that worker protections do not overly hamper businesses from hiring new staff.
- Housing market flexibility – ensuring that tax policies do not discourage mobility, for example through high property sales taxes.

Atkinson (2015) offers further major proposals to tackle potential unemployment and underemployment; of particular interest in this study is his suggestion that the government explicitly target unemployment by "offering guaranteed public employment at the minimum wage" (p. 140). A version of such a system is currently in place in some European countries such as Belgium and France, but restrictive access conditions mean they account for only a very small part of the economy in spite of high levels of unemployment (Atkinson, 2015).[10] In the US, investment in infrastructure is seen by many writers as a socially beneficial way to ensure human labour is re-deployed if large-scale automation is realised (Byrnjolfsson and McAfee, 2014; Ford, 2015). Bill Gates has also recently suggested that proposed robot-tax revenues could be directed to employment programs for healthcare and education (Delaney, 2017).

Industry-specific support for displaced drivers

If the economic policy settings described in general terms above were in place in a jurisdiction when the automation of truck driving started resulting in job losses, displaced truck drivers and other workers may have little to fear. They would have access to advice, counselling and support for education and re-location to take advantage of job opportunities in other industries or location. They would also have a guaranteed minimum income to draw on to avoid the worst financial consequences from job loss.

However, in most jurisdictions considered in this study, many of the elements described above are either missing or inadequate. And realistically, it is unlikely that such major economy-wide reforms could be implemented in a time compatible with what this report has shown to be the potential timeframe for driverless trucks, i.e. the next decade or so. For example, universal health coverage took decades to implement in the US, and some of the measures described above arguably involve greater change.

The strategy of supporting workers displaced by technology therefore could require industry-specific support to ensure an adequate safety net. Such industry-specific transitional assistance raises equity concerns, since more assistance may be available to workers in the targeted industry than other unemployed people facing similar or more acute difficulties (Productivity Commission, 2014). Assistance to displaced truck drivers would therefore need to be carefully designed to supplement (rather than replace) the assistance available in the rest of the tax and transfer system in place in the jurisdiction. Assistance could come in the form of active labour market programs to try to re-deploy workers and income replacement payments.

Active labour market programs for displaced drivers would mirror those described above as good practice for general unemployment support: job-search assistance, counselling, training, moving allowances, and even direct employment programs. Income replacement payments could also be provided, though these would need to be carefully designed to ensure there were good incentives to work, and that they were available to genuinely displaced drivers (rather than people opportunistically entering the occupation to take advantage of the transitional arrangements). For example, eligibility and level of compensation could be defined by reference to the amount of time in the industry and age, with more generous arrangements for long-serving drivers aged say 55-60 years old (i.e. still several years from retirement age but for whom retraining and redeployment may be an unviable economic proposition on average).

Transitional assistance programs would require significant funding in countries with a substantial number of drivers who become displaced. The most obvious source of revenue for these industry-specific programs is the permit system outlined above (whether an upfront charge or a cap-and-trade system). Such a system could be designed and implemented to raise significant revenue from users in addition to giving jurisdictions significant control over the speed of the transition. An operator would only purchase a permit if they would still find it profitable to deploy driverless technology. And if the revenue raised from this permit sale is re-distributed to ensure the displaced driver is not worse off by the technology, then there is the real prospect of making the situation win-win.

The pricing of permits and redistribution of revenues would likely be done at a national level in both the US and Europe. This would ensure that countries would maintain jurisdictional control over their own roads as well as retaining revenue and spending control within their own borders. Within the European Union, there may be a case for adopting a scheme based on prices and not on the number of permits issued by each country, and putting in place pricing caps and floors, to ensure that driverless truck permits are not used as a *de facto* limitation on the free movement of goods within the Union.

For reasons of fairness, funds targeted for the transitional assistance programs should be generated by the main beneficiaries of the operation of driverless trucks throughout the transport supply chain, including clients. The sale of permits to operators enjoying significant reductions of costs could be complemented by contributions of the general set of all road users, as they will benefit from improved road safety conditions. A small per-kilometre charge could be applied with this purpose, either as an addition to existing fuel charges or (where they already exist) to distance-based road tolls.

The temporary advisory body proposed above would be well placed to advise on all aspects of the transition support for displaced truck drivers. The board could recommend to government the type of labour market programs required, the appropriate design principles for income replacement payments, the level of funding required and the funding mechanisms that could be deployed. For instance, the board could suggest periodic fine-tuning of the number or price of permits (e.g. each year) according to the demand for driverless operation and developments in the labour market (both within truck driving and the extent of job opportunities outside the labour market). If demand for the permits was high, permits would attract high prices (or be sold in large volumes), giving strong revenues for active labour market programs that year; more displaced drivers could be supported, suggesting the release of more permits could be a welfare-improving change the following year. Under this arrangement, policy makers would be specifically empowered and informed to make the trade-off. However, care should be taken to ensure that the transition arrangements are indeed temporary, since institutional arrangements can outlive their intended lifespans as actors inside and outside government may seek to retain the new status quo.

There are further strategic reasons why trucking-industry specific transition arrangements could be beneficial:

- The sector might be one of the first to face wide-spread automation in the current technological "wave", the so-called "second machine age" (Brynjolfsson and McAffee, 2014). A more hands-on approach might enable policy makers to learn lessons about managing the transition that will be applicable to other sectors.
- Tailored arrangements would build confidence with drivers and labour unions that the transition can be smooth. This may assist in a faster and more orderly adoption of the technology so that the safety and productivity gains can be made earlier.

The final recommendation of this report is to *consider a temporary permit system to manage the speed of adoption and to support a just transition for displaced drivers, while ensuring fair access to markets across countries and across modes.*

Discussion

To some readers the proposals made here may seem radical. Directly intervening in the market to slow the adoption of safety- and productivity-improving technology may appear almost Luddite. Further, it may seem unfair to treat truck drivers separately from other workers exposed to job loss.

While the policy considerations proposed here for the labour transition do involve significant intervention, they seek to provide guidance rather than a single prescription. Individual governments will design appropriate transitional arrangements according to the market and policy conditions in their economy.

The policies proposed are also deliberately narrowly focused on truck drivers. This is not because they are more worthy of support, but due to the likely difficulty in introducing wide-ranging policy reform. If it were achievable in the short term, a broad-based safety net improvement would be preferred as it would provide a more equitable solution to the risks that could be faced by many workers in a not so distant future.

The approach proposed here should therefore be seen as achievable and prudent risk management of an uncertain future. It is possible that the transition to automation in the trucking sector and elsewhere will proceed in an orderly fashion, with market forces smoothly directing unemployed drivers into new opportunities elsewhere. In such a scenario, the government's intervention in transition would be largely unnecessary. In practice, the measures could be quickly withdrawn by issuing large numbers of permits or removing the need for permits altogether.

However, the rapid and unprecedented accumulation of computing power described in the previous section suggests that we may well reach a point where human labour is increasingly superseded. In such a scenario, the labour transition arrangements may well prove crucial in keeping humans in charge of their own futures before a strong set of vested interests are formed. Embedding this control into the fabric of the transition could make the adoption less risky from a social welfare perspective and more feasible from a political economy perspective. Transition arrangements proposed here for truck drivers may also help policy makers understand how to best respond to the broader challenges of inequality and underemployment that are proving difficult to tackle with existing policy settings.

References

Acemoglu, D. and J. Robinson (2012), *Why Nations Fail: The origins of power, prosperity, and poverty*, Random House Digital, Inc.

Allen, A. (2015), "Ports tackle profitability challenges through robotics, driverless vehicles and drones," CIPS, 14 December, http://www.cips.org/en/supply-management/news/2015/december/ports-tackle-profitability-challenges-through-robotics-driverless-vehicles-and-drones/ (accessed 3 May 2016).

Allum, A. (2017), "Jobs for the bots? How the UK jobs market is responding to automation", *Executive Insights*, L.E.K. Consulting, Vol. 19/15, http://www.lek.com/our-publications/lek-insights/uk-jobs-market-responding-to-automation (accessed 7 March 2017).

Arntz, M., T. Gregory and U. Zierahn (2016), "The Risk of Automation for Jobs in OECD Countries: A Comparative Analysis", *OECD Social, Employment and Migration Working Papers*, No. 189, OECD Publishing, Paris. http://dx.doi.org/10.1787/5jlz9h56dvq7-en

Atkinson, A. (2015), *Inequality: What can be done?* Harvard University Press, London.

Autor, D. (2015), "Why Are There Still So Many Jobs? The History and Future of Workplace Automation," *Journal of Economic Perspectives*, Vol. 29/3, Summer, pp. 3–30.

Autor, D., F. Levy and R. Murnane (2003), "The Skill Content of Recent Technological Change: An Empirical Exploration", *The Quarterly Journal of Economics*, Vol. 118/4, pp. 1279-1333.

AXA (2015), "The future of driverless haulage," September.

Bartels, A., E. Ulrich and A. Knapp (2014), "System classification and glossary," deliverable D2.1, AdaptIVe Consortium, https://www.adaptive-ip.eu/index.php/deliverables_papers.html (accessed 4 May 2016).

BCG (2015), "Revolution in the driver's seat: the road to autonomous vehicles", April, Boston.

Bessen, J. (2015), "Toil and technology", *Finance & Development*, pp. 16-19, http://www.imf.org/external/pubs/ft/fandd/2015/03/bessen.htm (accessed 7 March 2017)

Brand, J. (2015), "The far-reaching impact of job loss and unemployment," *Annual Review of Sociology*, Vol. 41, August, pp. 359-375.

Brand, J. and T. Von Wachter (2013), "The economic and social consequences of job loss and unemployment," Population Reference Bureau webinar, November 20, http://www.prb.org/Multimedia/Video/2013/job-loss-webinar.aspx (accessed 2 February 2017).

Brynjolfsson, E. and A. McAfee (2014), *The second machine age: work, progress, and prosperity in a time of brilliant technologies*, W.W. Norton & Company.

Bureau of Labor Statistics (2016a), “Current Population Survey”, http://www.nber.org/data/cps_basic.html (accessed 12 July 2016).

Bureau of Labor Statistics (2016b), “Occupational Employment Statistics”, https://www.bls.gov/oes/tables.htm (accessed 12 July 2016).

Bureau of Transport Statistics (2016), “U.S. Vehicle-Miles”, Table 1-35, https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_35.html (accessed 11 August 2016).

Campbell, P. and P. Waldmeir (2016), “Ford plans mass-market self-driving car by 2021,” *Financial Times*, August 16, https://www.ft.com/content/d2cfc64e-63c0-11e6-a08a-c7ac04ef00aa (accessed 17 August 2016).

Census Bureau (2016), Population Projections, https://www.census.gov/population/projections/, (accessed 12 July 2016).

Costello, B. and R. Suarez (2015), “Truck driver shortage analysis 2015,” American Trucking Associations, October.

Davenport, T. and J. Kirby (2016), O*nly Humans Need Apply: Winners and losers in the age of smart machines*, HarperCollins, New York.

“Declaration of Amsterdam: Cooperation in the Field of Connected and Automated Driving” (2016), The Netherlands EU Presidency 2016. http://english.eu2016.nl/documents/publications/2016/04/14/declaration-of-amsterdam.

Delaney, K. (2017), “The robot that takes your job should pay taxes, says Bill Gates”, Quartz, 17 February, https://qz.com/911968/bill-gates-the-robot-that-takes-your-job-should-pay-taxes/ (accessed 23 February 2017).

Department of Transport (DOT) (2017), “U.S. Department of Transportation designates 10 automated vehicle proving grounds to encourage testing of new technologies,” https://www.transportation.gov/briefing-room/dot1717 (accessed 10 May 2017).

Dionori, F., L. Casullo, S. Ellis et al. (2015), “Freight on road: Why EU shippers prefer truck to train,” report for the European Parliament’s Committee on Transport and Tourism.

Diss, K. (2015), “Driverless trucks move all iron ore at Rio Tinto's Pilbara mines, in world first”, ABC News, 19 October, http://www.abc.net.au/news/2015-10-18/rio-tinto-opens-worlds-first-automated-mine/6863814 (accessed 3 May 2016).

ERTRAC (2015), “Automated driving roadmap,” final report, August.

Erzurumlu, S. Sinan and Yaman O. Erzurumlu (2013), “Development and Deployment Drivers of Clean Technology Innovations.” *The Journal of High Technology Management Research*, Vol. 24/2, pp. 100–108. DOI:10.1016/j.hitech.2013.09.001.

European Commission (2016), CARE database (Community Road Accidents Database), http://ec.europa.eu/idabc/en/document/2281/5926.html (accessed 28 February 2017).

European Parliament (2017), “Robots and artificial intelligence: MEPs call for EU-wide liability rules”, Press release, 16 February, http://www.europarl.europa.eu/news/en/news-room/20170210IPR61808/robots-and-artificial-intelligence-meps-call-for-eu-wide-liability-rules (accessed 23 February 2017).

European Union (2015), “Transport in figures”, European Commission Directorate-General for Mobility and Transport.

Eurostat (2016a), “European Union labour force survey”, http://ec.europa.eu/eurostat/web/microdata/european-union-labour-force-survey (accessed 12 July 2016).

Eurostat (2016b), Population projections 2015 at national level, http://ec.europa.eu/eurostat/data/database (accessed 12 July 2016).

Eurostat (2016c), Annual road freight transport by maximum permissible laden weight of vehicle (Mio Tkm, Mio Veh-km, 1 000 Jrnys), code road_go_ta_mplw, http://ec.europa.eu/eurostat/data/database (accessed 11 August 2016).

Feldstein, M. (1978), “The private and social costs of unemployment,” NBER Working Paper 223, Cambridge.

Ford, M. (2015), *Rise of the Robots: Technology and the Threat of a Jobless Future*, Basic Books, New York.

Frey, C. and M. Osborne (2017), “The Future of Employment: How susceptible are jobs to computerisation?” *Technological Forecasting & Social Change*, Vol. 114, pp. 254-280.

Frisoni, R., A. Dall’Oglio, C. Nelson et al. (2016), “Self-piloted cars: The future of road transport?” report for the European Parliament’s Committee on Transport and Tourism.

Global Insight (2005), “The U.S. truck driver shortage: analysis and forecasts,” report prepared for the American Trucking Associations, May.

Grobart, S. (2015), “Daimler veers into maximum overdrive”, Bloomberg, 14 May, http://www.bloomberg.com/news/articles/2015-05-14/daimler-s-freightliner-tests-self-driving-truck-in-nevada (accessed 3 May 2016).

Grubler, A. (1990), *The Rise and Fall of Infrastructures: Dynamics of Evolution and Technological Change in Transport*, Heidelberg: Physica-Verlag. http://pure.iiasa.ac.at/3351/

Helliwell, J. and H. Huang (2014), “New Measures of the Costs of Unemployment: Evidence from the subjective well-being of 3.3 million Americans,” *Economic Inquiry*, Vol. 52/4, October, pp. 1485–1502.

Hogarth, T. and R. Wilson (2015), “The outlook for skills demand and supply in Europe,” in Dolphin, T. (ed.) *Technology, globalisation and the future of work in Europe: Essays on employment in a digitised economy*, Institute for Public Policy Research, London, pp. 17-24.

Horbach, J. 2008, “Determinants of Environmental Innovation: New evidence from German panel data sources,” *Research Policy*, Vol. 37/1, pp. 163–73. DOI:10.1016/j.respol.2007.08.006

IEA (2016), "Modelling of the Transport Sector in the Mobility Model (MoMo)," https://www.iea.org/etp/etpmodel/transport/ (accessed 21 October 2016).

ITF (2016a), "Data-driven Transport Policy,"*International Transport Forum Policy Papers*, No. 20, OECD Publishing, Paris.
DOI: http://dx.doi.org/10.1787/5jlwvz8g4vbs-en

ITF (2016b), *Zero Road Deaths and Serious Injuries: Leading a Paradigm Shift to a Safe System*, OECD Publishing, Paris.
DOI: http://dx.doi.org/10.1787/9789282108055-en

ITF (2016c), *Road Safety Annual Report 2016*, OECD Publishing, Paris.
DOI: http://dx.doi.org/10.1787/irtad-2016-en

ITF (2016d), IRTAD Road Safety Database, http://www.itf-oecd.org/irtad-road-safety-database (accessed 28 February 2017).

ITF (2016e), Survey on "Trends in the Transport Sector", http://stats.oecd.org/ (accessed 28 February 2017).

ITF (2015), "Automated and Autonomous Driving: Regulation under Uncertainty", *International Transport Forum Policy Papers*, No. 7, OECD Publishing, Paris.
DOI: http://dx.doi.org/10.1787/5jlwvzdfk640-en

Janssen, R. et al. (2015), "Truck platooning: Driving the future of transportation," TNO, Delft.

Keefe, P. (2015), "Port Automation Puts Labour on Notice," *Maritime Professional*, Vol. 3, pp. 28-33.

Keynes, J. (1930), "Economic possibilities for our grandchildren," in Keynes, J. (1963), *Essays in persuasion*, W.W. Norton & Co., New York, pp. 358-373.

KPMG (2015), "Connected and autonomous vehicles – the UK economic opportunity," March.

Lammert, M., A. Duran, J. Diez, K. Burton et al. (2014), "Effect of platooning on fuel consumption of class 8 vehicles over a range of speeds, following distances, and mass," *SAE International Journal of Commercial Vehicles*, Vol. 7/2, DOI:10.4271/2014-01-2438.

Lin, J. (2011), "Technological Adaptation, Cities, and New Work." *Review of Economics and Statistics*, Vol. 93/2, pp. 554–74.

Ministry of Infrastructure and the Environment (2015), "Self-driving vehicles - mobility, public transport and road safety," Onderwerp, https://www.government.nl/topics/mobility-public-transport-and-road-safety/contents/self-driving-vehicles (accessed 23 May 2016).

Morgan Stanley (2013), "Autonomous Cars: Self-driving the new auto industry paradigm," Blue paper, https://www.morganstanley.com/articles/autonomous-cars-the-future-is-now (accessed 29 March 2017).

Murthy, S. (2014), Top 10 job titles that didn't exist 5 years ago, https://business.linkedin.com/talent-solutions/blog/2014/01/top-10-job-titles-that-didnt-exist-5-years-ago-infographic# (accessed 20 September 2016).

National Highway Traffic Safety Administration (NHTSA) (2017), "Traffic safety facts, 2015 data: Large trucks", DOT HS 812 373, February, https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812373 (accessed 7 March 2017).

National Highway Traffic Safety Administration (NHTSA) (2016a), "Federal automated vehicles policy: accelerating the next revolution in roadway safety," September, https://www.transportation.gov/AV/federal-automated-vehicles-policy-september-2016 (accessed 24 January 2017).

National Highway Traffic Safety Administration (NHTSA) (2016b), Response to Google letter 12 November 2015, https://isearch.nhtsa.gov/files/Google%20--%20compiled%20response%20to%2012%20Nov%20%2015%20interp%20request%20--%204%20Feb%2016%20final.htm (accessed 24 January 2017).

National Highway Traffic Safety Administration (NHTSA) (1999), "NHTSA light vehicle antilock brake system research program task 4: A test track study of light vehicle ABS performance over a broad range of surfaces and manoeuvers," Final report, January, DOT HS 808 875.

National Research Council (2013), "Transitions to alternative vehicles and fuels," National Academies Press, Washington, D.C.

Newcomer E. and A. Webb (2016), "Uber self-driving truck packed with Budweiser makes first delivery in Colorado," Bloomberg Technology, https://www.bloomberg.com/news/articles/2016-10-25/uber-self-driving-truck-packed-with-budweiser-makes-first-delivery-in-colorado (accessed 24 January 2017).

Newman, K. (1988), *Falling from Grace: The Experience of Downward Mobility in the American Middle Class*, Vintage Books, New York.

Nordhaus, W. (2015), "Are We Approaching an Economic Singularity? Information Technology and the Future of Economic Growth", *NBER Working Paper*, 21547.

Nordhaus, W. (2007), "Two centuries of productivity growth in computing," *The Journal of Economic History*, Vol. 67/1, pp. 128-159.

O*NET Resources Center (2010), "Occupational Listings: New & Emerging occupations," https://www.onetcenter.org/taxonomy/2010/new_emerging.html (accessed 20 September 2016).

OECD (2016a), Historical population data and projections (1950-2050), http://stats.oecd.org/ (accessed 12 July 2016).

OECD (2016b), *Survey of adult skills (PIAAC)*, http://www.oecd.org/skills/piaac/publicdataandanalysis/ (accessed 20 September 2016).

OECD (2015), *In It Together: Why Less Inequality Benefits All*, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/9789264235120-en

OECD (2011), *Divided We Stand: Why Inequality Keeps Rising*, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/9789264119536-en

OECD (2008), *Growing Unequal?: Income Distribution and Poverty in OECD Countries*, OECD Publishing, Paris.
DOI: http://dx.doi.org/10.1787/9789264044197-en

OICA (2015), "Production Statistics" and "Sales Statistics" for 2014-15, http://www.oica.net/category/sales-statistics/ (accessed, 25 May 2016).

Panteia (2015), "Cost comparison and cost developments in the European road haulage sector," November, Zoetermeer.

Pew Research Center (2014), "AI, Robotics, and the Future of Jobs", August, http://www.pewinternet.org/2014/08/06/future-of-jobs/ (accessed 20 September 2016).

Podgursky, M and P. Swaim (1987), "Job Displacement and Earnings loss: Evidence from the displaced worker survey." *Industrial and Labor Relations Review*, Vol. 41, pp. 17-29.

Productivity Commission (2014), *Australia's automotive manufacturing industry*, Inquiry Report No. 70, Canberra.

PwC (2016), "UK Economic Outlook," March, http://www.pwc.co.uk/assets/pdf/ukeo/uk-economic-outlook-full-report-march-2016.pdf (accessed 19 September 2016).

PwC (2015a), "The 2015 global innovation 1000, innovation's new world order," report by Strategy&.

PwC (2015b), "Connected car study 2015, racing ahead with autonomous cars and digital innovation," report by Strategy&.

Quintini, G. and D. Venn (2013), "Back to work: Re-employment, earnings and skill use after job displacement", in *OECD Employment Outlook 2013*, OECD Publishing, Paris.
DOI: http://dx.doi.org/10.1787/empl_outlook-2013-8-en

Ross, A. (2016), *The industries of the future*, Simon & Schuster, New York.

SAE (2014), "Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems", http://standards.sae.org/j3016_201401/ (accessed 10 May 2016).

Samek Lodovici, M., E. Pastori, C. Corrias et al. (2009), "Shortage of qualified personnel in road freight transport," report for the European Parliament's Committee on Transport and Tourism.

Schwab, K. (2016), *The fourth industrial revolution*, World Economic Forum, Cologny/Geneva.

Singh, S. (2015), "Critical reasons for crashes investigated in the National Motor Vehicle Crash Causation Survey," National Highway Traffic Safety Administration, Traffic Safety Facts Crash Stats, Report No. DOT HS 812 115, Washington, D.C.

Somers, A. and K. Weeratunga (2015), "Automated vehicles: Are we ready?" report for Main Roads Western Australia, January.

State Government of Victoria (2013), "Creating a Market: Victorian Electric Vehicle Trial Mid-Term Report," Melbourne, http://apo.org.au/files/Resource/vicgov_electric-vehicle-trial-mid-term_2013.pdf (accessed 31 March 2017).

Stern, A. (with L. Kravitz) (2016), *Raising the Floor: how a universal basic income can renew our economy and rebuild the American dream*, Public Affairs, New York.

Stojaspal, J (2016), "Follow the Leader," *Intertraffic World*, annual showcase, pp. 26-29.

Sullivan, D. and T. von Wachter (2009), "Job Displacement and Mortality: An analysis using administrative data," *Quarterly Journal of Economics*, Vol. 124, pp. 1265-1306.

Takahashi, D. (2005), "Forty years of Moore's Law," *The Seattle Times*, 18 April, http://www.seattletimes.com/business/forty-years-of-moores-law/ (accessed 15 September 2016).

Tesla (2016), "Master plan, part deux," 20 July, https://www.tesla.com/fr_FR/blog/master-plan-part-deux (accessed 26 October 2016).

The Economist (2016a), "The shipping news," 19 March, http://www.economist.com/news/finance-and-economics/21695096-europes-biggest-port-barometer-world-economy-shipping-news (accessed 20 January 2017).

The Economist (2016b), "From not working to neural networking," 25 June, http://www.economist.com/node/21700756/ (accessed 15 September 2016).

Tobin, J. (1970), "On limiting the domain of inequality," *Journal of Law and Economics*, Vol. 13, pp. 263-277.

Triguero, A., L. Moreno-Mondéjar and M. Davia (2013), "Drivers of Different Types of Eco-Innovation in European SMEs," *Ecological Economics*, Vol. 92 (August), pp. 25–33. DOI:10.1016/j.ecolecon.2013.04.009.

Torrey, W. and D. Murray (2015), "An analysis of the operational costs of trucking: 2015 update," American Transportation Research Institute, Arlington.

Underwood, S. (2014), "Automated vehicles forecast, vehicle symposium opinion survey," presentation to Michigan Connected and Automated Vehicle Working Group Meeting, 9 October.

United Nations (2015), "World population prospects: Key findings and advanced tables," Department of Economic and Social Affairs - Population Division, New York.

US Department of Transport (US DOT) (2017), "U.S. Department of Transportation designates 10 automated vehicle proving grounds to encourage testing of new technologies," 19 January, https://www.transportation.gov/briefing-room/dot1717 (accessed 27 January 2017).

Verint (2016), "The digital tipping point: how do organizations balance the demands for digital and human customer service?", White Paper, http://www.verint.com/digital-tipping-point/ (accessed 7 March 2017).

Walker, J. and C. Johnson (2016), "Peak Car Ownership: The Market Opportunity of Electric Automated Mobility Services," Rocky Mountain Institute.

Walker Smith, B. (2014), "Automated vehicles are probably legal in the United States," *Texas A&M Law Review*, Vol. 1, pp. 411-521.

World Health Organization (WHO) (2015), *Global Status Report on Road Safety 2015*, www.who.int/violence_injury_prevention/road_safety_status/2015/en/ (accessed 26 January 2017).

Annex 1. Estimating heavy-truck driver employment

Comprehensive labour force data is not available either in the US or Europe on the exact employment category of heavy truck drivers. In the US, the largest challenge is that job category definitions are too aggregated in the workforce age data that are needed for the projections. In contrast, European data has detailed workforce age data for heavy truck drivers, but the series coverage is not comprehensive across countries or time. To overcome these challenges best-estimate datasets of the truck driver labour force are developed based on some simplifying assumptions for each region.

United States

Based on the classifications for occupations and industries used by the Bureau of Labor Statistics (BLS), the ideal definition for heavy-duty truck drivers in long-distance freight would combine the occupation "heavy and tractor-trailer truck drivers" (SOC 53-3032) and the industries "general freight trucking, long-distance" (NAICS 48412) and "specialized freight trucking, long-distance" (NAICS 48413). Unfortunately, the Current Population Survey collected by BLS does not contain microdata (i.e. with age and gender categories) at this level of occupation disaggregation. Instead workers employed as "driver/sales workers and truck drivers" (SOC 53-3030) are isolated within the "truck transportation" industry (NAICS 484). To support this task, the BLS undertakes a detailed but occasional survey that yields data for the Occupational Employment Statistics program. From this data, it can be estimated that in May 2015 94% of people employed as "driver/sales workers and truck drivers" in the "truck transportation" industry are heavy and tractor-trailer truck drivers (Table A1). This percentage can then be used to scale the age microdata of employment in the truck transportation industry to estimate heavy-truck drivers by age group.

Table A1. **US employment by occupation and industry, May 2015**

	Classification (2010 SOC)	All industries	Truck transportation industry (NAICS 484)	
		Employment	Employment	Share (%)
Driver/sales workers	53-3031	417 660	6 720	1
Heavy and tractor-trailer truck drivers	53-3032	1 678 280	848 640	94
Light truck or delivery services drivers	53-3033	826 510	51 080	6
Total	**53-3030**	**2 922 450**	**906 440**	**100**

Source: Bureau of Labor Statistics (2016b) Occupational Employment Statistics.

To complete the estimate of heavy-truck drivers, in-house drivers also need to be accounted for. From the Occupational Employment Statistics, which does not include self-employed, it can be estimated that the truck transportation industry employs around half of all heavy and trailer-tractor drivers. This percentage is applied to the number of employees obtained from the microdata (78% of the sample) and added to the self-employed figure. In this way the entire population of heavy-truck drivers can be estimated (Table A2).

Table A2. **Development of annual heavy-truck employment estimates for the US, 2015 data**

Employment classification	Employment	Sources and assumptions
Driver/sales workers and truck drivers in the truck transportation industry (excluding self-employed)	1.1 million	Current Population Survey (2015)
Heavy-truck drivers in the truck transportation industry (excluding self-employed)	1.0 million	Apply 94% of “Driver/sales workers and truck drivers” taken from Table A1
Heavy-truck drivers in all industries (excluding self-employed)	2.1 million	Apply ratio of heavy truck drivers in all industries to truck transportation industry (1 678 280/848 640 = 2.0) from Table A1
Heavy-truck drivers in all industries (including self-employed)	2.4 million	Current Population Survey (2015)

Europe

European data is based on the International Labour Organization (ILO) classifications, and the closest match for this study is “heavy truck and lorry drivers” (ISCO 8324 until 2010 and ISCO 8332 since 2011). Not all the European countries provide labour force microdata with occupations at a 4-digit level. Instead, for some it is only possible to identify more aggregated categories: “motor-vehicle drivers” until 2010 (ISCO 832) and “heavy truck and bus drivers” (ISCO 833) since 2011. In 2015, heavy truck drivers account for around 79% of these 3-digit employment categories in the 21 countries with 4-digit information. These countries with 4-digit-level occupations data cover 73% of total 3-digit driver employment in the sample in 2015. As such, the 79% factor was applied to the 3-digit employment numbers in cases where a full time series of 4-digit heavy truck driver employment is not available. This gives an estimate for overall 4-digit heavy truck driver employment numbers for Europe (Table A3).

Table A3. **Development of annual heavy-truck employment estimates for Europe, 2015 data**

Country group	Countries	Aggregated employment	Disaggregated employment	
		"Heavy truck and bus drivers" (3-digit, ISCO 833)	"Heavy truck and lorry drivers" (4-digit, ISCO 8332)	Ratio
Complete data	21*	3.0 million	2.4 million	0.79
Reporting at 3-digits	8**	1.1 million	0.9 million***	0.79***
Total	29	**4.1 million**	**3.2 million*** **	**0.79*** **

* Countries are: Austria, Belgium, Cyprus[2], Czech Republic, Estonia, Finland, France, Germany, Hungary, Ireland, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Romania, Sweden, Slovak Republic, Slovenia and United Kingdom. Of these, only 16 were reporting at the 4-digit level for the period 2006-2015.
** Countries are: Bulgaria, Denmark, Greece, Iceland, Italy, Latvia, Portugal and Spain.
*** Estimate.
Source: ITF calculations based on Eurostat (2016a) European Labour Force Surveys.

In addition to these challenges, some minor data smoothing was required in some individual country series to ensure a time series was available back to 2004. First, for Norway and Malta, 4-digit data was missing for 2004 and 2005. The above approach was applied to produce estimates for these years. Second, for Germany, the 2011 data (at the time of the transition between two ILO classifications) was anomalous, so an estimate based on an interpolation of the 2010 and 2012 observations was produced.

[2] Note by Turkey
The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Creek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue".

Note by all the European Union Member States of the OECD and the European Union
The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey the information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

Notes

1 These categories are not exhaustive of the entire freight task, but provide a functional distinction for the purposes of high level quantification of impacts.

2 Janssen et al. (2015) argue that there is a possible intermediate scenario where the driver in a "trailing vehicle" would be able to rest (sleep, recreation, etc.), so as to stagger active driving shifts in the leading vehicle. While this could offer some improved range for long-distance trucks in a given day, there would still be labour expense and labour constraints on the number of operating hours per day (constraints would be more permissive than for the case with all members of a platoon being "active" drivers).

3 Several incumbent operators are collaborating with technology companies (e.g. GM-Lyft and potentially Ford-Google) or exploring fully self-driving cars themselves (e.g. Volvo's Drive Me pilot).

4 In the US the hurdle is that vehicles with automated driving systems need to be self-certified (and a sample tested by NHTSA), but driverless operation seems not to be illegal to per se (NHTSA, 2016b; Walker Smith, 2014). In Europe, the Vienna (1949) and Geneva (1968) conventions would need to be amended to relax the requirements for a "driver" (Frisoni et al., 2016).

5 It is clear that for driverless systems, the insurance liability and premiums would need to fall on the vehicle or system manufacturer rather than the driver or road freight operator. Nevertheless, such costs would ultimately be passed on to road freight operators through the price of the vehicle so this report does not explore this issue further.

6 Other reasons for lower or slower passenger vehicle adoption compared to freight transport might include a positive enjoyment of driving, or a dislike of the passenger experience with driverless technology.

7 Indeed the shift towards computer-based driving systems introduces new risks that will be hard for the public to assess. For example, the risk of malicious hacking into systems and the risk of software and hardware malfunctions both have the potential to cause crashes.

8 For an example of lobbying against changes in road vehicle weights and dimensions supported by competing transport modes see http://www.nomegatrucks.eu/.

9 This average figure masks the difference between urban and long-distance freight "driver intensity": in urban areas lower speeds and more frequent stops would mean that a higher than average number of drivers would be required to complete a million truck kilometres. However, neither the employment nor the vehicle kilometre series distinguish between urban and long-distance, so for simplicity we apply the same ratio in both cases.

10 For example, in France there are two programs that offer employers large wage subsidies to employ either younger unskilled workers (*emploi d'avenir*) or older workers (*contrat unique d'insertion*) for a period of one to three years.

Managing the Transition to Driverless Road Freight Transport

This report considers how a transition to driverless road freight transport could happen. Today's technology already makes it possible to operate automated trucks. Reduced reliance on humans to move road freight in the future could offer large cost savings for businesses and consumers. It could also disrupt the careers and lives of millions of professional truck drivers. Based on different scenarios for the large-scale introduction of automated road freight transport, this study makes recommendations to help governments manage potential disruption and ensure a just transition for affected drivers.

Three leading transport-sector organisations joined the International Transport Forum for this study to assess benefits, costs and risks of driverless trucks. The International Road Transport Union, the International Transport Workers' Federation and the European Automobile Manufacturers Association contributed data and insights on driverless technology in the road freight sector as well as funds for the research.

This report is part of the International Transport Forum's Case-Specific Policy Analysis series. These are topical studies on specific issues carried out by the ITF in agreement with local institutions.

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