Locked into the car: How a vision of unfettered transport freedom transformed personal mobility and reshaped the world

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Table of Contents

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This paper looks at what the car means to Australians, and how the mass adoption of the car has come about over the last century. More widely, it also considers whether contemporary governments, developers and users had the ability to anticipate the future costs, benefits and mass-production of the personal automobile. Did individuals or governments have the ability to decide the course of adoption or were they overtaken by events? This is an important consideration for theTechnologies for Austrlaia's Future Project, particularly in relation to the impact of government and industry interventions in the prediction, meaning, adoption and diffusion of particular technologies.

Key words: Incremental technological change, meaning, prediction, scale, composability, affordability, cost, status, vested interest, business model, infrastructure, technological lock-in, boundaries/classification, well-being, lifecycle analysis

Overview

- The internal combustion engine is a defining technology of the 20th century, helping to shape our security, cultural, democratic, social and economic systems, global environments, mass transport and infrastructure systems, and urban landscapes.
- Incremental advances in technologies and processes as well as regulatory and behavioural changes on a large scale led to the formation of the automobile industry at the beginning of the 20th century.
- A business model focused on composability (the interoperability of components), mass production, affordability and highly effective marketing (mapping societal values onto a technology) underpinned the success and evolution of the internal combustion engine industry and differentiated it from electric and steam engine manufacturers.
- Social norms moulded and were moulded by the personal automobile industry, leading to intended and unintended consequences such as increased freedom, rural lifestyles, congestion, accidents, 'cruising', sedentary lifestyles, increased pace of life and land use for vehicle infrastructure.
- Technological classification greatly impacts measurement outcomes. Almost one-third of new cars bought in Australia in 2013 were sport utility vehicles (SUVs). Small car fuel efficiency increases per year but this estimate does not include SUV data, therefore the actual personal automobile fuel efficiency average for Australia is skewed.
- Mass adoption and development of a supporting infrastructure led to technological lock-in (roads, car parks, repair facilities, refuelling stations, fuel distribution etc.). Problems of our security, cultural, democratic, social and economic systems which come from this technological lock-in include congestion, air pollution and human and environmental damage.
- Lifecycle assessment evaluates the costs and beneifts of the manufacture, use and disposal of new and emerging technology . Analysing energy use and emissions this way shows that the overall damage costing of hybrid electric vehicles is on a par with that of conventional gasoline vehicles, although the analysis crucially depends on what is costed (i.e. lifecycle, well-to-tank, 'in use only' analysis etc.) and how (underlying assumptions and motivations).
- Various events might overcome technological lock-in– a crisis in the existing technology (such as lack of fuel), regulation (such as an emissions tax), technological breakthrough producing a real or imagined cost reduction, new component technologies, new technology from a different discipline adopted into the automobile industry, changes in taste (e.g. environmentally friendly),

niche markets (growth of high cost emerging technology) and scientific results (improved measurement of external effects of the industry).

Adopting the car: the socio-technical complex of automobile adoption and innovation

The car is an integral part of modern Western societies. In a sense it can be viewed as a technological object, but the true meanings of the personal automobile include its functions as status symbol, a mode of personal transport, a private place, a hobby, a lifelong passion, and a livelihood. A century of the growth of a relationship between humans and automobiles has led to pervasive and varied individual uses, involving attitudes towards it, economic impacts, environmental impacts, and rules and regulations.

> In general: some cars are just appliances to get from point A to B. Other cars however, are magical. I can't tell you what makes the difference, but you know it when feel it.
>
> To me: my car is my life. It gives me something to do, something to be proud of, and something to give me freedom ... when it's running that is. (Speedmonkey, 2013)

Almost everyone has an opinion about cars; it is imbued with meanings and identities by the designers, makers and users of the car. The symbolism and projection of self through an individuals' choice of car to communicate wealth, status, gender, age and profession is a well-documented phenomenon (Giblett, 2000). In Australia, this sense of identity through the car has led to tribe-like behaviour, with more than 50 years of Ford/Holden rivalry, the technically proficient 'hoon' who modifies old cars and takes risks, and the highly skilled 'bush mechanic' who maintains cars in the Outback, instilling high community status (Tranter, 2003, Morley, 2013). It's fair to say that most individuals have some sort of emotional attachment to their car (many even name their cars). But where did this all begin, and how has the mass adoption of the car affected us?

Economic and management levers of technological innovation and adoption during the formative years of the automobile industry

The mode of personal transport used today was not predicted by most at the end of the 19th century. There was no transport crisis at the time– people used bicycles and horses or horse-drawn buggies for personal transport, and there was no grave international horse shortage, or other desperate need for a technological fix. So the gasoline engine powered motorcar was not invented in response to crisis.

> 'National leaders, influential thinkers, and editorial writers were not calling for the replacement of the horse, nor were ordinary citizens anxiously hoping that some inventors would soon fill a serious societal and personal need for motor transportation' (Basalla, 1988).

The use of cars was very much in its infancy a hundred years ago. The first automobiles were considered toys, purchased only by the rich in 1895–1905, the first decade of the invention's existence (Basalla, 1988). In 1899, the US automobile market was dominated by the electric automobile (1575 sold) or steam automobile (1681 sold). In the same year 936 gasoline cars were sold (Flink J J, 1970).

The US electric vehicle industry seemed prepared to continue dominating the transport sector The producers of electric vehicles had easy access to all necessary interchangeable car components. The electric vehicle was the first to reach 100 km/hr. Thomas Edison had promised to solve the poor energy storage capacity of the electric car battery. And the Electric Vehicle Company held the 'Selden patent', crucial for the gasoline car (Schallenberg R. H., 1982).

But a number of economic, regulatory and behavioural factors determined the course of automobile history. Those selling electric cars practiced technological elitism, selling cars only to 'suitable' consumers at a high price. This elitism, when combined with the cost of production, led to the electric car's loss of market share. In 1914, the average price for an electric car was US$2950 compared with that of a Ford town car, which cost US$440. By then the gasoline engine, with its improved power, driving range and speed, had outpaced the electric car. With their motivation to produce affordable cars for the masses, the overturning of the 'Selden Patent' decision, and improvements in existing technology, Henry Ford and similar internal combustion engine manufacturers gained market dominance (Cowan et al., 1996, Gregoire J A, 1981, Hird and Knie, 1993).

The convergence and evolution of technologies and processes over 100 years was instrumental in making mass production of cars possible. The Oldsmobile Factory in Lansing, Michigan, developed production-line methods in 1902 (Ryaby Backer P, Accessed 2014) by combining assembly line techniques dating back to 1802 (Marc Isambard Brunel) with the mass production of interchangeable parts (Thomas Blanchard, 1821). The culmination of these technological innovations and improved assembly line methods heralded the Model T Ford in 1909. Henry Ford reduced production time of a Model T from 12 hours to 1 hour 33 minutes. One of the main production bottlenecks was paint-drying time. Japan Black paint dried fastest, and led to Ford's phrase, 'Any colour as long as it's black'. It wasn't until the invention of Duco Lacquer in 1926 that colours were reintroduced into the mass production of Ford automobiles (Georgano G N, 2000).

Worldwide availability aided Ford market dominance outside the US by founding Ford France and Ford Britain in 1911, Ford Denmark in 1923, Ford Germany in 1925 and Ford Australia in 1925 (Wikipedia, Accessed 2014a, Ford, Accessed 2014). Advances in car assembly line production led to market dominance by companies that embraced this form of manufacture. By 1930, 250 US car companies who did not use this form of automobile production had gone out of operation (Georgano G N, 2000). Global access to large-scale manufacture of interoperable parts remains vital to the automobile industry today, through shared powertrains[1] and platforms which include interchangeable brakes, suspension etc. However, the ability to produce such a technology *en masse*, even with global reach, does not guarantee an enduring industry. What led to automobile market dominance?

Development of personal transport technologies in Australia

Transport has been a vital component in the evolution of Australian society, particularly given the remote and vast nature of this nation. Modification of all manner of imported transport methods, depending on the local need, has been a mainstay of Australian transport culture. Motivation for

[1] A 'powertrain' consists of all the components required to rotate the driving wheels of a vehicle, including the engine, clutch (or torque converter), transmission, drive shaft, and axles.

practical technological changes generally came from unexpected shortages, specific manufacturing techniques or sheer necessity (such as wartime). The end of the 19th century saw the initial patenting of diesel, internal combustion and electric engines. Over a century of research, development and tinkering led to a myriad of automobile engine choices in Australia (Table 1).

The automobile is widely portrayed as an example of technology invention in response to a need (enhanced transport), although as already discussed, the gasoline engine powered motorcar was not invented in response to any need (Basalla, 1988). The rapid adoption of the car was facilitated by pre-existing components, infrastructure and changing modes in personal transport culture. The increased interest in the bicycle as a mode of transport was a key intermediary step between horse and car transport. The development of smooth paved bicycle and horse buggy was a useful precursor for the building of roads for cars (Herlihy, 2004).

Adoption of the bicycle meant an increase in designers working with this technology. Bicycle enthusiasts produced many of the first automobiles, and many components initially invented for the bicycle were adapted and incorporated into the car, including ball bearings, pneumatic tyres, chain-driven sprockets and tension-spoked wheels (Gartman, 1994) (Heitmann, 2009). This provides an example of the importance of technology ‘crossover’ – the application and modification of existing technology designed and used for one kind of technology (the bicycle) into new technology (the car).

The first petrol-driven car manufactured in Australia was produced by Henry A. Tarrant in 1897 using a 6 h.p. Benz internal combustion engine. One of the main factors in the progress and adoption of automobile technology was the advantage to commerce it allowed by conquering vast distances (Blainey, 1983). The early 19th century emergence of automobile technology heralded an era of modernity in Australia:

> The car’s promise to overcome the hostile, alien Australian bush made it seem like the victory weapon in the colonial battle. With the bush controlled, the colonial period would give way to a better future, a prosperous modern future of social advancement founded on technological solutions (Tranter, 2003, Knott, 2000).

This era of modernity required the convergence of changes that were technological, regulatory and behavioural in nature in order for the mass adoption of personal automobiles to begin.

Development of the auto industry in the US at the beginning of the 20th century gave rise to mass production of affordable automobiles and made the American right of freedom a reality for a substantial proportion of the population. The Model T Ford replaced the horse and buggy in the US and Australia as a practical and economical mode of transport. Henry Ford ensured that employee salaries were high (threefold higher than average) and promoted the car as something every American deserved, thus aiding in the creation of instant market demand.

Table 1: History of personal automobile technology

initial discovery/patent	engine type	automobile adoption rate
1893	diesel engine	low (high in ships)
1898	internal combustion engine	high (K Benz, Germany)
~1900	electric engine	low
1940s	2 stroke engine	high (Australia)
1972	orbital engine (Ingles B, 1988)	low (Australia)
1970s	rotary engine (Schnaars, 1989)	low
1980s	hydrogen engine	nil (Australia)
1990s	hybrid electric vehicles	low
2000s	thorium engine	nil

Worldwide mass adoption was greatly enhanced by affordability and by associating individual freedom and status with this technology, with significant economic benefits for a small proportion of society (The Henry Ford, 2011). The social effect of the modern motorcar was unprecedented, changing relationships within societies and society's interaction with the environment. Essentially, the capacity for unrestricted terrestrial movement altered recreational activities, urban planning and farm management (Ingles, 1988). Hindsight has allowed the analysis of some of the benefits and costs associated with the ubiquitous automobile, such as effects on employment, independence and environmental and human health impacts including those associated with CO_2 emissions (Table 2).

Attitudes, marketing and automobile adoption

Attitudes to technology can be shaped and reshaped, particularly in relation to risk. Many of the technologies which current society could not conceive of living without were met with fear upon initial introduction – electricity, for example (electrocution was not uncommon when electricity was first used, particularly in the workplace), or the postal service (there was public fear of a lack of privacy). The introduction of the car at the turn of the 19th century was no exception. It was met with both jubilation and horror. Initially perhaps the automobile risks were overestimated but with familiarity they have now become somewhat underestimated. The worldwide average of 1.24 million deaths a year in traffic accidents (World Health Organization, 2014) is not as visible as the much more widespread worry about nuclear power generation, although traffic accidents are responsible for 1000 to 10,000 times the number of deaths a year, taking the most pessimistic analysis of nuclear accidents to date (Wang, 2011) (Wikipedia, 2014).

Attitudes of the American public were key to the development of the automobile industry. Individual freedom as a right of every citizen, high levels of acceptable risk and an abundance of natural resources had profound effects on the mass adoption of the automobile. In addition, the culture of haste which involved conquering time and distance and the possibility of choosing when, where and how you travelled was an irresistible motivation for widespread adoption of the automobile (The Henry Ford, 2011).

In Australia reactions were more mixed. Whilst some members of the Australian elite embraced a new technological toy and saw the speed of the automobile on city streets as no more dangerous than the speed of electric streetcars (Melosi, Accessed 2014), others scorned this dangerous commodity.

> The real truth is that when the motor comes into universal use life will not be worth living … To live in a city when motors have superseded horses will be like living in a cotton mill, with a boiler factory on one side and a merry-go-round with a steam organ on the other … A horse does not like to run a man down if he can help it, but a machine of steel and brass will delight in killing people (The Argus, 1900).

In an attempt to prove the capabilities and safety of this noisy unknown technology, in 1888 Bertha Benz borrowed one of the first cars ever made from her husband and business partner Karl Benz, and travelled approximately 106 kilometres with her two children (typically, cars drove only short distances at the time). She was the first woman to complete a long distance journey in an automobile powered by an internal combustion engine without mechanical assistance, and her action helped to establish the safety of the new technology. The attention her trip gained led to the first sales of the Patent Motorwagon automobile, highlighting the importance of marketing and gaining public acceptance of a new technology, a lesson the Benz brand has not forgotten (Mercedes Benz/Wikipedia, Accessed 2014).

To many, the car became a symbol of modernity and progress. Amidst much rejoicing, in 1926 Mrs Marion Bell completed the first automobile circumnavigation of Australia with her daughter, a total of 12,000 miles (Perth correspondent of 'The Age', 1926, Clarsen, 1999). In *The Brisbane Courier* newspaper, the Perth correspondent for *The Age* reported that ' in all the States and capital cities through which she passed she was feted and extolled for her courage, her daring, and her resourcefulness' (*The Age*, 1926).

Australian adaptability

The initial use of the car at the beginning of the 20th century shows the effect of regulatory rigidity on the adoption of technological change. At this time bicycles, horses and buggies dominated transport, and regulations reflected this. If a horse and buggy stopped on the side of a public road, a person was required to accompany the horse at all times, because horses are unpredictable and may require attention. However, this rule was also initially applied to parked cars, and an industry developed around car parking when people were employed to accompany parked cars in public places (ABC, 2011).

But as technologies change and adapt, so too must regulation. Australian regulators were extremely forward thinking in the adoption of this emerging technology. Although there was considerable public anxiety toward the emerging automobile technology, the legal response did not reflect this attitude. Victoria's *Motor Car Act 1909* was open, flexible, inclusive and happy to ignore previous road legislation that had obvious flaws. This Act was influenced by a UK template, by lobbying by the ACV, by the notion of progress through technology, and by the ideal of the regulative state (law as technology) which introduced motor vehicle registration and licencing. Speed restrictions were not put in place, and nor were other aspects of UK motor car legislation, although this often happened with other Australian legislation at the time. One of the stipulations of the UK *Locomotive Act 1865* governing motor vehicles at the time was that 'self-propelled vehicles should be accompanied by a crew of three; and if the vehicle was attached to two or more vehicles an additional person was to accompany the vehicles, and a man with a red flag walking at least 60 yards (55 metres) ahead of each vehicle, who was also required assist with the passage of horses and carriages. The vehicle was required to stop at the signal of the flag-bearer (The Red Flag Act).' (Wikipedia, Accessed 2014b). As this aspect of UK legislation (like many others) was not adopted by Australian motor car legislators, it is clear that strong public anxiety toward an emerging technology did not lead to restrictive motor vehicle legislation (Tranter, 2005).

Highly effective marketing emanating from the US changed the automobile into an affordable status symbol for many from the 1930s.[2] Advertising campaigns pioneered by Alfred Sloan of General Motors promoted the automobile as a visual representation of success, which is correlated to significantly increased sales (Figure 1). A General Motors pricing structure allowing consumers to move up the product ladder as aspiration and wealth increased, from Chevrolet to Pontiac to Oldsmobile to Buick to Cadillac, became known as the 'Ladder of Success'. Price-banding of specific automobile models promoted the visual display of an individual's salary capacity by equating an expensive car with success and therefore a positive self-image (Steg, 2005, Beck, 2013, Beirão Gabriela and Sarsfield Cabral JA., 2007).

Planned obsolescence and annual styling changes were also introduced by General Motors during this time, fostering a market aspiring to cutting edge technology and style whilst fuelling increased production and pricing. The main market opposition to General Motors at that time was Ford. As Ford did not move to a similar business model, General Motors held market dominance over almost seven decades (Federas, 2010).[3]

In addition, vested interest is thought to have increased public reliance on personal transport over public transport in order to promote the adoption of specific technology. Allegations and criminal charges at that time connected General Motors and others with the buying and dismantling of electric street cars (to corner 'the sale of supplies') in the US to remove public transport options and increase reliance on personal transport ('Great Street Car Scandal'). Implementation of personal and public transport infrastructure requires many inputs such as transport technology, urban policy, road funding, and residential preference (Wetzel Tom, 2009). Therefore, a case for industrial vested interest as the sole reason for lack of a complex cultural shift has remained highly controversial. This also shows how rapidly adopted technology can make anticipating outcomes and mitigating damage by government or users very difficult.

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[2] Interestingly, consumers report that promoting an image of status does not affect personal preference when purchasing automobilesJohannsen-Stenman O and Martinsson P 2004). When surveyed, respondents considered their own concern for status when purchasing a car to be minor in comparison with the status concerns of others. It is difficult to get a clear understanding of the degree to which modern day car ownership is influenced by status anxiety. It is necessary to factor in this sort of cognitive bias that most people have, which results in a substantially higher weighting being put on status concern by others, but a much lesser degree placed on explanations of one's own car purchase decisions. Therefore, 'irrational' factors really matter in the adoption of specific technologies, which is quite evident in contemporary car advertising. See 'SAF05 Chapter Attitudes and Behaviour' for a discussion of the implications of cognitive bias and technology.

[3] For an interesting discussion on the contrasting capitalist approaches taken by General Motors and Ford see *Consuming power: a social history of American energies* (1999) by David E. Nye (MIT Press, p. 146).

Figure 1: General Motors advertising campaign (1950s)
Source: (Vintage Cars, Accessed 2014)

Legacy of the car industry

Society's tango with technology – consequences of adopting automobile technology *en masse*

Mass adoption of the automobile has had significant effects on society. As with pervasive adoption of any technology, impacts have been both good and bad. It certainly illustrates two of Melvin Kranzberg's Laws; 'Technology is neither good nor bad; nor is it neutral' (what matters is what you do with it); 'Technology can both create and solve problems' (Kranzberg, 1986). Table 2 highlights the many and varied intended and unintended impacts of automobile adoption.

Table 2: Societal effects of personal automobile technology: intended and unintended consequences
Sources (Tranter, 2010, The National Academies, 2010, Woodcock et al., 2009, van Vliet et al., 1997, Schonfeld et al., 2005, Redshaw, 2012)

consequences	societal effect	
intended	attitude shift	Cultural shift toward increased freedom and recreation (Ingles B, 1988)
	employment	Greater employment opportunities through increased mobility (Ingles B, 1988)
	urban/rural habitation	Increased accessibility (jobs, services) (Ingles B, 1988)
	car racing	Promotion of technology innovations to increase vehicle speed
	public health	An initial benefit by decreasing the use of horses (dealing with large amounts of effluent in public places was a serious problem in the early 1900s) Morris Eric, accessed 2014
unintended	congestion	Leading to urban stress/'road rage'

accidents	Increased unintended death and injury (Australian Bureau of Statistics, 2012b)
public health	Large scale adoption has created air pollution leading to health and environmental damage (Woodcock et al., 2009, Frumkin, 2002, van Vliet et al., 1997)
symbolism	Adoption of the car as a status symbol (i.e. luxury cars). Affected design of new cars based on values rather than efficiency. (Schonfeld et al., 2005)
sedentary lifestyle	Effect on fitness; correlations between sedentary behaviour and obesity (Owen et al., 2011, Bassett et al., 2008)
urban sprawl	Making other forms of transport such as public transport much more difficult and expensive to provide (Kenworthy and Laube, 1996)
relationships	Increased privacy; teenage access to cars in the 1950s and 1960s has been credited with contributing to changing sexual norms
pace of life	Increased sense of urgency
environment	Land use; environmental disturbance (Kenworthy and Laube, 1996)

Driving a car remains a source of much delight to users, in addition to being an economical and practical mode of transport. However, it is also thought to have irreversibly affected the pace of life by improving users' ability to cover greater distances faster, which has contributed to an increased sense of urgency (Ingles, 1988). It could equally be said that the general public enjoy the capacity to travel to a particular destination as fast possible. This desire has both developed and necessitated a pervasive infrastructure of networked roads, bridges and footpaths[4].

This desire is not new: it was central to the adoption of horse drawn carriages during the 19th century and only after mass adoption of this technology did negative consequences of scale become apparent. In the US, the car promised to solve a public health crisis brought on by an explosion in the urban horse population (Morris Eric, Accessed 2014).

Initially, mass adoption of the car was seen as a significant improvement for public health, particularly in urban areas, as it decreased the need for horses. Horses and the buggies they pulled were a main mode of transport before the mass adoption of the car. Apart from being somewhat noisy and unpredictable they were not toilet-trained.

'And what goes in must come out. Experts of the day estimated that each horse produced between fifteen and thirty pounds of manure [a little less than 7-14 kg] per day. For New York and Brooklyn, which had a combined horse population of between 150,000 and 175,000 in 1880 (long before the horse population reached its peak), this meant that between three and four million pounds of manure [1.36-1.8 tonnes] were deposited on city streets and in city stables every day. Each horse also produced about a quart of urine daily, which added up to around 40,000 gallons per day for New York and Brooklyn.'

[4] that most societies cannot choose to live without

The positive side to large-scale manure production was the formation of a booming market selling fertiliser to farmers, but as the scale of urban equine transport increased this boom became a bust, leaving serious public health issues in its wake.

> Vacant lots across America were piled high with manure; in New York these sometimes rose to forty and even sixty feet.

The negative side of unkempt large-scale manure production in urban areas is that it harbours tetanus spores, a culinary delight for the common house fly. One estimate is that three billion flies a day hatched in horse manure in US cities in the year 1900. Flies endanger human health by picking up and depositing bacteria and diseases (such as typhoid) wherever they chose to land (Morris Eric, Accessed 2014).[5]

No technology only solves problems; every technology has the capacity to create problems. Just as the mass adoption of horse transport led to negative consequences, so too has the mass adoption of the automobile. Just as the public health issues of equine urban transport became more apparent toward the end of the 19th century (due to mass use and improved knowledge, such asgerm theory) so too have the consequences of mass automobile use.

Similarly, transport freedom turns to congestion during peak traffic, but the capacity to travel whenever and wherever you choose and the ability to rove vast distances in your car are still the most important and positive aspects of the car to an individual user.

The positive and negative impacts of technology can be a consequence of the scale of its use.The long adoption timeline of the car and its associated infrastructure mean that the negative impacts of such technology can creep up on society slowly. The associated infrastructure, such as urban design, can then lock us in to an extent, and become the status quo which is perceived as 'normal' (and therefore right) – which can nevertheless be changed. For instance, recent innovations have produced the capability to use historical and current information to better model, test and understand the potential consequences of our actions (Douglas, 2014).

Locking in the internal combustion engine

Technological lock-in is a primary reason for the continued mass use of the internal combustion engine today. Technological lock-in is a form of economic path dependence – in essence, the market selects a technological standard and, because of network effects, gets locked-in or stuck with that standard even though market participants may be better off with an alternative (Liebowitz S J and Margolis S E., 1995).

Both intra-industry and inter-industry factors are involved in this phenomenon. A path-dependence model within a specific industry has been described as a reason for technological lock-in, a small historical event or sequence of events that leads to lock-in of a technology (accident, haphazard marketing gadget, urgent political problem). An initial advantage gained by one technology can create a snow-balling effect which causes the prompt adoption of the technology by others. The interdependence of economic, technical and political decisions that gradually develop in an

[5] Estimate the CO_2 emissions if horses were used today at the same scale as cars are?

economy, are also factors in path dependence. Essentially, the factors of technological lock-in come from both within and outside the industry in which the technology operates (Cowan et al., 1996).

Therefore, to move away from technological lock-in one must look at the levers available within society as a whole. In the literature, mechanisms by which a significant move from the ubiquitous internal combustion engine technology could occur include:

- a crisis in the existing technology (lack of fuel)
- regulation (emissions tax)
- technological breakthrough producing a real or imagined cost breakthrough
- changes in taste (for example, a desire for environmentally friendly technology)
- niche markets (growth of high-cost emerging technology), and
- scientific results (improved measurement of external effects of the industry) (Cowan and Gunby, 1996, Cowan R, 1990, Cowan et al., 1996, Ostlund S, 1984).

Understanding of the effects of the automobile industry on the user and on society as a whole requires an analysis of its inherent characteristics, including innovation, motivations, regulatory effects, behavioural norms, and lifecycle assessment of the automobile industry.

How mass adoption of the automobile affected the innovation process: the interplay between regulation, motivation, innovation and uptake

Affordability has allowed internal combustion engine manufacturers to maintain market dominance to the present day. The goal of the car was to give everyone the capacity to travel when and where they chose, not to provide the most efficient form of transport, therefore significant retro-fitting of technology, infrastructure, cultural attitudes, management and industry would have to occur to diverge from this trajectory. This section considers whether more than a century of technological advancement has led to a highly efficient form of transport technology. In the financial year 2011–12 alone, the Australian automotive industry R&D expenditure totalled almost $700 million (Australian Bureau of Statistics, 2012a). Components of the internal combustion engine have changed dramatically over the last century through research and development. Many (such as hybrid engines) were first patented over a century ago and have evolved and been adapted. Energy efficiency developments have dominated the top ten internal combustion engine technologies as energy use has grown substantially. The main global drivers toward greater energy efficiency include the price of fuel, peak oil price fears, regulations, personal choice (power, status etc.) and the personal environmental values movement (Table 3)(The National Academies, 2010, George, 2014).

Table 3: Top ten engine design improvements: timeline and reasons for adoption (George, 2014)

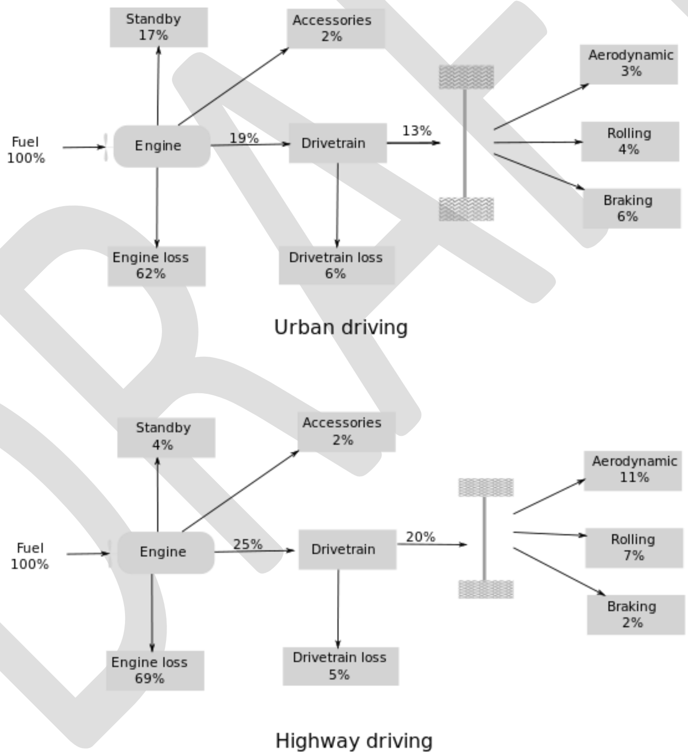
internal combustion engine technology	first patent date	use in production cars	benefits – in use	drawbacks – in use	reason
1. hybrid engines	~1900 Ferdinand Porsche	2000s	fuel economy	high initial cost, complexity	high gas prices, environmental awareness

2. clean diesel	n/a	2000s	torque, fuel economy, cleaner emissions	cost of fuel, low RPMs, higher initial cost	high gas prices
3. on-board engine computers	many parts, first microprocessor? 1971	1981	fuel economy, better diagnostics	cost, complexity	US *Clean Air Act 1978*
4. variable valve timing	1920s us patent 1,527,456	1980 Alfa Romeo Spider	fuel economy	large production cost	increase engine power?
5. overhead camshafts	camshafts date back to 3rd century BC (Wilson A, 2002)	1980s	better performance	increased complexity & cost	increased power
6. aluminum engine blocks	aluminum use over 100yrs ago	1970s	lighter weight leads to more efficiency and better handling	can warp at high temperatures	1970s oil crisis – fuel efficiency
7. direct injection	1902 Leon Levavasseur	2000s	better fuel economy & power	increased cost, new tech	fuel efficiency
8. fuel injection	1925 Hesselmann engine	late 1980s	better throttle response, increased fuel efficiency, more power, easier starting	more complex, potentially expensive repairs	fuel efficiency
9. forced induction	1885 Gottleib Daimler	2000s	more power without increasing engine size	fuel consumption, turbo lag	increased power
10. 4-stroke cycle	late 1800s	industry standard	more fuel-efficient, less emissions	more complicated and more expensive to produce	increased fuel efficiency

What is the current state of internal combustion engine technology and is there room for improvement? Firstly, the law of thermodynamics imposes an efficiency ceiling. Internal combustion engines are very inefficient at converting the fuel's chemical energy to mechanical energy, losing energy to engine friction, pumping air into and out of the engine, and wasted heat (California Energy Commission, Accessed 2014)(**Error! Reference source not found.**). Only 15% of the energy put into powering a car engine is used to move the car; 85% of the energy put into powering a car engine is lost through inefficiencies, essentially heat and noise (California Energy Commission, 2014). After driving, the second largest use of energy in cars is air-conditioning. In hot climates air-conditioning use can account for up to 30% of fuel consumption (Weilenmann M et al., 2010). Advanced engine technologies such as variable valve timing and lift, turbocharging, direct fuel injection, and cylinder deactivation can reduce these losses.

In addition, the weight of a car significantly affects the amount of fuel needed to propel it. Replacing steel car parts with plastic and composite materials improves fuel efficiency by producing a lighter car. However, an environmental impact analysis of the use of composite material in cars reported that the car must be driven over 132,000 km to gain overall savings in energy use and recycling compared to a non-composite car. This is a result of the combination of the cost of fuel and the cost of recycling plastic/composite material, which is higher than that of steel (Dufluo, 2009).[6]

Figure 2: Energy dissipation in city and highway driving (Transportation Research Board, 2006)



Government leverage of technology adoption and public behaviour – effects of promoting fuel efficiency technology, technological classification and measurement outcomes

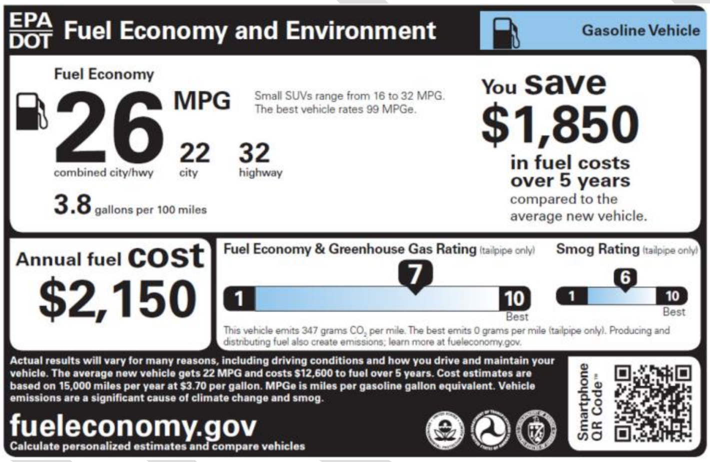
Fuel economy is the ubiquitous method used to describe the energy efficiency of a particular vehicle. It is a ratio of distance travelled per unit of fuel consumed; miles per gallon (mpg) or litres per 100 kilometres (L/100 km) are the standards in the US and Australia, respectively. Australian fuel consumption for passenger vehicles was 24.998 mpg (11.3 litres per 100 km) in 2008 (James M J, 2013) and in the US, new-vehicle fuel efficiency is identical (approximately 25 mpg). In Europe, new-

[6] See Sanchez D, SAF05 Working Paper, Technologies for waste management

vehicle fuel economy is approximately 40 miles per gallon, which is driven by rising fuel costs and taxes. Australia plans to set regulations in line with European and Japanese fuel efficiency and CO_2 emission standards (James M J, 2013). The US Government has promoted energy-efficient technology by mandating fuel economy labelling of automobiles with the aim of providing the public with credible information to compare the fuel economy and environmental impact of automobiles. EPA mandated labelling includes fuel economy (mpg, city and highway), annual fuel costs, and greenhouse gas emissions data (CO_2) which are directly comparable across all personal automobiles sold in the US (**Error! Reference source not found.**).

In the US the effect of government-mandated fuel efficiency labels was significant. Linking fuel efficiency information to individual consumer cost promoted public motivation to attain an understanding of automobile technology efficiency. For instance, the mpg information for fuel economy changes depending on how the machine is used. The mpg for the same vehicle varies from city to highway (22 and 32 mpg, respectively), and it is possible to achieve 66 mpg if a personal automobile is driven at the highest efficiency rate whenever possible.

Figure 3: US EPA new fuel economy label 2013 (US EPA, 2013)



In addition, the transparent information on the US EPA label allowed the American public to directly compare the credibility of information such as mpg/CO_2 emissions provided by the motor industry. For example, in a victory for environmentally conscious consumers, the American public noticed the Ford C-Max 2013 fuel economy label did not equate to the actual fuel economy in practice. Their complaints forced Ford to correct the fuel economy label for the 2013 C-Max (US EPA, 2013) (Table 4).

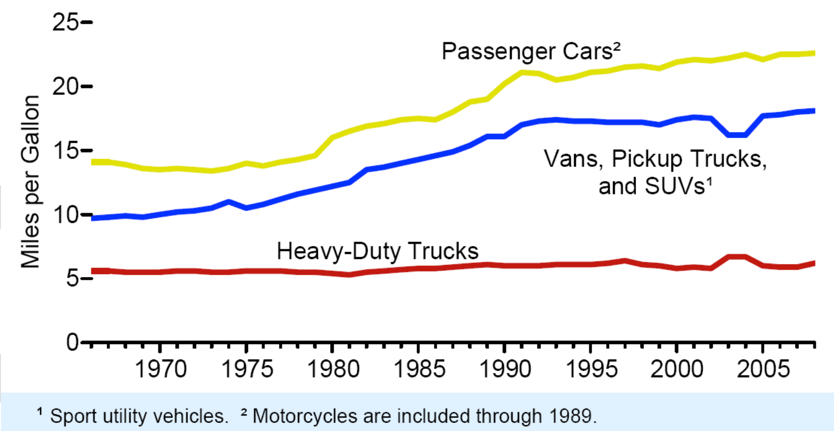
Table 4: Original and revised fuel economy label values for 2013 Ford C-Max

original 2013C-Max label mpg values			new 2013 label values			change in mpg		
combined	city	highway	combined	city	highway	combined	city	highway
47	47	47	43	45	40	-4	+2	+7

The interplay between technology classification, regulation and societal effects

Technology classification can also affect measurement outcomes. For instance, small car fuel efficiency is reported to increase by as little as 1% a year. However, a 1% a year advance in fuel efficient technology (such as in vehicle drivetrain efficiency) is more significant if it applies to larger/faster vehicles which require more energy than the more fuel-efficient lightweight vehicles (Copulos M R, 1986, US Energy Information Administration, 2011, The National Academies, 2010). Sport utility vehicles (SUVs) are classed as trucks, not small cars. Almost one-third of new cars bought in Australia in 2013 were SUVs (Ottley S, 2013). Any meaningful assessment of changes in personal vehicle fuel efficiency needs to take such issues of classification into account. The US *Energy Tax Act* of 1978 set a statutory threshold for the fuel economy of new cars; any car with a fuel economy above the threshold incurred larger taxes. As this tax does not apply to trucks or SUVs, this attempt to incentivise fuel efficiency in cars has instead had the opposite effect, because it has encouraged production and purchase of fuel inefficient cars (US Dept of Energy, Accessed 2014, US Energy Information Administration, 2011) (**Error! Reference source not found.**).

Figure 4: Motor vehicle efficiency 1966–2006 (US Energy Information Administration, 2011)



Societal effects of promoting traffic mortality issues

In 2009, President Obama signed an executive order to ban federal employees from texting while driving. This led to unprecedented attention to the issue of distracted driving and traffic mortality in the US, including a Department of Transport summit. To date, 41 US states have banned texting whilst driving, and by 2013 twelve states had banned cell phone (mobile) use whilst driving (Sunstein C, 2013, Governors highway safety association, 2014).[7]

[7] What are the effects of automobile regulation in Australia? In Australia, total road fatalities have decreased significantly over the last 50 years, from 3798 deaths in 1970 to 1193 in 2013 (DEPT OF INFRASTRUCTURE AND REGIONAL DEVELOPMENT 2013. Road Safety.). However, age-standardised rates of transport injury showed little change from 1999 to 2011 – the base rate was 248.3 cases per 100,000 population in 1999 and 249.5 in 2011 (POINTER S 2012. Trends in hospitalised injury, Australia 1999–00 to 2010–11. Australian Institute of Health and Welfare). There were more than 52,000 cases of transport-related injury in 2012.

The following section describes benefits, costs and alternatives due to the mass adoption of automobile technology, and discusses socially responsible personal transport options.

What is a socially responsible choice for future personal automobile technology?

As with the use of any technology, there are benefits, costs and alternatives to be considered. We can now use a quantitative approach to costing the impacts of transport technology throughout a technology lifecycle (i.e. manufacture, use and disposal) because modern technology can aid in understanding the societal implications of a technology and inform government policy choices.

Table 5 Personal automobile technology: benefits, costs and alternatives (which also have costs and benefits!)

benefits	costs	alternatives
industry/job creation	energy consumption	bus
revenue generation (tax)	health damage	tram
societal wellbeing (convenience, independence, leisure)	environmental damage	bicycle
	costs to society (road maintenance, land use, vehicle production and disposal)	walk
		car-pool/car-share
		other rapid personal transport (such as Segways)
on-demand transport	infrastructure design	
infrastructure design	identity projection	
identity projection		

What are the overall effects of the automobile industry on society - lifecycle analysis of vehicle engines

From a quantitative viewpoint, benefits of the Australian automotive industry include more than 1 million cars in 2012, with a $160 billion turnover for the automotive industry as a whole. The Australian automotive sector included over 110,000 businesses employing over 313,000 people in motor vehicle and parts manufacturing, wholesaling, retailing and automotive repair and maintenance in 2013. The automotive industry is the largest contributor to manufacturing research and development in Australia, investing around $694 million in 2010–11 (Federal chamber of automotive industries, 2013).

Conversely, the annual economic cost of road crashes in Australia is enormous – an estimated$27 billion a year – and the social impacts are devastating (Dept of Infrastructure and Regional Development, 2013). The 'gross economic burden' due to transport pollution in all Australian capital cities was estimated as ~$3.3 billion/year in 2003. In addition, the number of traffic pollution-induced deaths was calculated as marginally higher than the number of traffic fatalities in that same year (Amoako et al., 2003). Using the ExternE valuation of a human life (€1 million) the cost of total road-related deaths in Australia in 2010 (2615 people) equates to €2.615 billion (Australian Bureau of Statistics, 2012b, European Commission, 2008). These are considerable amounts, particularly in context of the road transport industry which was calculated as contributing $20.54 billion to the Australian economy in 2009–10 (Australian Bureau of Statistics, 2012b).

When assessing the value of any technology, a narrow view is almost always misleading. It is now possible to more thoroughly understand the all-inclusive effects the automobile industry may have on society due to modern technology – such as the cost to the economy, human and environmental health damage, and cost of vehicle manufacturing use and disposal. The US National Academies conducted a qualitative and quantitative analysis of the energy required for transport and its consequences in 2005, and a forecast for 2030. The analysis considered energy use, emissions and externalities for petroleum-based fuels and electric vehicles for highway transport. A combination of models including Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (‘GREET’) and Air Pollution Emission Experiments and Policy (‘APEEP’) estimated the physical effects and monetary damages due to the use of more than 75% of US energy in the transport sector (The National Academies, 2010). This form of life cycle impact assessment is considered state of the art and was built upon methods developed to evaluate health, resource and environmental impacts of industrial, agricultural and energy technology systems (J.C, 2002, Commission, 2008, Guinée, 1993, Horvath, 1995, Hofstetter, 1998, Hertwich, 2001, International Atomic Energy Agency, 1999).

The life cycle effects associated with using energy for transport include extracting and processing of fuel, building transport system infrastructure (roads, pipelines, etc.), manufacturing and transporting the vehicles, and vehicle energy use. GREET was used to calculate consumption of total energy during manufacture and disposal of light-duty petroleum, diesel and grid-dependent hybrid electric vehicles. The energy used in 2008 and predicted for 2030 was comparable for petroleum and diesel engines (91 and 115 in 2008, and 99 and 117 gigajoules (GJ) in 2035 respectively) and considerably higher for grid-dependent hybrid electric vehicles in 2035 (135 GJ) (

Table 6).

Table 6 Lifecycle assessment estimates of personal automobile technology (extracted from [42])

lifecycle assessment estimates	petroleum (conventional gasoline)		diesel, low-sulphur (compression ignition, DI)		grid-dependent hybrid electric vehicle		hydrogen fuel cell	
	2005	2030	2005	2030	2005	2030	2005	2030
average miles per gallon	25	35.5	25	35.5				
health & non-GHG emissions damage (US pop. adjusted mean, US cents/vehicle mile travelled)	1.34	1.35	1.49	1.19	1.40–1.49	1.50–1.59	1.30–1.39	>1.60
carbon dioxide equivalent (CO_2-eq) emissions GHGs (g/vehicle mile travelled)	564 CG SI	365 CG SI	476	372	350–500	350–500	250-350	250-350
energy use during manufacture and disposal (GJ/light-duty vehicle) (Bandivadekar et al., 2008)	2008 97	2035 115	2008 99	2035 117	2008 114 (plug-in hybrid electric vehicle)	2035 138 (plug-in hybrid electric vehicle*)*	2008 n/a	2035 n/a

GREET was also used to calculate emissions of carbon dioxide equivalent greenhouse gases (GHGs) (CO_2, methane and nitrous oxide) and health damages due to air pollutant emissions (volatile organic compounds, nitrous oxides, particulate matter smaller than 10 µM and 2.5 µM and sulphur oxides) for a given vehicle and fuel system per vehicle mile travelled. Emissions per vehicle mile travelled included emissions from fuel production, vehicle operation and vehicle production.

In most cases the actual operation of the vehicle was calculated as one-quarter to one-third of the aggregate damages; emissions incurred due to fuel refinement and vehicle manufacture are responsible for the larger part of the aggregate damages (The National Academies, 2010).

Who is paying for the rest of the damages if not the producer or user (i.e. government, taxpayers who are the consumers)? This requires further investigation.

What are the alternatives to the internal combustion engine?

Current personal rapid transport alternatives to the internal combustion engine include electric vehicles, hybrid electric vehicles, diesel vehicles and hydrogen fuel cell vehicles.

Global uptake of electric and hybrid electric vehicles has increased over the last decade. Approximately 60,000 hybrid electric vehicles had been sold in Australia by 2012 (Energy supply association Australia, 2013). There are a number of public charging stations in Australia, but there is no standardisation for the connectors required to charge electric vehicles at public charging stations, and this will be crucial to the mass adoption of electric vehicle technology (Chargepoint, Accessed 2014). Government and industry policy potential is significant in this space.

Future research and development that enables electric vehicle technology could significantly improve electric vehicle mass adoption potential. For instance, invention of a battery with five times the storage capacity of current batteries could lead to a significantly more efficient electric vehicle than the current internal combustion engine. One way to incentivise innovation is through competition. The sport of car racing, from the Indianapolis 500-Mile Race to Formula One, improved internal combustion engine speed dramatically. Formula E has recently begun, backed by Leonardo DiCaprio, to promote 'clean' electric vehicle technology through an all-electric vehicle competition (FIA Fromula-E Championship, 2013). This form of incentive could dramatically improve electric vehicle technology in future.

However, it is useful to consider the following questions before the potential mass adoption of a hybrid electric vehicle technology:

- If market share of electric vehicles rises to 5–15%, is there electrical capacity to power them?
- Are safety procedures in place for the manufacture and disposal of battery metals/solvents?
- What are the emissions from this form of electric vehicle (i.e. fossil fuel vs. non-fossil fuel power source)?
- Does this technology aid urban traffic congestion problems?

Hybrid electric vehicles (HEVs) are promoted as fuel efficient, with low CO_2 emissions compared to those of fossil fuel combustion engines. However, external costs of hybrid vehicles include electricity generation to power the vehicle, and battery production and disposal. The US National Academy of Sciences estimates remarkably similar health and non-greenhouse gas damage estimates, regardless of the combination of fuels/vehicle technologies used in 2005 and the projected estimates for 2030 (

Table 6).

Lifecycle assessments report higher health and non-GHG damages from grid-dependent HEVs in 2005 than from conventional gasoline and diesel light-duty vehicles. HEVs have significant advantages over all other fuel technologies when only 'in use' damages are considered. By contrast, the damages associated with the current and projected mixes of electricity add substantial damages to the totals. The increased energy associated with battery manufacture adds approximately 20% to damage estimates from hybrid vehicle manufacture in 2008 (97, 99, 114 GJ energy/light-duty vehicle respectively, for conventional gasoline, diesel and grid-dependent HEVs). Government legislation to reduce emissions and electricity grid burden could improve expected damages substantially.

Diesel, which has relatively high damages in 2005, is estimated to have one of the lowest damage levels in 2030 due to regulatory intervention (

Table 6). This is due mainly to the substantial reductions in particulate matter and nitrous oxide emissions that a diesel vehicle is required to attain in the US by 2030 (Highway Diesel Rule).

Hydrogen fuel cells are meant to be a strong contender in the quest for zero emission vehicles. Hydrogen fuel cells extract chemical energy from hydrogen without combustion. By combining hydrogen and oxygen electrochemically an electric current and water is produced through a proton exchange membrane. Fuel cells potentially have a three to four-fold increased efficiency compared to the internal combustion engine, by producing over 300 miles per tank of hydrogen. A mandate by the California Air Resource Board to have 1.5 million zero emission vehicles sold by 2025 is increasing fuel cell vehicle interest (8 US states have adopted similar practices; the number of vehicles this would involve would be 1 in 4 US cars). A number of issues are apparent with fuel cell technology, including lack of infrastructure, cost of production and toxic emission production. In order to build a hydrogen fuel cell refuelling infrastructure in the US, funding of $US20–500 billion would be required. In 2013, the cost of fuel cell production was ~$US1500 per kilowatt of power, but mass production of this technology would reduce this cost in line with internal combustion engine prices at ~$US50 per kilowatt of power. In addition, the reactive catalyst (platinum–palladium) used by fuel cells requires an estimated decade of R&D to improve catalytic activity and decrease the likelihood of impurities such as carbon monoxide. The current method used to produce hydrogen is reformation of natural gas, which produces 11.9 kg CO_2 for every 1 kg of hydrogen produced due to steam reformation of gas. This equates to the production of 175 gr CO_2 per hydrogen fuel cell mile driven. By comparison, a Volkswagen diesel produces 145 g CO_2/mile and a Toyota Prius produces 167 gr CO_2/mile. For hydrogen fuel cell engines to be true zero emission vehicles, the energy required to produce the hydrogen would have to come from a zero emission source (Babbage Science and Technology, 2013).

Growing concern for Earth's environmental health is leading to increased interest in using hybrid electric vehicles instead of internal combustion engine vehicles, which is a potentially misguided 'eco-friendly' view. A large-scale shift from internal combustion engine to electric vehicle manufacture could have significant negative effects on greenhouse gas emissions, natural resource extraction and energy requirements, leading to risk-shifting as opposed to risk mitigation.

Conclusions

The complexity of technology prediction

The impact of the mass adoption of the personal automobile was far-reaching: a cultural shift toward increased freedom and recreation, increased rural habitation, traffic congestion, increased accidents/unintended deaths, air pollution, sedentary lifestyle, vehicle infrastructure land use and an increased pace of life. Evidence of the expected impact of the personal automobile before its mass adoption by society is scant. Understanding technology adoption of complex systems has been evidenced as 50% accurate at best due to the nature of complex systems.[8] For instance, a 1960s prediction reported that steering, braking, accelerating and transmission of the car would soon be controlled by a single stick (Schnaars, 1989).

[8] See Sanchez D, SAF05 Working Paper, Technology Prediction

The impacts of new and emerging technology on our security, cultural, democratic, social and economic systems depend on understanding the context within which the new/emerging technology is considered to have an effect. New and emerging technology adoption in the car industry must contend with a highly regulated and standardised system, a vast infrastructural network, significant vested interest and limited potential due to technological lock-in of the internal combustion engine industry.

Origins of technology

The automobile is widely portrayed as an example of technology invention in response to a need (enhanced transport). In fact, the gasoline engine powered motorcar was not invented in response to necessity – there was no grave international horse shortage or crisis in the late 19th century to jeopardise the current mode of transport.

> 'National leaders, influential thinkers, and editorial writers were not calling for the replacement of the horse, nor were ordinary citizens anxiously hoping that some inventors would soon fill a serious societal and personal need for motor transportation' (Basalla, 1988)

By contrast, the first automobiles were considered toys, purchased only by the rich during the first decade of its existence (1895–1905) (Basalla George 1988).

The evolution of technology, standards, composability and business models led to the availability of the mass produced personal automobile at the beginning of the 20th century. It should be noted that the some of the initial innovations that led to automobile manufacture began in early 20th century bicycle workshops without a drive for immediate economic prospects but a motivation to pursue private scientific or technological enthusiasms (Narasimha et al., 2003). European advancements at the start of the 20th century in technological and process developments such as engine patents (electric, steam and internal combustion), assembly line techniques and interchangeable part mass production led to advanced production line technologies and the capability to manufacture personal automobiles in unprecedented quantities.

The success of the internal combustion engine industry (vs. electric or steam engine) depended on the co-evolution of technology composability and platformisation, and on mass production, marketing and affordability. The availability of affordable automobiles as a result of the development of the US automotive industry at the beginning of the 20th century made freedom a reality for much of the population. Worldwide mass adoption was greatly enhanced by associating individual freedom and status with this technology, which had significant economic benefits for a small proportion of society (The Henry Ford, 2011).

Survival of the automotive manufacturing industry will rely on adaptability and diversification, particularly in Australia. Both the automotive workforce and industry will need to evolve in order to mitigate risk in a global economy. Diversification to multiple supply chains and regions and even diversification of product through customisation is a proven method to improve industry profitability in the automotive sector. For example, Melbourne Tooling Co manufactures and designs components for Ford, Holden, Toyota, Nissan, Mitsubishi and Cadillac. Tomcar Australia currently uses innovative business models including selling cars online to the consumer (via an Australian manufacturer MtM), focusing on niche markets (allowing customisation of individual cars for specific sectors such as agriculture, tourism and mining), and using alternative payment methods such as the cyber-currency bitcoin (Khadem, 2013). Air International Thermal Systems has traditionally provided air conditioning and climate control systems to auto manufacturers. However, the company's underlying expertise in thermodynamics has allowed it to move into battery pack designs for electric vehicles (Finnin, 2014).

Adaptability and resilience to changing market needs are key to industry and government uptake of technology in Australia.

Factors of technology adoption

Perception of technology/societal attitudes

The association of positive human emotions and values such as freedom, control and status with the personal automobile greatly affected its public perception and catapulted its adoption through highly effective marketing campaigns.[9]

It is useful to note current social attitudes when considering uptake of new technologies. Electric vehicles were first produced in the late 19th century. In 1899 the US automobile market was dominated by the electric and steam automobiles (1575 and 1681 sales, respectively). At that time 936 gasoline cars had been sold (Flink J J, 1970). In recent decades the popularity of the electric vehicle has risen for reasons including high oil prices and a push toward environmentally friendly transport, but the technology is still a minor component of our motoring. In 2013, there were over 1 billion petroleum fuelled vehicles in circulation globally, and over 80 million alternative fuel vehicles (Plunkett Research, 2014, Sousanis J, 2011).

Adoption of 'new' technology such as the hybrid electric vehicle will be effected by major infrastructure development (electricity stations), increased research and development (improved battery storage), a decrease in technology cost, industrial vested interest in selling the technology, public demand; crisis in dominant fuel prices, and alterations in our perceptions of risks and benefits (Cowan et al., 1996).

Technology and regulation

Government policy assessment of technological uncertainty and risk

Decades of strong public action on the effects of global warming have pushed regulatory changes and forced industry uptake of technological innovations to counteract rising atmospheric CO_2 levels. Associations with environmentally friendly technology have led to the promotion and adoption of hybrid electric vehicles in an effort to reduce our individual carbon footprint. What evidence is there that this has beneficial consequences?

[9] In Australia in 2012, 1310 people died in road accidents and over 52,000 people were treated in hospital for transport related injuries (Bureau of Infrastructure Transport and Regional Economics (BITRE), 2013). These facts are diluted amongst over 20 million people, the car is not perceived as dangerous, why? The popular zero risk bias which applies to many new technologies (i.e. genetic modification, nanotechnology, autonomous vehicles) does not apply to the car, why? Is this a generational effect (ubiquity of car means it is 'part of the furniture')? Or do the individual benefits simply outweigh the overall societal risks?

Lifecycle assessment can provide credible evidence-based information to inform technology risk assessment. From a lifecycle assessment viewpoint, all current personal vehicle engines (internal combustion engines, electric, diesel) produce toxic emissions on a large scale because substantial amounts of fossil fuels are required during the manufacture and processing of the energy source. External costs of hybrid vehicles include electricity generation to power the vehicle and battery production/disposal. The estimated damages to health and to non-greenhouse gases in 2005 (and projected for 2030) are remarkably similar regardless of which kind of fuel is chosen (petroleum, electric, diesel) or type of vehicle technology (internal combustion engine, plug-in hybrid electric), according to the US National Academy of Sciences.

Regulatory lifecycle assessment can reduce harm to human health and the environment from adoption of automobile technology. Regulation through disclosure requirements promoting transparent information in context can aid in reducing the societal effects of personal automobile fuel consumption. For instance, the US EPA/DOT fuel economy labelling system encouraged informed public decision-making on fuel consumption of personal automobile technology. It will be useful to measure and understand the effect that regulating car activities has had in Australia (for example, drink driving regulations, speed limits, or mandatory use of seatbelts) on transport deaths versus transport injuries as an example. In addition, what is the evidence that increased accessibility to knowledge through ICT or otherwise can aid in understanding the impacts of complex systems (complex modelling, simulations etc.) to inform decision making?

Regulating technology and the technology of regulation

A recent need identified for technology regulation is texting whilst driving due to the mass adoption of smartphones. This can be viewed as an unintended consequence of one technology (ICT) for another technology (cars). It is also an example of how a regulation (against texting whilst driving) has promoted the uptake of technological innovation within the automotive industry in the form of on board computers to allow speech recognition in cars.

Technology evaluation

What has the mass adoption of the car cost society?

Mass technological adoption and development of a supporting infrastructure have led to technological lock-in of the automobile industry.

> Two main results emerge from the literature on the past and current evolution of the car regime: - the car regime was established thanks to the ability of purposeful private actors to use the technology of internal combustion to influence markets and institutions, and finally society as a whole; - previous attempts to make urban and regional mobility more sustainable fail because multiple - and mutually reinforcing - path-dependence phenomena lock the society into the car regime (Marletto G, 2011).

Technological lock-in can be seen as a liability if it decreases the capacity for technological innovation. Even with more than a hundred years of research and development into the internal combustion engine, its fuel efficiency limitations are still significant (10–20%) and have been widely known for decades. How has vested interest hindered the invention and adoption of more efficient modes of transport? How would we deal with the sunk costs of vehicle infrastructure if we adopted a new mode of transport that did not require the existing infrastructure?

> For the future, the dominant scenario appears to be the internal transformation of the existing car regime, which is currently driven by the automotive industry and based on hybrid technology; the

emergence of an alternative electric car regime - driven by producers of batteries and managers of electric utilities - remains a secondary option.

Further research is needed to understand how - starting from the existing alternatives to the car and the innovations in the car itself - a coalition of public and private actors may be promoted and sustained to create a new regime of sustainable mobility (Marletto G, 2011).

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