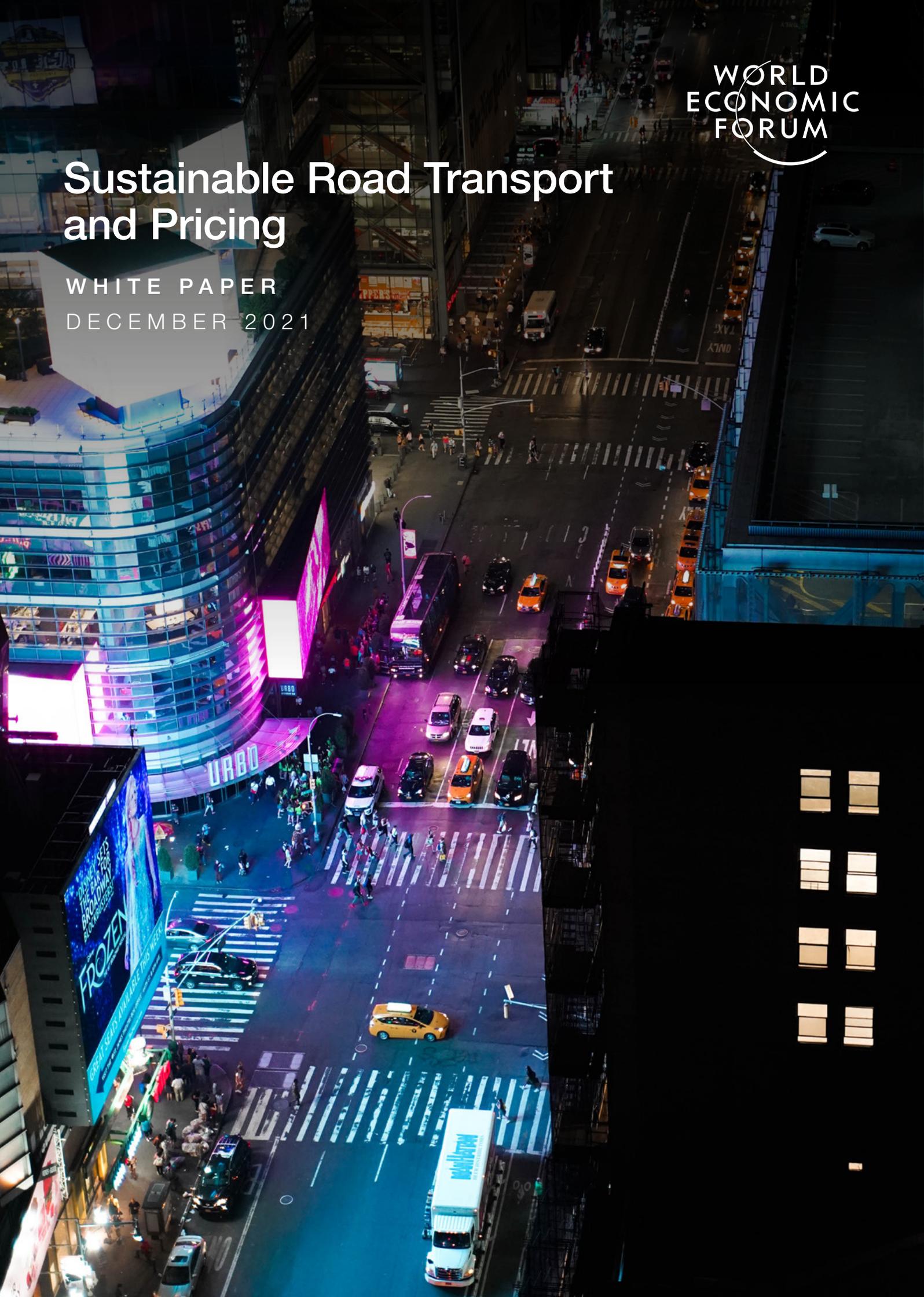


Sustainable Road Transport and Pricing

WHITE PAPER
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Preface

Initial transport responses to the COVID-19 pandemic included a suite of changes to road-space utilization: for example, parking areas converted to designated loading zones or restaurant spaces, or roads closed to through traffic and opened to pedestrians and active mobility users. These changes in road-use (or land-use) regulation exposed the many alternative uses of streets, curbs and sidewalks and sparked a public debate. At the heart of the discussion is the question of how public space can best be allocated to mobility stakeholders. This topic is not new to experts and advocates in the field, who have been grappling for some time to determine policy tools to balance the societal, environmental and economic impacts of traffic.

New York recently announced it would join cities like Singapore, London and Stockholm in implementing a pricing scheme for road users on its most highly trafficked streets. Other cities in the United States began exploring pricing schemes – often colloquially referred to as “congestion pricing” in the media – to

mitigate various pressures on urban public space and generate much needed funding for public transport.¹ In the intent to price road traffic to reflect its cost, it is clear that pricing schemes must be designed with the impact on travellers in mind.

The World Economic Forum’s multistakeholder and interdisciplinary [Global Future Council on Urban Mobility Transitions](#) examines the intersection of cities and mobility at the nexus of such challenges. It assesses how urban mobility affects communities and seeks to foster a sustainable mobility future that is clean, equitable and financially resilient.

This White Paper is a joint effort of the members of the Global Future Council on Urban Mobility Transitions to examine the elements of road pricing mechanisms and evaluate how changes could have an effect on travellers and mobility operators alike. Its goal is to call for the acceleration towards equitable, clean and financially resilient mobility through continued examination of the impact of road transport on society.



Executive summary

Mobility is a fundamental human need and an essential part of everyday life as it provides access to employment, food, education, health and social needs. It lays the foundation for prosperity and growth and depends on other critical systems, at an individual, community and societal level. A well-informed choice of accessible transport modes for every trip or delivery is still a luxury for many, and the lack of choice perpetuates existing inequities.

One option for road traffic to become more sustainable and efficient is to adjust pricing mechanisms to better reflect the overall costs and effects on society of the respective mode. Historically, the cost of using roads and curbside parking spaces in many cases has neither been felt in the wallets of individuals traversing city streets nor by mobility operators. The full direct and indirect costs of driving on congested roads in city centres, of parking vehicles in public spaces, or of emitting pollutants are not reflected in the price mobility operators and users pay. Additionally, mobility taxes are often low, do not reflect the effective use of assets or infrastructure, or take into account the overall effects on public health, public safety, air quality, traffic flows or the many associated

economic costs. Since the 1970s, cities across the globe have implemented pricing mechanisms for parking, emission and congestion pricing.

This White Paper offers a rationale for re-examining current mobility costs with a particular focus on road transport. It reviews approaches to apply the concept of mobility pricing more broadly: for example through parking, emission, congestion and curb pricing schemes. The development of technological solutions enabling smart charging schemes and the advent of new mobility options, such as ride-hailing and e-scooter sharing, provide the opportunity to use pricing mechanisms to re-establish the allocation of public space and redeploy the scarcity of resources to cleaner, more equitable and financially resilient mobility. Noting the inherent inequities of road transport, this paper calls for revisions to pricing mechanisms made in conjunction with comprehensive mobility plans designed in partnership with communities to address their needs. With investment in shared, zero-emission and active mobility solutions combined with differential mobility fees, credits or scrappage schemes, changes to road transport pricing can address the prevailing challenges.



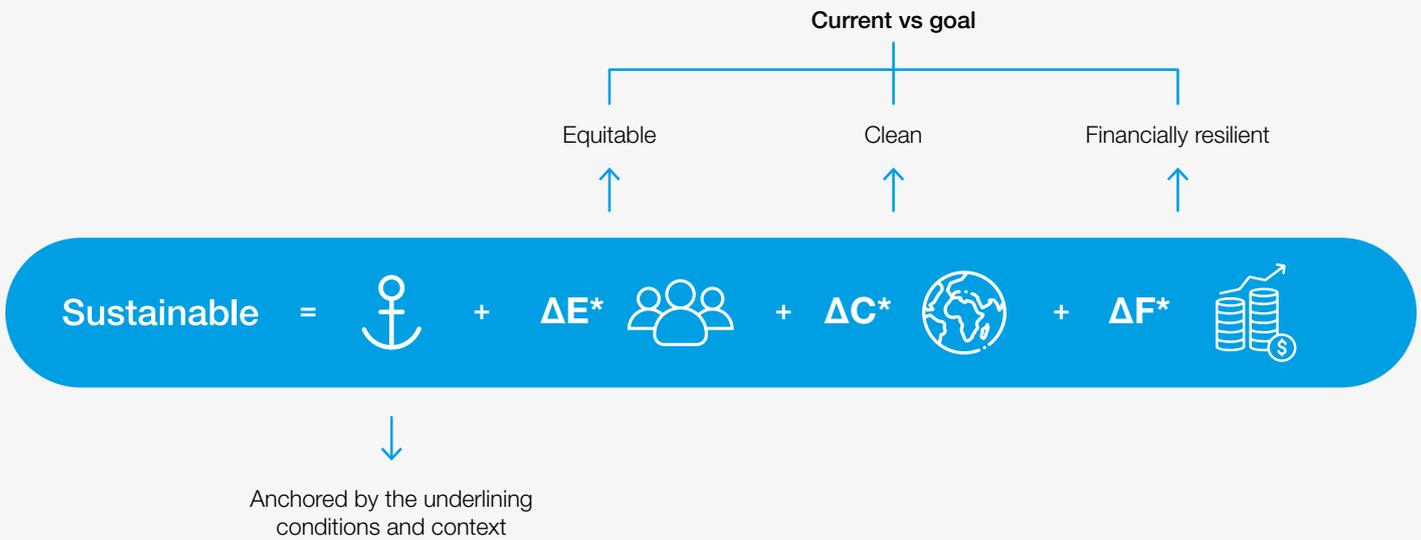
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Introduction

No discussion on mobility can be structured without first clarifying the goals it means to accomplish. The authors of this White Paper assert that an ideal mobility future is one that is: 1) equitable as well as efficient for all; 2) safe, secure, clean and supportive of the Paris Agreement on climate change; and 3) financially resilient. The authors also stress that these goals should be pursued jointly and not addressed separately. Mobility goals can be manifested in a single word: sustainability² (Figure 1).

Contemporary mobility discourse is rooted in these common goals and the potential trade-offs between them. Does improving the safety and security of a transit system in turn weaken its efficiency? And if universal access to it is provided, does that alter the transport system's ability to be fiscally resilient or ensure decarbonization? How can these compromises be decided?

FIGURE 1 Formulating a sustainable mobility ecosystem



Source: World Economic Forum

Is it possible for road pricing mechanisms to place the transport system on a path to efficiency and financial resiliency and at the same time on a path of decarbonization and equity? As shown in Figure 2, road pricing systems should be designed to account for the economic, environmental and societal impacts of road transport:

- **Societal impact:** Road pricing should allow the efficient achievement of social goals. It can increase social inclusivity by enabling historically underserved communities living in “mobility deserts” to access jobs, healthcare, education and other vital aspects of everyday life efficiently, safely and affordably.
- **Environmental impact:** Road pricing should provide incentives to achieve environmental targets such as net zero carbon, zero NOx/SOx, zero human-made particulate matter or zero noise goals. It can include incentives for transitioning fuel type to electric or hydrogen propulsion. Additionally, it can encourage changes in overall road usage to alleviate

challenges during peak periods and alter how space is used, such as for parking.

- **Economic impact:** Road pricing should allow the efficient use of scarce infrastructure for parking and traffic by refinancing its life cycle cost. It should limit non-essential motor vehicle traffic, which will help to reduce the direct and indirect costs of congestion and improve travel times for essential journeys. The pricing ideally should fluctuate dynamically according to space utilization and the levels of usage over time, and induce efficient road infrastructure use. Scarce infrastructure commands a higher price to use.

This paper summarizes how revised road transport pricing for motor vehicles could support sustainable mobility, what the potential ramifications of disrupting the status quo would be and how road pricing changes could be implemented.

To date, three road pricing models can be distinguished: 1) zone pricing (cordon tax); 2) curb

pricing; and 3) trip pricing (per-ride, managed lanes, occupancy level). Experimentation with these so far has been limited. Pricing mechanisms have been initiated as the mindset and acceptance of a wide array of users have changed. Typically, mobility users and communities (directly or indirectly) gain comfort with pricing schemes by participating in the planning process through direct consultation addressing concerns and through the real-life experience of pilot implementation and initial results. The realities of car-free streets and clean air forced on the world by the COVID-19 pandemic could provide a real-life experience for cities.

The pathway to efficient and transparently priced road usage should lead to a clean, equitable and financially resilient – or, in other words, sustainable – future, if carefully and thoughtfully reimagined, redesigned and implemented.

Figure 3 shows alternative terminology to refer to the societal, environmental and economic components of sustainable road transport. In this paper, the terms used to describe sustainable mobility are “equitable”, “clean” and “financially resilient”.

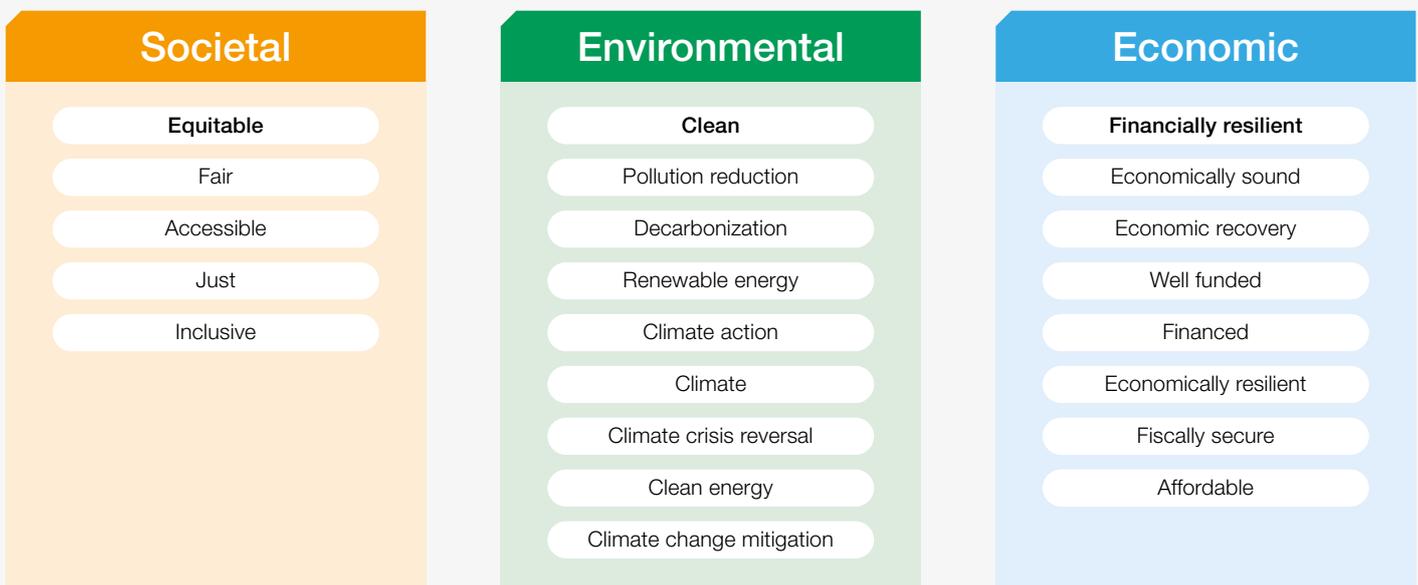
FIGURE 2 Road pricing: Making road traffic sustainable by incorporating societal impacts in individual choices

Sub-goals for road pricing in the context of sustainable mobility

Goals	Examples
 <p>Economic: Efficient use of scarce infrastructure</p>	<ul style="list-style-type: none"> – Financing life cycle infrastructure costs through user fees – Allowing intermodal competition by dynamically allocating scarce capacity through flexible pricing for both parking and traffic flows
 <p>Environmental: Efficient achievement of environmental targets</p>	<ul style="list-style-type: none"> – Defining pricing relative to specific space usage – Incentivizing low/zero emission drivetrains (emissions: CO₂, NO₂, particulate matter, noise) – Allocating space for moving or parked vehicles
 <p>Societal: Efficient achievement of social goals</p>	<ul style="list-style-type: none"> – Enabling communities' efficient, safe and affordable access to vital life services – Improving access for all communities, including for people of colour, individuals with disabilities, low-income individuals, LGBTQ individuals, women – Providing differential mobility fees or credits

Source: World Economic Forum

FIGURE 3 Finding the right terminology to refer to the components of sustainable road transport



Source: World Economic Forum

2

Towards transparent pricing:

Price modifications that can account for the societal, environmental and economic impacts of road transport

2.1 Why prices work: The rationale behind pricing mechanisms

Several schools of thought have attempted to evaluate the societal costs of activities such as environmental and ecological economics. Information about and alignment over the spread of costs and value across temporal and spatial, direct and indirect elements of a range of activities remain debatable.³ Recognizing this, this paper focuses specifically on pricing mechanisms in the context of road transport use – one element of mobility pricing overall. In this context, pricing mechanisms reflect the fundamental economic idea that prices synchronize supply and demand in an efficient way. Prices, when allowed to dynamically fluctuate, function as an allocation mechanism for scarce or finite resources, such as roads and parking.

Mobility pricing mechanisms fail when components often thought of as public goods, such as road usage and parking, are not deployed in an equitable and efficient way, contributing to increased pollution and emissions and impeding financial resilience. In economics, this phenomenon is explained as the “tragedy of the commons”, a situation in which users tend to overexploit shared resources as long as externalities, such as environmental degradation, remain unaccounted for. The tragedy of the commons is what travellers experience during their morning rush hour commutes or when they spend hours in traffic jams before a holiday. Building more roads will not solve this issue of overcrowding. As recent research has found, in the absence of road pricing, the expanded road network will become just as congested as previously⁴ – the tragedy of the commons at work.

One may argue that users already incur significant cost when losing hours in traffic jams as they adapt their behaviour according to expected delays and congestion shown on web mapping platforms.

However, road users typically accept excess fuelling or charging costs and even time stuck in traffic as personal costs. Yet no individual or single mobility provider can take into account the full combined social cost of their actions – the climate, health and economic consequences imposed on society – for example, their vehicle adding to traffic and therefore contributing to the delay of other travellers. Obviously, the same applies to the impact on the health of local communities as the individual travels in a private vehicle powered by fossil fuels on a highway that divides low-income communities, or to the increase in overall carbon emissions that affects global climate for decades to come. This difference between private and social costs is an economic externality that only policy-makers are positioned to solve. A pricing mechanism aims to make the costs to society of transportation usage transparent and tangible so individual choices can be improved and adjusted according to their “real” cost or impact on society.

Given the complexity of internalizing the costs of road-use borne by society, policy-makers need to rely on interdisciplinary research and tools, which are still evolving. Economists have been working on internalizing externalities by using price tags that level the difference between private and societal costs (climate, health, economic costs that impact even those who are not using the common good) for over two decades. The desired result is to determine the complete cost for using a resource, be it road space, grid capacity, ecosystem services or any other “common” with a discrepancy between the private and social costs of consumption. Given the evolving nature of society, mobility and technology, and the spatial and temporal differences in the way pricing factors are valued, any cost is subject to change over time and place.

“ A pricing mechanism aims to make the costs to society of transportation usage transparent and tangible so individual choices can be improved and adjusted according to their “real” cost or impact on society.

2.2 Direct and indirect transport costs

Using road infrastructure incurs various types of costs that can be classified as direct, or visible, and indirect, or hidden. Direct costs are associated with assets like building and maintaining the road infrastructure and areas that are used for parking. These costs mostly stay with the authority that built the asset and owns it. The authority may charge usage fees through taxes and built-in fees. Indirect costs are more difficult to quantify, as they are linked to the societal effects of road usage through traffic and therefore are rarely charged. Revising pricing mechanisms is an attempt to better account for the socio-economic impact of mobility that is not reflected in the direct cost of amortizing the capital and operating cost of the physical asset.

Table 1 outlines key transportation costs that should be taken into consideration when revising road transport pricing to reflect societal, environmental and economic impacts. A road pricing scheme better reflecting both the direct and indirect costs will alter road users' travel decisions and how they assess affordability, accessibility and efficiency, and understand their preferences.

Previously hidden costs – related to personal time or convenience as a result of road congestion – may now be featured as part of the “economic cost” and considered more greatly by users debating how to adjust their travel. Affordability may also become a greater issue. Users will be affected differently depending on access to alternate methods of travel.

TABLE 1 Types of transport cost

Cost	Type	For	From	Negative impact
Direct costs (visible costs related to infrastructure)	Infrastructure cost	The development and construction of physical and technological assets for road transport (including road infrastructure and parking infrastructure)	Taxes and/or user fees	<ul style="list-style-type: none"> – Lack of integrated planning of transport and city infrastructure – Increased population density
	Maintenance cost	The upkeep of physical and technological assets for road transport (including road infrastructure and parking infrastructure)	Taxes and/or user fees	
Indirect cost (hidden costs related to society's use of road transport)	Communal cost	The cumulative physical and psychological impact on communities and society	Not included in user fees	<ul style="list-style-type: none"> – Lack of equitable, accessible and affordable mobility options – Depreciation of land value due to infrastructure – Difficult to quantify
	Parking and curb cost	The occupation of infrastructure space for temporary road transport use (e.g. vehicle storage, vehicle loading or locating services)	User fees	<ul style="list-style-type: none"> – Opportunity cost for land use/potential use to limit access to the inner city – Contribution to congestion (equivalent to 30% of city traffic) through parking space searches – Difficult to quantify
	Congestion cost	The use of road transport infrastructure and facilities at an exceeded capacity	Taxes and user fees	<ul style="list-style-type: none"> – Opportunity cost for the individual from lost time in traffic – Societal cost through wasted productive time – Difficult to quantify
	Climate cost	Road-transport-induced climate change caused by land use, infrastructure and fossil-fuel-powered vehicles	Not included in user fees	<ul style="list-style-type: none"> – Lack of equitable, accessible and affordable zero-emission mobility options – Increased cost as long as fossil-fuelled vehicles remain preferred/only possible mode and incentivized by regulators and operators – Difficult to quantify
	Health cost	Air pollution, noise pollution, injury or loss of life due to road transport	Not included in user fees	<ul style="list-style-type: none"> – Variable according to the proximity to high-traffic roads – Disproportionate impact on people of colour and low-income groups – Difficult to quantify
	Financial cost	Monetary loss at the individual or societal level	Not included in user fees	<ul style="list-style-type: none"> – Difficult to quantify

2.3 Reactions to pricing mechanisms

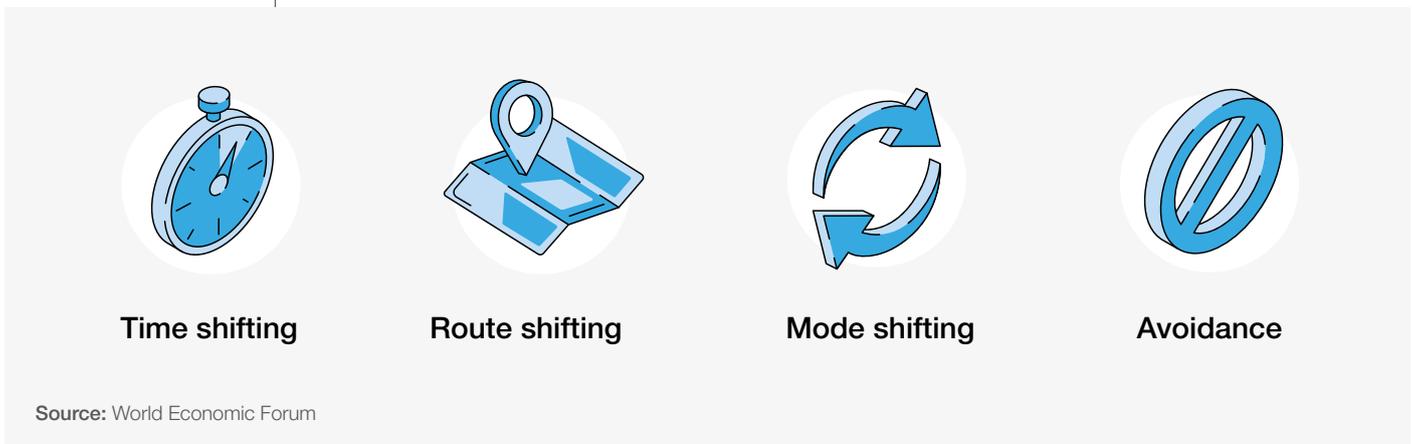
Reactions to dynamic pricing mechanisms (Figure 4),⁵ regardless of whether they represent consequential adjustments or preferences, generate four types of mobility user responses:

- **Time shifting:** leaving earlier or later to avoid peak hours or to account for longer trips
- **Route shifting:** modifying the path travelled either by travelling circuitously to avoid pricing zones or by changing destinations

- **Mode shifting:** using one or more mode(s)
- **Avoidance:** forgoing travel due to lack of alternative route, mode or affordability.

It is critical to design a pricing mechanism that takes into account and closely evaluates the pricing effects on the full mobility system.

FIGURE 4 Reactions to dynamic pricing



Implementation mechanisms and technology

3.1 Mechanisms to devise road prices in relation to actual costs

Marginal-cost pricing, “the practice of setting the price of a product to equal the extra cost of producing an extra unit of output”,⁶ has become an accepted approach to achieve improved accessibility and efficiency on congested roadways during peak periods. In addition to implementing pricing mechanisms in accordance to a geography’s transportation policy, the policies of each related sector, such as infrastructure and power systems, must be considered. Policy-makers should define quality objectives that lead to cleaner, more equitable and financially resilient sectors (for example through target road speeds, a pollution limit or a maximum noise level, as well as provisions for subsidized discounts and mobility credits). These objectives will impose capacity constraints on these sectors, which marginal-cost pricing can help to balance.

To achieve a meaningful response through shifts in demand and to reflect external costs, prices should be as dynamic and differentiated as possible and should take into consideration geographical nuances. In a road congestion context, prices should ideally be flexible to balance supply and demand, and should consequently vary over time and location as well as according to vehicle type, size, occupancy level, air pollution emissions, etc. Road capacity (or supply) changes in relation to time and location and can thus align well with demand by vehicle type. A similarly differentiated pricing regime is being applied to electricity grid congestion management, where the marginal costs of electric vehicle charging vary by time and location. As the cost of carbon emissions is independent of location and time, a temporal and spatial price differentiation of that element may not be required. Land use

and infrastructure cost also do not require a temporal and spatial price differentiation.

A core questions when pricing road transport is how to determine the price relative to the actual costs of the direct and indirect externalities specified in Table 1. Traditional pricing approaches typically assume a centralized market design in which an independent operator broadcasts time- and location-dependent price signals to travellers in the anticipation that the travellers will adjust their mobility behaviour accordingly. This approach assumes knowledge of individual price elasticities or the responsiveness of users to varying prices, which complicates the definition and setting of prices. Modern approaches have been proposed that “learn” how users respond to prices and price elasticities through real-world experimentation and simulations.⁷ A standard price approach reflects supply and demand and avoids issues of price elasticity. Policy-makers define objectives or quantities and use the price mechanism to ensure that these objectives are achieved.

Both the traditional approach of fixed pricing and the modern approach of dynamic pricing are challenging to implement. Road transportation is an essential component of everyday life and making alterations to its pricing structure – even in temporary pilot schemes – can negatively impact the basic well-being of individuals and communities. Additionally, studies take considerable time, whether they comprise simulations or live pilots. The example of Singapore, however, illustrates that differentiated and continuously updated pricing can be implemented with success by using centralized price-setting algorithms. (See Box 2 for more information on pricing mechanisms in Singapore.)

“ Prices should be as dynamic and differentiated as possible and should take into consideration geographical nuances.

3.2 Lessons learned from international cases

Globally, several existing pricing mechanisms offer solutions that can bring road transport pricing in line with actual costs (Table 2). Existing pricing schemes can be distinguished by: 1) the type of spatial

differentiation in prices (e.g. facility-based, area-based, distance-based); 2) the degree of temporal differentiation in prices; and 3) other dimensions of toll differentiation (e.g. car size, emissions).⁸

TABLE 2 Selected road pricing scheme evaluation by key performance indicator

Key performance indicator	Stockholm	London	Singapore	Milan	Gothenburg
Mechanism	LEZ 1996 CC 2007	CC 2003 LEZ 2008	ALS 1975 ERP 1998	LEZ 2008 CC 2012	CC 2013
Time to prepare	4 years	3 years (CC)	13 years (ERP)	2 years (LEZ)	9 years
Motor vehicle trip reduction	22%	16% all 30% charged	44% initially (in 1975); additional 15% with new technology in 1998	34%	12%
GHG reduction	14%	17%	15%	22%	2.5%
Travel time	33% reduction in delays	30% reduction in delays	Price adjustments manage speeds to targets	30% reduction in delays	10-20% faster in corridors
Net annual revenue	\$150 million	\$230 million	\$100 million	\$20 million	\$90 million

Notes: ALS = Area Licensing System; CC = congestion charging; ERP = Electronic Road Pricing; GHG = greenhouse gas; LEZ = Low Emission Zone.

Source: Based on Seattle Department of Transportation, "Seattle Congestion Pricing Study", Phase 1 Summary Report, 2019, p. 9 infographic

Emission pricing

This pricing considers greenhouse gas (GHG) emissions (climate costs) and pollutant emissions (health costs). A possible approach to pricing these emissions could be the adoption of market-based emission management. For example, emission capacity as determined by regulatory emission limits could be reflected in price signals taking into account demand (traffic from non-emission neutral transport) and supply (the remaining capacity until emission limits are reached). The EU Emission Trading Scheme is a first step in this direction as it allocates annual CO₂ limits for certain (industrial) sectors (e.g. energy, process industries). Thus, a price on pollutant emissions would incentivize the use of low-emission technologies such as electric vehicles.

London

In 2008, a Londonwide Low Emission Zone was set for heavy goods vehicles. Tighter standards were introduced in March 2021, with a daily charge of up to £300 for non-compliant vehicles. In April 2019, London implemented the Ultra Low Emission Zone (ULEZ), within the same perimeter

as the Congestion Charge Zone, to charge vehicles travelling in the area that do not meet emission standards. This fee has replaced London's T-Charge or Emissions Surcharge in operation since October 2017 as a precursor to the ULEZ and is applied exclusive of fees associated with congestion pricing. Vehicles meeting emissions standards are exempt from the charge.⁹ Certain non-complying vehicles, such as existing taxis, local residents' vehicles, vehicles for individuals with disabilities and non-profit shared transport operators, are eligible for a time-limited exception.¹⁰ Vehicles ranging from motorcycles to vans that contravene the ULEZ are charged £12.50 a day while large buses and trucks are charged £100 a day.¹¹ The data for the first four months of implementation indicates a greater than 60% reduction in non-compliant vehicles in the zone since February 2017 when initial T-Charge plans were announced.¹² The ULEZ was extended in October 2021 to cover inner London, 18 times larger than the size of the central London zone.



Road pricing

Road pricing includes user fees for vehicles' usage of roadways. Several methods and reasons for implementing fees exist. Systems can use fees to assist with transport demand management, such as through cordon pricing and area pricing mechanisms. Cordon pricing and area pricing require fees to be paid for usage in a specific geographical zone, which are typically already congested commercial centres that undergo an additional surge during peak hours. Cordon pricing is charged upon entry or exit while area pricing is charged for use within the zone as well.¹³

London

In 2003, London launched a congestion pricing plan to charge vehicles a fixed rate for entering the city centre during the day.¹⁴ Temporary changes were introduced in June 2020 as an emergency response to the transport challenges caused by COVID-19. This included increasing the charge to £15 and extending the operating hours to 07.00-22.00, seven days a week.¹⁵

Stockholm

The Stockholm congestion tax, collected in the city centre, was implemented in August 2007 after a full

pilot trial period in 2006. It is a congestion pricing system implemented as a tax, not as a toll or fee. Using automatic number plate recognition, every vehicle passing the unmanned control points is identified. Prices range from 0 Swedish krona (SEK) (between 18.30 and 06.30) to SEK 35 at peak times (between 07.30 and 08.30 and between 16.00 and 17.30). Exempt from charges are emergency vehicles, buses, diplomatic vehicles, motorcycles, military vehicles and cars with a parking permit for individuals with disabilities. Electric vehicles were exempt until August 2012. Before its implementation, the tax was heavily criticized as unfair by commuters working in Stockholm's city centre. The system was nevertheless introduced in 2006 as a pilot and was permanently implemented after the pilot period led to public acceptance. A referendum was held a few weeks after the end of the initial trial with the people voting in favour of the charge. Overall, the system proved a success; traffic decreased by 22% within the first few weeks. Stockholm's comprehensive public transit coverage with its wide spectrum of traffic modes, including bus, metro and light railway, combined with the congestion tax encourages travellers to take public transit, reducing congestion.¹⁶

BOX 1

The Netherlands: A failed attempt to deploy road pricing

Since 2001, political parties in the Netherlands have debated the introduction of road pricing. In 2009, plans to initiate a road pricing system were published. The plan was to charge a basic rate for each kilometre travelled by car and a higher rate during peak hours and at busy locations, recorded via satellite technology. Revenues from the pricing system were to be used for maintenance and the construction

of roads or public transport infrastructure. Owing to strong public opposition, excessive technological complexity and cost, the plan was not implemented. Despite this failed attempt, pricing mechanisms continue to be considered.¹⁷ A recent 2019 survey shows that support in the Netherlands is growing for some form of usage-based road pricing through which motorists will pay for every kilometre they drive.¹⁸



BOX 2 | Singapore

The Singapore Electronic Road Pricing (ERP) system is a usage-based pricing mechanism adopted in 1998 to manage traffic via road pricing. It was implemented to replace the manual Area Licensing System (ALS) that operated from 1975 to 1998. ALS was a cordon pricing system: an imaginary cordon was set around the most congested parts of the central area known as the “restricted zone” (RZ) and was demarcated by 28 overhead gantry signs. During restricted hours, restricted categories of vehicles had to purchase and display an area licence on their windscreens to enter the RZ. The gantries were monitored manually by traffic wardens who carried out visual checks and recorded any violations.

In 1998, the overhead gantry signs were replaced by ERP gantries using a dedicated short-range radio communication system. ERP was also introduced in nine locations along major expressways and has since been extended to others. Each ERP gantry consists of sensors and licence plate recognition cameras. As of 2019, Singapore has 78 ERP gantries. They are located along expressways and arterial roads with heavy traffic to dissuade usage during peak hours. Singapore-registered vehicles are mandated to acquire an in-vehicle unit (IU) device for 155.80 Singapore dollars (SGD) to use the ERP priced roads. Foreign vehicles can install IUs or pay a flat rate of SGD 5 per day, allowing them unlimited use of all ERP priced roads. These charges do not apply if they do not use any ERP priced roads.

With the introduction of the ERP system, changes in rates and hours of operation were easily implemented. ERP charges are dependent on vehicle type, time of entry and location. These rates are generally set in half-hour periods, reviewed quarterly and before the June and December school holidays, based on the traffic conditions at the time. The rates are adjusted to keep traffic moving at

an optimal speed of between 20 and 30 km per hour on arterial roads and 45 to 65 km per hour on expressways,¹⁹ with speeds determined using the 85th percentile method speed measurement. The same trip passing 5 gantries costs about SGD 15 during peak hours and about SGD 2 during off-peak periods. The ERP system has also been adapted for other purposes, such as for the Electronic Parking System, which taps on existing ERP technologies and deducts parking charges via IUs when a vehicle leaves the car park.

The ERP system has been effective in helping manage congestion in Singapore as it charges per pass through a gantry instead of allowing for unlimited daily entries like the ALS. In the central business district, traffic was reduced 10-15% during ERP operational hours in the initial months of its introduction as compared to traffic under the ALS.²⁰

The next-generation ERP system is now in development. The Land Transport Authority (LTA) reports that current IUs will be replaced with new on-board units (OBUs) in the latter half of 2023 (timings were recently pushed back due to the global microchip shortage). These innovations to the ERP system will allow for real-time congestion management using the Global Navigation Satellite System (GNSS). In addition to details regarding the ERP system, OBUs will inform users about current traffic patterns and special zones with reduced speeds, among other information. The OBUs will support payment processing and could ultimately enable distanced-based road pricing.

The ERP provides exemptions to some vehicle types in support of providing efficient and equitable services while maintaining public acceptance. To support use of more sustainable modes, Singapore has recently expanded its public transport and increased walking and cycling infrastructure.

Parking pricing

Parking – the ultimate destination of all personal vehicle trips – is closely tied to transport demand, road usage and congestion. Parking fees are a pricing mechanism that users have traditionally been comfortable with. In some instances, parking fees are established according to residential status or vehicle emissions. In other cases, parking is considered free or fees are much lower than the land value. Revised parking pricing mechanisms could be implemented for parking facilities or where pre-existing meters already exist. In addition to static prices, rates can vary according to time-dependent or demand-responsive schemes.

San Francisco

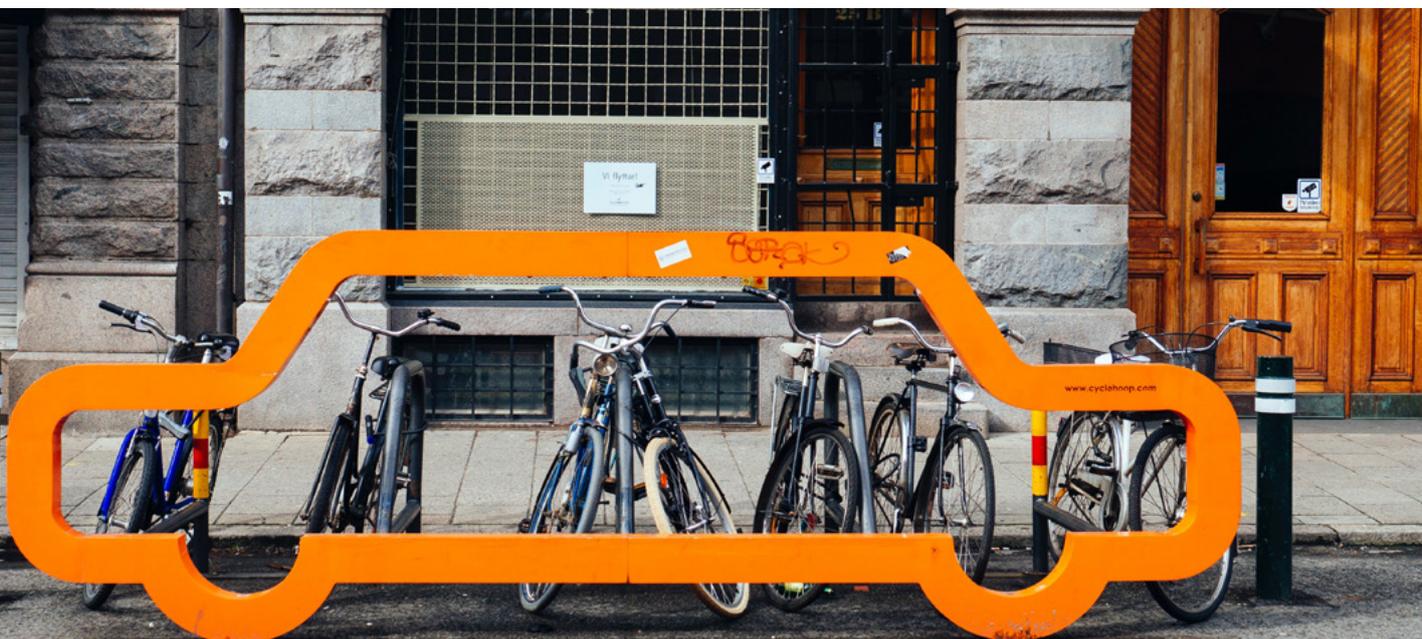
In 2011, the San Francisco Municipal Transportation Agency (SFMTA) launched SFpark, an automated system to manage the on- and off-street parking

facilities in the city. Initially, SFpark piloting was introduced in city-owned parking spaces that included about 25% of on-street metered spaces and 75% of parking facilities. SFpark uses demand-responsive pricing to make parking spaces available on each block and drivers can access open parking spaces in real time.²¹ With better parking availability, parking cruise – when drivers drive around looking for parking – decreases, and related congestion and air quality improve. In 2017, demand-responsive pricing was expanded to all city-owned spaces with hourly rates capped at \$8.²² SFpark rates depend on location and time and are adjusted quarterly. To reflect demand, rates are modified by \$0.25 depending on occupancy – increasing when spaces are 80% full and decreasing when spaces are less than 60% full.²³

Curb pricing

The curb space, as a public resource, can be used for on-street parking, ride-hailing vehicle pick-ups and drop-offs, delivery truck loading, cycling and scootering. Additionally, the use of curb space has been growing for non-mobility economic and environmental purposes, including as space for local retailers and restaurants or parklets. With the proliferation of on-demand ride-hailing services, an increase in shared micromobility options and the exploration of non-mobility uses, the curbside space is becoming a scarce resource in urban mobility management that should be addressed equitably. Urban freight, due to the e-commerce boom and the increased number of deliveries, adds further pressure on the need to regulate and price access to the curb. Curb pricing could be one incentive for

creating more efficient urban freight delivery systems. Overall, new and expanding transport services, such as shared bikes or scooters, require access to or the use of curb space in multiple locations in a manner different from traditional transport services such as mass transport. The demand for curb access has grown rapidly, in some cases creating the need to regulate the access and congestion. Users of the curb should pay a price that better reflects the use costs and impact of this increasingly scarce commodity, and therefore a pricing mechanism should be implemented to address curb congestion. Curb space pricing can be considered within the framework of parking pricing if the management objective is well defined. Some emerging studies also view curb space as a “flex zone” with pricing strategies for the spatial-temporal occupation of these areas.



3.3 New approaches: Revising pricing through technology and market design

“Based on new connected vehicle technology, smart mechanism design and intelligent agent development, pricing more reflective of costs will soon be operationalized in conjunction with integrated, sustainable mobility planning.”

Current transport pricing mechanisms do not equal the theoretical total of direct costs (e.g. infrastructure and maintenance) and indirect costs (the climate, societal, health and economic effects) of transport. This is largely due to the challenge of establishing benchmarks, the setting of prices and the subsequent implementation of real-time dynamic price adjustments in concrete environments.

Three core building blocks can facilitate pricing mechanisms when implemented jointly:

1. Measuring consumption in real time

Measuring usage in an accurate and timely manner is a core requirement to make transport pricing work in practice. Connected vehicle technology, coupled with state-of-the-art 5G technology, allows tracking and disseminating road use information in real time. Vehicle positions, speeds, carbon emissions and other relevant information are captured in real time without the need for expensive infrastructure investment. Through strategically placed internet of things (IoT)-enabled sensors along the road network, pollutant emission levels as well as road and grid capacity levels can be measured in real time at a relatively low cost. The process of measuring road usage will simplify as modern connected vehicle technology increases prevalence. Regulatory challenges remain, especially on data protection and privacy, but the European Commission's Connected Automated Mobility policy initiative and the work of groups like the 5G Automotive Association demonstrate the increasing awareness of public and private stakeholders. An example of how this is in practice today is Singapore's latest update to the ERP system, which includes the real-time measurement of individual road usage through GPS tracking and a retrofitted onboard connectivity unit.

2. Eliciting prices in real time per sector

Recently, alternative pricing mechanisms that rely on auctions have been proposed. Auctions are an effective price determination mechanism and are especially useful when the exact value of an item or a resource is unknown. By eliciting information from market participants (e.g. on-demand mobility service providers) in the form of bids, road-use or mobility service-use prices are determined. Current examples of auctions at work include stock markets, wholesale electricity/power exchanges like the European Energy Exchange or the Electric Reliability Council of Texas, or even automated ad-inventory auctions like Google Ads.

Auction-based, fully automated smart markets can elicit prices and award quantities at high

frequencies, which is important for transport pricing. Typically, human operators have limited involvement in the bidding process, and autonomous agents instead do the bidding on the user's behalf.²⁴ On-demand mobility service providers already employ price-based coordination algorithms that use dynamic per-trip prices that vary depending on supply and demand conditions (e.g. “surge pricing”). While, in theory, outcomes reflect the best profitability for the mobility operator, studies show a limited or even negative impact on traffic and service quality and recommend a policy-driven auction mechanism for the transportation sector.^{25,26}

Pilots and simulation studies lay the groundwork towards widespread adoption of real-time market mechanisms, with bidding agents integrated in vehicles and/or a user's mobile device. Usually focused on a single road or a single sector, a robust policy-led dynamic pricing auction would then target the entire road network. In this way, auction-based allocation mechanisms are a promising form of market-based coordination for transportation infrastructure, which will become feasible as the digitalization of the transportation sector continues and the full automation of real-time auction processes can be facilitated. Recent research in market design offers promising approaches in this direction.²⁷

3. Enabling decision-making in real time

Real-time price signals constitute information overflow for humans. This results in the inability to react to these signals, rendering the pricing mechanism less effective. Effective, and largely autonomous, decision support systems are needed, such as an equitably designed intelligent software agent that processes market signals and balances the direct costs (e.g. the infrastructure, maintenance, parking and curb costs) and the indirect costs (e.g. the climate, societal, health and economic effects) of the transport system. The agent would act on the individual's behalf based on explicitly and implicitly obtained individual and community preferences and local contexts. This agent would learn an individual's travel needs and considerations (including accessibility and affordability) and make travel plans that include all background market bidding and enable a demand response. Bidding agents were initially introduced in finance, where trading algorithms are now responsible for the majority of trade volume. Other examples include bidding software for online shopping auctions, like eBay, that optimally and automatically place bids in alignment with the user's price expectations.



Bidding agents have been piloted in electric vehicle charging applications where software agents have been successfully employed in simulation studies to bid for grid capacity and manage individual charging cycles based on user charging preferences and willingness to pay. One example is RUGGEDISED, which is funded by the European Union's Horizon 2020 and develops smart charging algorithms for home applications and electric bus charging. Algorithms developed through RUGGEDISED were used to charge more than 50 electric buses in Rotterdam's public transport network with cost efficiency and network optimization. Another recent example is the joint venture between Jedlix, a Dutch smart charging platform operator, and Next Kraftwerke, an aggregator of decentral energy production units. Through a field test aggregating up to 100 vehicles, the joint venture is exploring how to balance the transmission system by controlling the electric vehicle charging cycles of individual vehicles. Jedlix provides the bidding agent software and NextKraftwerke

supplies the real-time communications between vehicles, the platform operator and the balancing market. Similar approaches for decision support could be extended beyond the transportation-electricity interface to road infrastructure usage. The MyTransport.SG mobile app from the LTA of Singapore takes an important step in this direction. The integrated multimodal route planner helps users make informed transport choices (such as route shifting, time shifting, mode shifting) by presenting the pricing of the ERP system and additional pertinent information.

Based on new connected vehicle technology, smart mechanism design and intelligent agent development, pricing more reflective of costs can soon be operationalized in conjunction with integrated, sustainable mobility planning. In the meantime, policy-makers can explore fixed, centrally determined top-down pricing approaches as part of clean, equitable and financially resilient mobility measures to improve the status quo.

4

Addressing pricing’s impact on mobility equity

4.1 Pricing as part of an integrated plan

Modifications to road pricing schemes address traffic congestion in an urban centre or on a highway. Considering what other challenges are testing a mobility system is also important. Pricing revisions, in relation to actual cost, must be part of an integrated urban transport policy that balances its consequences across the transportation needs of individuals and communities. In the attempt to eliminate congestion, support environmental and social justice, balance modal split and generate redistributive revenue for transportation departments, pricing schemes and interrelated system modifications must intend to positively impact mobility equity and drive more efficient use.²⁸ Therefore, implemented pricing mechanisms should include:

- The intentional, direct involvement of affected stakeholders (communities, user groups, businesses, mobility operators) to ensure pricing mechanisms maximize societal benefits
- Investment in low- or zero-emission shared or active transport modes (including in overall accessibility, safety, affordability as well as related components, such as charging infrastructure, transportation demand management solutions, etc.) to improve overall system performance and decarbonization
- Transparently subsidized discounts, differential mobility fees, mobility credits and/or scrappage schemes to support compliance with emissions standards to ensure communities can access services and goods.



BOX 3 Mobility equity

A mobility system is equitable if it “increases access to high-quality mobility options, reduces air pollution, and enhances economic opportunity”²⁹ for historically marginalized individuals and communities. Mobility equity promotes decreasing fossil-fuel consumption and carbon emissions, and encourages limiting overall road usage to improve air quality. Systems that are equitable foster affordability and access to economic opportunities, such as jobs, social opportunities and basic services and healthcare facilities.³⁰

The accessibility of a specific mobility system is measured via its success in efficiently connecting people and communities. A geography’s accessibility is impacted by the community’s overall distance to education, employment, and medical

and social opportunities. Without the thoughtful and proper deployment of pricing mechanisms, the disparity of access to transportation services will further widen between communities, which could lead to lower economic performance for many cities and towns around the world.³¹ Key to implementing equitable pricing mechanisms is ensuring access for historically marginalized individuals and communities.³²

Some groups and organizations at the forefront of addressing and calling awareness to mobility inequities and injustices are the North American multiracial collective the Untokening,³³ the US-specific work of The Greenlining Institute³⁴ and TransForm,³⁵ and the global work of Sustainable Mobility for All (SuM4All).³⁶

“ Pricing mechanisms should be adapted progressively or incrementally to the level of income, the level of accessibility, the residency status or the frequency of need.

The success or failure of initiating road pricing schemes is largely attributed to community and political acceptance. Communities should be given space, authority and compensation to participate in and shape transportation planning practices. Plans will not be viable without acceptance from the affected community. Further, when seeking community engagement, planners and transportation officials must revise and rethink when, how and to what extent communities are able to participate in the planning process. As a result of peripheralizing policies over many generations, communities most vulnerable to poorly implemented pricing policies might well be sceptical and may not trust authorities to make changes that will benefit them. To repair these relationships, transportation planners must evaluate, design and socialize policies in full collaboration with communities and their leaders. Collaboration must extend beyond just listening to community concerns to fully acting upon their needs. Through participatory planning and direct public communications campaigns, the full range of transportation options should be broadcast to ensure as many individuals as possible are aware of the mobility options available.³⁷

The implementation of road pricing mechanisms should be supported by a comprehensive mobility and land use plan. Planning should prioritize the funding and deployment of low- or zero-emission shared or active mobility services (including their overall accessibility, safety, affordability as well as related components, such as charging infrastructure, transportation demand management solutions, etc.) with subsidized discounts, differential fees or mobility credits. As prices increase for road use, individuals will rethink how they travel and will be forced to choose alternative paths or times, or will switch to a different mode. Transportation planners and other mobility partners must work collaboratively in anticipation of these shifts' impact to improve the affordability, safety and accessibility of and access to public transport – from technology upgrades to fleet electrification – and of active mobility

options, such as walking, biking and scootering. These alternative modes' higher efficiency and usability and the fair allocation to these transport modes of revenue from pricing schemes will contribute to their success.³⁸ When pricing mechanisms are implemented such that they contribute to investment in other modes, the total performance of the network will be improved.³⁹

Transparently calculated subsidies or credits should ensure communities' equitable access to a city's transportation network. To ease the financial burden and keep the share of transportation costs commensurate with income and essential expenses, discounts or credits should be available for multiple modes. Shared modes, such as public transport or shared micromobility options, should be made affordable through transparent subsidies at a rate progressive to income level or incremental to use to further encourage adoption and reduce the financial burden for current users.⁴⁰ Scrappage schemes should be introduced to support compliance with emissions standards.

For some individuals, private car trips are unavoidable due to specific needs, employment locations and residency. Pricing mechanisms should be adapted progressively or incrementally to the level of income, the level of accessibility, the residency status or the frequency of need. Individuals earning below an income threshold should receive a discount on implemented pricing schemes. For individuals with disabilities who require cars for transportation, similar subsidized discounted pricing schemes should be applied. Subsidies provided to groups need to be funded transparently and must not operate in conflict with the overall goals of the pricing mechanism. Another option to ensure communities are not further excluded is to award mobility credits. Calculations for awarding mobility budgets or credits to groups, whether to low-income individuals or to people with disabilities, should be publicly available. Communities should receive mobility credits proportional to their level of income or accessibility.⁴¹

4.2 Mobility partnerships during design

Road pricing mechanisms can encourage a modal shift, but users may be unable to switch modes if pricing is implemented without other structural changes or improvements to the transportation networks. Personal car usage and even public transport could quickly become for the elite few. Further, many of the communities that lack access to efficient, safe and affordable mobility to critical destinations (employment areas and educational, financial and health hubs, etc.) also suffer disproportionately from the negative consequences of road traffic (pollution, noise, real-estate

devaluation, etc.). Both outcomes are part of the indirect transport costs already mentioned.

Multiple factors, which differ across geographies, influence a transportation network's total cost. These factors include the density and hierarchy of the road network as well as the composition of public and private vehicle fleets. The types of vehicles on the road (internal combustion engine or electric) affect a region's air quality. The incurred costs also depend on the characteristics of the geography – from the type of urban sprawl to the physical environment.

Pricing mechanisms are wholly dependent on the typology of the geography – from the concentration of housing and the distribution of commerce to the transportation flows. The effects of increasing, extreme weather events, such as heat waves, powerful storms and fires, on available (or usable) transportation modes should also be considered.

A risk is that increasing the transport price of one mode could cause an increase in the transport network's overall price, both upfront and related to time, safety and convenience. Road pricing can potentially correct transport costs that have thus far been borne inequitably. If designed as part of a local cross-modal plan together with impacted stakeholders in a partnership, adverse effects on historically marginalized individuals and communities can be avoided, and mobility injustices can start to be repaired.⁴² Partnerships with the local communities that may be affected by road pricing should begin at the design stage and go beyond consultation hearings to address local concerns. Users will ultimately benefit if revenues earned from pricing, whether they result from congestion charging or tolls or are emissions based, are returned to recoup underlying transport costs and are invested in shared or active, or low- or zero-emission mobility transport.

Where effective public and shared transportation options are not yet available, authorities should

provide efficient and affordable shared or active transportation services. People living in mobility deserts where housing may be more affordable but is far from jobs, or those unable to use available public transportation as a result of other considerations (physical, financial or safety limitations), will be adversely affected by road pricing mechanisms due to the lack of alternatives. And communities may lack alternatives to private car usage because of the initial design of the transportation networks and may not have the option to switch modes.⁴³

An important challenge to implementing pricing mechanisms is the difficulty and need to account for the local context. Pricing mechanisms suitable for one country or region may not be relevant for another. The mechanisms will also vary according to the policies of the city and to the regulatory framework of the country or region. In most cases, the national framework will have a major influence on local regulations. International, national and local laws regulating related systems, such as air pollution, taxation or housing, will add a conditional element to the possible pricing mechanisms. Generally, regulatory frameworks should be defined at the level most relevant to the transport system considered: at the national level for national networks, at the regional level for regional networks and at the local level for city networks.



Conclusion

This White Paper proposes a range of policy approaches of relevance to policy-makers, mobility operators, technology vendors and the general public. Its recommendations, derived from a thematic overview of transport pricing that aims to cover the

actual costs to society, the environment and the economy, pertain to: 1) how to define clear goals and objectives (value propositions); 2) how to navigate the complexity of available pricing mechanisms and tools; and 3) how to implement sustainable mobility.

1. Defining clear goals and objectives

- **A focus on sustainable mobility:** Road transport pricing should aim to address existing societal, environmental and economic challenges to mobility while reflecting local priorities. Transport pricing mechanisms should be implemented as part of an integrated transport plan established with intentional, direct community involvement. Plans should propel investment in sustainable, shared and active transport modes to amplify the mobility ecosystem's overall performance. Any discounts and mobility credits (for communities or operators) should be offered in a fully transparency manner and as a means to close gaps (and should therefore be designed to gradually phase out). In addition, pricing mechanisms should include an explicit plan for revenue utilization.
 - **Stakeholder and community acceptance and participation:** Community support is earned by clearly demonstrating community need prioritization through improvements to overall mobility access, affordability, safety and efficiency. Community participation is critical for setting the right price in a manner that reflects existing gaps, and acceptance is key to the approval of pricing modifications. Transport modifications should comprise easy-to-use technological solutions (with provisions for groups with limited access to specific technologies or who are underbanked) and easily understood data privacy protections.
- The perspectives and operating constraints of mobility operators should be considered when addressing overall mobility system improvements. Third parties (skilled knowledge brokers) can facilitate the involvement of mobility operators but lobbying activities should be excluded.

2. Navigating the complexity of design

- **Comprehensive system design:** Prices should account for usage, infrastructure and maintenance costs, air quality, public health, societal access to mobility and CO₂ reduction levels. The inclusion of indirect costs is essential; although not precise, they will be politically determined. The pricing scheme should be differentiated but simple enough to be easily understood by the general public. It should be comprehensive, covering the entire mobility network (rather than just a single area, road, sector or mode), and should set a level playing field for individual users and various mobility operators.
- **Dynamic and differential design:** Pricing policies should be as dynamic as possible across location and time, should accurately reflect capacity constraints and should take into account the local context and community needs. Regularly reviewing and updating the cost and pricing levels will improve the pricing mechanisms' efficacy and will provide mobility users with the information needed to make better travel decisions. If it is not possible to implement dynamic prices due to geographical concerns or technological limitations, pricing schemes should start with revised "flat prices" for mobility users with transparent cost assessments and subsidized discounts or mobility credits for communities.
- **Partnerships with the local community:** Engaging and partnering with community stakeholders at the earliest stage and heeding their input are essential. It is necessary also to address current needs and run pilot programmes to test new mobility approaches or pricing schemes and address concerns via multiple iteration rounds. A pricing scheme that is successful in one geography may not be suitable for another location. Its feasibility should reflect considerations of the current transport system's overall sustainability, including how clean, equitable and financially resilient it is.



3. Implementing sustainable mobility

- **Regulatory framework building:** Regulatory frameworks at the local and national levels should be revised to support integrated approaches to mobility that seek to resolve inequities, decarbonize transport and increase financial resiliency. Regulatory frameworks should be updated to reflect recent mobility innovations and solutions.
- **A transparent, technology-agnostic approach:** Pricing mechanisms should be implemented through vendor-agnostic and open systems that can spur innovation and the development of new value-added services from the private sector. Modern connected vehicle technologies, on-demand services, location-based tools and automation have made significant progress towards enabling differentiated pricing in practice. It is also necessary to explore the potential of new (digital) technologies to define and implement pricing.
- **Improvement and adaptation:** With community and mobility stakeholder involvement, pilot and permanent schemes should include regular reviews that assess and adapt price levels to achieve the desired demand response and reflect the impact on communities and mobility stakeholders.

Despite the clear advantages, the introduction of road pricing schemes is still in the early stage of development. If well designed with equity in mind and if implemented in partnership with the communities concerned, road pricing could significantly contribute towards a more sustainable mobility system.

With this White Paper and its examples of successful cases, the World Economic Forum Global Future Council on Urban Mobility Transitions seeks to foster continued discussion and collaboration towards the acceleration of sustainable pricing systems in order to yield an equitable, clean and financially resilient road transport system.

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This White Paper is a joint effort of the members of the World Economic Forum [Global Future Council on Urban Mobility Transitions](#), who represent the public and private sectors as well as a civil society.

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