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The Institutional Lock-out of Sustainable Transport Technologies: Inherent, Intentional, Invertible?

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The worldwide transportation sector remains 93% dependent on the oil industry. While other economic sectors in developed nations have begun to decarbonize in recent decades, greenhouse gas emissions from transportation have continued to rise. This article examines how automobiles came to be so dependent on a finite and socially detrimental resource when electric and ethanol-powered vehicles have always offered distinct performance advantages, and how the latter vehicles fell from socio-political favour to technological lock-out.

Introduction

While other economic sectors have begun to decarbonize following the international resolve to combat anthropogenic climate change, carbon emissions from transportation continue to rise. Economic growth is the two-word explanation for this, as globalization of trade has had a double-edged impact on transportation demand. A global market is only possible with increased transport volume, and the prosperity it has generated for a greater share of the population has generated a larger market for personal vehicles. However, this fails to explain why the carbon intensity of modern transport modes has remained so high. An absurd 93% of worldwide transport is fuelled by oil, meaning it is the economic sector that remains most monopolized by fossil fuels today. This trend runs counter to logic, as there are numerous reasons throughout automotive history which should have moved the market away from fossil dependency.

First of all, electric vehicles (EVs) and biofuels have existed for almost two centuries as alternatives to petrol cars, much longer than renewable electricity or nuclear power for example, which are already displacing thermal power generation. Second, the security risks and price volatility characteristic of a cartel-dominated global market were starkly demonstrated by the oil shocks of the 1970s. Third, worldwide concerns over air pollution and its health effects have largely been attributed to the decentralized nature of transport emissions. Fourth, the widely assumed technical superiority of gasoline cars is a misconception by nearly every performance measure. Fifth, as with all extractive industries, the finite nature of the resource dictates that the transition away from oil is inevitable. Despite all these rational motivations and the additional impetus of environmental sustainability, global oil consumption has increased 70% since the oil embargo of 1973 (International Energy Agency 2017).

The first aim of this paper is to explore how the oil-powered vehicle has been able to enjoy such market dominance and build such profound inertia to change by following the history of the automotive industry through a neo-institutionalist lens. Focused exclusively on the United States and Europe, the second objective is to compare the institutions and policies that have developed around modern mobility in these societies which pioneered motorization. The US and the EU may be the champions of Western capitalist democracy, but the plentiful differences beneath the surface provide fertile ground for drilling to the core of our oil addiction.

The final goal is to incorporate these insights into legislative roadmaps for a sustainable mobility future. The novel concept of techno-institutional lock-out is developed here as a political economy analysis tool, supplementary to the established theories of path dependency, new institutional economics and technological lock-in. This framework can be used to diagnose specific mechanisms by which technological change (TC) has been hindered at the actor, industry and societal levels. It can thus be useful in determining the relative ease of alleviating each individual lock-out force, which can be helpful in developing legislative priorities over varying timescales.

Theoretical Framework

Path dependency theory is founded on the simple assertion that history matters, and it lays the foundation for the present analysis. Commonly applied to economics for the study of TC (Arthur 1989, 116; Arthur 1994; Coase 1998, 72–74; David 1985, 332–337; David 2001; North 1991, 97–112; Pierson 2000, 251–267; Schilling 2002, 387–398), it represents an alternative to the neoclassical assertion that a free market will always return the singular most efficient equilibrium. Instead, it emphasizes the existence of multiple possible equilibria and the importance of initial conditions – institutional and historical context – in determining the ultimate market outcome, such that the most optimal does not always win.[1]

Several formal schools of economic thought – most recently Ronald Coase's new institutional economics (NIE)[2] – embrace the influence of these stochastic forces external to the market and the resulting dynamism of economic systems. NIE retains the neoclassical fundamentals of resource scarcity, competition and the law of

1. It is important to note that while these theories are most easily described in terms of technological development, they can also be applied across the realm of the social sciences.
2. Others include the 'institutional', 'historical' and 'evolutionary' schools of economics.

diminishing returns, which continuously pulls an established market back toward its equilibrium. However, Coase diverges from the mainstream by placing particular emphasis on the principle of increasing returns, which describes processes running parallel to path dependency during the birth of a new market.

The dominant design theory describes the human tendency to establish a universal standard for knowledge-intensive and highly networked technologies for the sake of simplicity. This phenomenon elucidates how path dependency and increasing returns can rapidly propel a potentially inferior design to market dominance, as frequently observed throughout history. Four distinct mechanisms have been prescribed by which increasing returns can generate positive feedback loops for this initial choice.

First, economies of scale produce greater returns on investment simply by increasing output volume for those who can afford the initial set-up costs. The second is learning effects, which describes the industry's ability to develop expertise and adapt to consumer preference. Third, network effects is a broad concept, which means that the product's value to its users increases as its level of pervasiveness increases in society. Finally, adaptive expectations describes when consumers and producers adapt their behaviour to the new expectation that this dominance will persist, thus ensuring it does so (Unruh 2000, 817–830).

Once the cost of switching to a superior alternative appears greater than the benefit, the dominant design is said to have become locked in. The lock-in effect deepens as infrastructure arises to support the technology, co-developed industries become dependent upon it, societal and political institutions evolve alongside it, and behavioural institutions are formed around it. Together, these create a techno-institutional complex (TIC) which entrenches the technology within society (Unruh 2000, 817–830).

A TIC wields tremendous power in the political economy, such that all competitors may become locked out from the market. This techno-institutional lock-out depends on the confluence of several lock-out forces, and it is important to recognize and understand each of them individually. To aid in this analysis, these mechanisms can be divided into two broad classifications: inherent and intentional lock-out. The former is a set of existing institutions which dictate rational behaviours and naturally oppose a diversified market, such as investor bias for the dominant design and a lack of education for alternative technologies. The latter describes concerted efforts by actors in the TIC to suppress competition, accomplished through lobbying, media influence and market manipulation.

History of the Transportation Techno-Institutional Complex (TTIC)

Car Wars: Combustion versus Electric

When the first internal combustion engine (ICE) was invented in 1826, the petrol car was by no means destined to be the future of transport. This prototype was actually designed to run on ethanol, as the first oil well would not be drilled until 1859. As automotion began to grow, ICEs were the least popular choice behind

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steam engines and EVs at the turn of the twentieth century. At the time, EVs had become the consumer favourite since they offered better driveability, safety, air quality and performance as they set world records for both range and speed (Kovarik 1998, 7–27).

The market would be flipped on its head beginning in 1908, when Ford pioneered mass production of the Model T, a bold strategy which allowed the company to capture increasing returns to scale. The sharp decline in vehicle price brought the technology to a whole new segment of the market, which in turn produced learning effects for ICE manufacturers to improve their product. Furthermore, the increasing number of drivers meant a demand for more roads, and the US government would soon provide this infrastructure outside of urban areas as a public service (Kovarik 1998, 7–27; Unruh 2000, 817–830). Driving range then became paramount, and the ICE industry was lucky to have an immensely powerful natural ally in Standard Oil, which quickly installed filling stations nationwide. This tandem of network effects now provided gasoline cars with a distinct advantage over the competition despite its technical deficiencies (Carolan 2009, 421–448).

EVs disappeared from the roads by 1930 (Kovarik 1998, 7–27), at which point 80% of the global car market was controlled by the 'big three' of Ford, GM and Chrysler. This oligopoly created a market environment which encouraged only incremental innovations to maintain the dominant design rather than pursue riskier projects in alternative technologies, thus funnelling all investment capital in the sector back into the ICE. The labour market responded accordingly, and new fields of study such as automotive engineering focused exclusively on the ICE (Unruh 2000, 817–830). EVs were now in a state of inherent financial and educational lock-out.

Fuel Duel: Petrol versus Ethanol

The dominance of gasoline for fuelling the ICE was similarly determined by path dependence. Just three years after the US began producing oil, the Revenue Act of 1862 placed a heavy sin tax on alcohol (unintentionally including fuel ethanol) to help fund the Civil War. This stroke of serendipity led to the popularization of gasoline use in ICEs, even though the Model T and many other early cars were actually flex-fuel vehicles (FFVs) fully capable of handling pure ethanol (Carolan 2009, 421–448; Kovarik 1998, 7–27; Kovarik 2013, 1–22).

Oil reserves were thought to be very scarce at the time (Carolan 2009, 421–448), while ethanol is not only renewable but offered superior performance (Kovarik 1998, 7–27). Petrol's only edge over ethanol was its cost, due in part to its higher energy density, but also to price fixing by Standard Oil as proven in a 1911 Supreme Court ruling. Perhaps the story would be different had Standard Oil been divided three years earlier when the alcohol tax was lifted, but alas ethanol was not able to penetrate the US market.

Meanwhile in Europe, many countries saw ethanol as a path toward energy independence. They enacted diverse policy support schemes for ethanol production and innovation, resulting in everything from pure ethanol cars and trains to clothes irons (Kovarik 1998, 7–27). Even more impressively, research on waste-based and algae-based ethanol, today considered 'advanced' biofuels, was already underway in some countries during the interwar period (Kovarik 1998, 7–27). Gasohol – gasoline blended with ethanol – had become the standard motor fuel since pure gasoline is actually unsafe for engines even today due to its low octane content.

Among the most vocal proponents of gasohol in the US were Ford and GM, who held fuel quality to be paramount for their products (Kovarik 1998, 7–27). Despite the discovery of new oil fields, they recognized that the auto industry does not depend on the petroleum industry but rather vice versa. However, this sentiment disappeared in 1921 when GM discovered a new additive: tetra-ethyl lead (TEL). Leaded gasoline sported the same price and performance as gasohol, but regardless of the drawback of horrific public health effects (Reyes 2007)[3] it had the distinct advantage of patentability (Carolan 2009, 421–448; Kovarik 1998, 7–27). In 1924 Standard Oil of New Jersey (now ExxonMobil) and GM launched a joint venture, called Ethyl Gasoline Corporation (Ethyl Corp), to secure the patent, and this insidious partnership solidified the TTIC around gasoline-powered ICEs.

Coincidentally, the American Petroleum Institute (API) was founded as an oil industry trade association in 1919, just in time to spearhead the TTIC alongside Ethyl Corp. As the US gasohol movement gained political traction as a lifeline for farmers during the Great Depression, these two coordinated a massive campaign to spread propaganda, suppress scientific studies, bribe politicians and withhold distribution licenses from sellers of gasohol (Carolan 2009, 421–448). The Supreme Court would rule this last business practice to be illegal in 1940, but this was again too late as leaded petrol already commanded a 90% US market share (Carolan 2009, 421–448). The intentional lock-out of ethanol from the US had been a resounding success.

The morbid effects of lead were household knowledge, but somehow Ethyl Corp managed to cover up several employee deaths from TEL (Kitman 2000) and convince the world to act against common sense. Campaign contributions and personal connections endowed Ethyl Corp with the lobbying power to transform public health regulators into product advertisers both at home and abroad (Kitman 2000). In fact, the misinformation campaign proved so effective that GM and Exxon have never been held accountable for this atrocity. The US anti-air pollution movement of the 1960s is credited with enforcing the introduction of catalytic converters to control smog and acid rain, but the issue of lead was never raised (Kitman 2000). Only by sheer coincidence did this also lead to the phase-out of TEL, since lead contact destroys these devices.

Ethyl Corp was ultimately also able to achieve dominance in Europe courtesy of the Second World War – during which it gladly supplied fuel for both sides (O'Hanlon 1984, 211–232) – and the subsequent Marshall Plan for

3. Retrospective studies have shown that the average American, during the leaded gasoline era, experienced lead poisoning, by medical definition, to which has been attributed 5000 annual deaths, lower mean IQ and higher crime rate.

reconstruction, of which oil exports constituted the single largest expenditure (Painter 1984, 359–383). The new political priorities in Europe and cheap, abundant oil from the Middle East ensured the inherent lock-out of ethanol in Europe.

This suggests that the institutional power of the TTIC could even override national security concerns, the justification for pre-war ethanol subsidies given by European nations devoid of oil. This was more starkly evidenced in the US by the oil shocks of the 1970s, to which lawmakers failed to react despite mass economic hysteria. A tax incentive for ethanol producers was finally enacted in December 1980, almost two years after the second oil shock of January 1979, more as a protection against imports from Brazil (where the shocks prompted a massive public investment into biofuels) than as a threat to the oil industry.

An EV research funding programme was also granted in 1976, only to be cancelled five years later (Matulka 2014). Still, these minor victories signalled the end of the legislative lock-out of alternative transport fuels. It can be argued that this was only possible because GM and Exxon had sold Ethyl Corp ahead of the TEL phase-out (Kitman 2000), thus allowing for a divergence of interests between the oil and auto industries. For once, historical circumstances turned path dependency against the TTIC.

The oil industry was able to momentarily prolong its intentional lock-out of ethanol by creating new chemical octane boosters, which were shown to also be toxic (Kitman 2000; Kovarik 2013). The latter could not be concealed for so long this time, and ethanol blending was finally mandated by US Congress in 2005 and the EU Parliament in 2003. EV purchasing incentives have also since become commonplace, as institution-building around climate protection has slowly begun. It stands to reason, though, that this would be a considerably lesser challenge if only a handful of events had turned out differently a century ago.

Modern Transportation Institutions

United States

A young, sprawling nation priding itself on innovation, individualism, freedom and financial prosperity, American society readily moulded its culture around the motor vehicle throughout the twentieth century. The car quickly became an expression of status and identity, and Americans stereotypically chose to showcase their power through muscle cars, pickup trucks and SUVs. Highways were constructed through and between cities, giving rise to the suburban ideal, a life where there are no transport alternatives to the car.

Today, the US is predictably characterized by the largest number of vehicles per capita (US Department of Energy 2014) in the world, as well as by sporting the largest average vehicle size (US Energy Information Administration 2018),[4] and

4. Close second behind Canada in average vehicle footprint.

the lowest average fuel efficiency (US Energy Information Administration 2018). Not surprisingly, the country consumes the largest quantity of gasoline per capita in the world – 439 gallons annually, or 143.37 billion gallons total in 2017 (US Energy Information Administration 2018; International Energy Agency 2017) – made possible by the highest oil subsidies ($246 billion annually) and lowest gasoline prices of any advanced economy (Bárány and Grigonyté 2015). This immense public forfeiture highlights how deeply rooted the TTIC has become in the American political economy. It has now orchestrated a new interest group to push its agenda, the climate change denial machine. API and Exxon Mobil combined to spend $92 million on obstructive climate lobbying in 2015 (Influence Map 2016), and this doesn't include the undisclosed sums they channel to SuperPACs, anti-climate think tanks and 'astroturf' organizations (Dunlap and McCright 2011, 144–160)[5], all of which are typical of US lobbying institutions.

Since the 2005 Renewable Fuel Standard (RFS) institutionalized gasohol in the US, the API has redoubled its efforts to sow doubt on the merits of ethanol, best illustrated by the 'food versus fuel' myth. A 10% ethanol (E10) blending mandate is currently in effect, and the RFS aims for biofuels to contribute 25% of all transport fuels by 2022. However, the latter target is in jeopardy because the API's efforts led Congress to cap crop-based ethanol support at the current per annum volume, and most advanced biofuels have yet to become market ready.

To compound this issue, the fossil fuels industry has chanced upon a golden age for regulatory capture with the Trump presidency. Climate change deniers now sit atop the most critical government agencies, such as the Environmental Protection Agency (EPA), which has since exempted numerous oil refineries from the RFS blending mandate. At this critical juncture, a sustainable mobility future depends on collective action (Seto *et al.* 2016, 425–452), and this may hinge upon leadership from the auto industry or other established actors in the political economy.

European Union

In contrast, European transport institutions were shaped very differently by geography, culture, and the absence of domestic oil reserves. Travel distances were generally shorter than in the US since population density is higher, local economies were more institutionalized, and countries didn't share open borders until 1985. Smaller cars were necessary to navigate the narrow streets of centuries-old cities, but also because the petrol prices are among the world's highest.

Car ownership rates in the EU are about 27% lower than in the US (US Department of Energy 2014), the vehicle fleet is the most fuel-efficient in the world (US Energy Information Administration 2018), and alternative transport

5. 'Astroturf' organizations are privately funded political entities designed to resemble a grassroots movement.

modes such as scooters, bicycles, public transport, and walking are better integrated (European Commission, Eurostat 2016). In total, the EU consumed 85.12 billion gallons of gasoline and diesel in 2015 (165.3 gallons per capita), about 70% lower than the US stats (European Commission, Eurostat 2017).

The EU has also exhibited a socio-political proclivity for climate protection, which may be a symptom of its historical energy dependence on its immediate rivals, the US and Russia. These factors both contribute to the EU boasting the lowest oil subsidization rate in the world (Bárány and Grigonyté 2015), an indication of the dampened lobbying influence and intentional lock-out enjoyed by the TTIC.

However, some of the EU's well-intentioned policies lacked sufficient foresight and may have actually contributed to the lock-out of sustainable fuels. These will be deemed unintentional lock-out forces. For one, the EU set the world's most stringent CO_2 emissions standards in 1998, but a slight double standard was afforded to diesel engines given their naturally higher efficiency (Nesbit *et al.* 2016). Diesel cars until very recently commanded a large market share in the EU – 53% in 2016 (Nesbit *et al.* 2016)[6] – which has had at least two adverse impacts.

First, diesel emissions contain significantly higher amounts of nitrous oxide (NOx), which contributes almost 300 times more to atmospheric warming than CO_2. New regulations required diesel vehicles to be fitted with NOx traps, but this comes at the expense of fuel economy. This set the scene for Volkswagen's infamous 'dieselgate' scandal, a horrific step backward for the climate, as their new diesel vehicles would have failed either US NOx standards without NOx traps or EU CO_2 limits with them.

Second, diesel engines are not compatible with ethanol or even biodiesel, meaning these drivers are locked out from the current biofuels market. Renewable diesel fuels are an emerging technology which can change that, but these are many years from market readiness and already face an enormous demand for road freight decarbonization.

The EU biofuels policy itself has also been the cause of unintentional lock-out of biofuels owing to its frequently shifting targets. Regulatory uncertainty can be a major deterrent of investors and entrepreneurs, especially in an industry which must rely on policy support to compete. The 2009 Renewable Energy Directive (RED) set a target of 10% renewable energy in transport by 2020, and steady progress led to a 7.1% share as of 2016 (European Commission, Eurostat 2018). However, the European Commission has since proposed to phase out crop-based biofuels due to new food versus fuel concerns,[7] despite the fact that these fuels account for only 4.3% (Phillips 2017) of that 7.1% (while EVs remain well below 1%) (International Energy Agency 2018). Ultimately, the 2018 RED II set a 7% cap on such fuels and a meagre 14% renewable transport fuel target for 2030.

6. Compared with 0.8% in the US.
7. The new debate is over indirect land use change (ILUC), the concern that crop-based biofuels may displace food production and associated emissions to other land, particularly forests.

Conclusion and Policy Implications

In the US, the greatest barrier to TC in the transport sector is intentional lock-out by the TTIC, which has effectively come to resemble a state monopoly within a liberal market economy. That is, the success of TTIC firms and the lock-out of competing technologies are in the direct interest of government agents who wield the power to override market forces. The annual global expenditure against climate policy is estimated to exceed \$500 million, compared with just ~\$5 million spent on climate action lobbying (InfluenceMap 2016), and the fuels market has been proportionately distorted. Climate-oriented businesses must establish a coherent TIC, and with it a centralized lobbying platform akin to the API through which they can concentrate spending on the most critical issues.

The most significant barriers in the EU are largely self-imposed unintentional lock-out forces. Although uncertainty is an inevitability of science, the EU seeks to support only 'unequivocally sustainable' fuels which emit at least 60% less GHG than the fossil fuel they replace. This may prove noble in the long run, but presently it locks out market-ready fuels that are unequivocally more sustainable than oil. Instead, policies should focus on displacing oil as quickly as possible by fostering increasing returns for alternative fuels.

The first step for establishing such market presence is to build absorptive capacity (del Río and Unruh 2012, 231–255), like the affordability of the Model T accomplished for Ford. Ford also had the vision to provide drivers with flex fuel capacity, and today this can be taken a step further. Most major automakers already produce both FFVs and PHEVs (plug-in hybrid electric vehicles), albeit for different markets, but a flex-fuel plug-in hybrid (FFPHEV) has yet to appear on the market, notwithstanding the ease of converting an ICE to flex fuel (Dutreuil *et al.* 2008).[8] Governments should consider manufacturer incentives for FFPHEVs in the near term because such a vehicle fleet would free policymakers to either pursue a truly technology-neutral approach or to support specific technologies with a reduced risk of long-term lock-in.

FFPHEVs are the embodiment of the American ideals of innovation and the free market. Drivers would have the freedom of choice between petrol, ethanol, methanol and electricity based on price, performance, availability or preference. The hope is that this type of social appeal may translate to the market demand that EVs have thus far failed to generate. It follows that this could ultimately decouple the auto industry from the TTIC.

To combat inherent lock-out, public infrastructure investments should be considered for EV charging stations and corrosion-resistant ethanol pipelines, which would also serve to stimulate network effects. To avoid the lock-in of outdated chargers as the technology continues to improve, public charging networks are best viewed as a medium-term goal. However, passivation of existing pipelines should be pursued in the short term to prepare for gasohol blends of over 15% ethanol (Singh 2009).

8. The 2007 Chevrolet Volt concept was in fact a FFPHEV, but the production model would not be sold as flex fuel for undisclosed reasons.

Another barrier to transport decarbonization is the behavioural lock-in of car culture, considered the final phase of technological lock-in (Seto *et al.* 2016, 425–452; Unruh 2000) and the most difficult to reverse (Kohler 2012). Car dependency is well established in the US, and ownership rates are projected to increase in Europe (European Commission 2016) and worldwide (US Department of Energy 2014), thus reinforcing the need for absorptive capacity in the vehicle fleet. Furthermore, the US and the EU should be motivated to spur alternative vehicle innovation in order to maintain the relevance of their domestic auto industries. China is now home to 40% of the global EV share (International Energy Agency 2018), and Toyota do Brasil has recently announced a flex fuel Prius model, just a plug-in battery removed from being the first FFPHEV.

The most relevant lesson to be learned from path dependency is that short-term actions are the most important, and this holds particularly true in the age of climate change. In the medium or long term, unequivocal sustainability will be achievable with greater knowledge, but that must be guided by empirical evidence rather than solely through projections, however sophisticated they may be.

For the EU, climate leadership could conceivably be a lever for global influence in an uncertain geopolitical future, and the biggest barrier holding it back is itself. Rather than justify inaction with uncertainty – thereby aiding the TTIC in intentional lock-out – the path forward must first address inherent lock-outs, particularly in finance, with flexibility in mind. Once the best options are clear, policy must seek to facilitate increasing returns and establish new technological institutions before it is too late.

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