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Research article

The lock-in effect and the greening of automotive cooling systems in the European Union

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ABSTRACT

As of 2017, the sale and use of the refrigerants most commonly used in automotive cooling systems – hydrofluorocarbons – are entirely banned in all new vehicles placed on the market in the European Union. These refrigerants have been recognised as potent greenhouse gases and, therefore, direct contributors to climate change. It is within this regulation-driven market that the technologies for a sustainable solution have been developed. However, this paper argues that the market for automotive cooling systems has been 'locked-in', which means that competing technologies, operating under dynamic increasing returns, will allow for one – potentially inferior technology – to dominate the market. Whilst such a situation is not uncommon, this paper discusses the way that regulation has reinforced a patented monopoly in 'picking winners': to the advantage of a synthetic chemical, R-1234yf, as opposed to the natural solution, which is CO_2. By developing a generic conceptual framework of path dependence and lock-in, the presented evidence seeks to show how a snowballing effect has led to the intensification of differences in market share. We also argue that the automotive industry is potentially promoting short-term fixes, rather than long-term, sustainable and economically viable solutions.

1. Introduction

As we approach the 30th anniversary of the 1989 Montreal Protocol and its successful ban on the use of chlorofluorocarbons (CFCs) – the refrigerants blamed for depleting the ozone layer – the gases that were chosen to replace CFCs have, regrettably, been identified as significant contributors to climate change. Hydrofluorocarbons (HFCs), the synthetic refrigerants developed in the 1990s as ozone-friendly alternatives to CFCs, eventually emerged as potent greenhouse gases (GHGs), with thousands of times greater greenhouse potential than CO_2. HFCs are most commonly used in mobile air conditioning (MAC) - and thus in automotive cooling systems - and, along with a rapidly expanding market for cooling worldwide, the EU MAC Directive 2006/40/EC, has banned the use of all cooling agents in new passenger vehicles with a global warming potential (GWP) above 150 across the European Union (EU) as of 2017.

The EU MAC Directive is deemed 'technology-neutral'. This means that any substitute to HFC-134a – the refrigerant to be banned (whose GWP is 1430) – is accepted as long as the refrigerant has a GWP below 150. The MAC Directive gave producers five years to develop alternatives to the climate-damaging predecessor from the Directive's implementation in 2006, and through extensive research and testing by manufacturers and suppliers it eventually became clear that the synthetic refrigerant R-1234yf and natural option of CO_2 were the major contenders. The EU does not currently mandate the use of either, as long as the aforementioned guidelines are followed (European Commission, 2014).

Although the market for automotive cooling systems in the EU has largely been driven by regulation in recent decades, research continues to remain focused on its technological development, often disregarding the socio-economic conditions driving (or limiting) their development or deployment. This paper seeks to address this gap, and argues that the regulatory framework of the EU has reinforced a patented monopoly held by the producers of R-1234yf – one of the two major contenders. At the time of writing, R-1234yf is widely known as the dominant replacement for HFC-134a MAC systems. It is already used in 18 million vehicles worldwide and all car manufacturers are shifting to R-1234yf, with the exception of Audi and Daimler, which plan to offer CO_2 systems as an option in some vehicles in 2017. In order to illustrate the way in

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which a patented monopoly has been reinforced through a regulatory framework, the objective of this paper is to highlight how the market for MAC systems has been 'locked-in'; this means that when two technologies are in competition with one another, operating under dynamic increasing returns, one (potentially inferior) technology, with a first-mover advantage, will eventually dominate the market.

1.1. Literature review: path dependence and lock-in revisited

The concepts of path dependence and lock-in are rooted in evolutionary approaches to understanding technological change. The concepts are broadly used to explain how technologies develop and endure, or why they simply disappear (Cairns, 2014). Central to these approaches is that certain 'choices' (although not necessarily conscious ones) lead to the way in which technologies and systems are designed. Different paths can be taken, which can lead to entirely different technological solutions and products entering the market (Foxon, 2011). Path dependence specifically, as (Margolis, 2009, p. 166) put it, "is a condition in which economic outcomes exhibit inertia." As such, theories of path dependence argue that this evolutionary process of technological development can sometimes get stuck, temporarily and sometimes even permanently (North, 1990). Given that technological development in this sense is historically contingent, and not necessarily governed by optimality, a technology can base itself on inferior designs (Maréchal, 2009). This concept of path dependence, then, seeks to explain why sub-optimal solutions can sometimes prevail in the market.

David (1985) and Arthur (1989) are considered the pioneers behind technological lock-in, a concept used to understand the technological outcome of path dependence when markets are subject to inertia. The concept especially draws attention to the historically contingent nature of economic change (Maréchal, 2007). The idea of lock-in broadly sees that, in the event of two competing technologies being adopted in succession of one another, the market will tend to avoid experimentation, despite other alternatives potentially being superior or more efficient. Scholars of neoclassical economics argue that market processes would allow for a more efficient technology to be taken up by the market, given that manufacturers and users should automatically seek out the most efficient alternative. However, in a world of uncertainty and bounded rationality, this does not necessarily hold with regard to the fast-changing nature of technological change. As such, technologies cannot be considered as isolated mechanisms, but instead belonging to technological systems that include natural, social and institutional elements (Unruh, 2000). Once historical conditions and the interrelation of characteristics have led to the emergence of such a system, their many components lead to the stabilisation and inertia of the system. Solving environmental or social issues through regulatory frameworks in an effective way requires a broader integration of social and natural sciences (Virapongse et al., 2016).

Specifically, through a series of self-reinforcing mechanisms of increasing returns (implying that the more a technology is adopted, the higher the likelihood that even more of the technology will be adopted), there are four classes that can lead to the first technology (out of two) dominating the market; these are (i) scale economies, (ii) learning effects, (iii) adaptive expectations and (iv) network effects (Arthur, 1989). From this, we can draw two central ideas from lock-in. The first is that technological systems can become deeply embedded into inert, durable, potentially sub-optimal and inferior patterns and designs. The second is that these systems are deeply entrenched in complex, interdependent technological and socio-economic systems that can be difficult to escape from. Thus, research into locked-in systems requires taking system-wide policy approaches into account in order to understand their full effect (Perkins, 2003). Understanding the principal causes of this inertia is crucial for enforcing system change (Marechal and Lazaric, 2010). As Carrillo-Hermosilla (2006, p. 718) put it: "early superiority is no guarantee of long-term suitability."

1.1.1. Self-reinforcing mechanisms

When two technologies compete for the same market, a snowballing effect can lead to the intensification of minor differences in market share (Arthur, 1989). Choices, or decision-making processes, will then exhibit self-reinforcing mechanisms and feedback effects, where inferior and potentially inefficient technologies can become locked in (see Fig. 1). Thus, when increasing returns or feedback effects are present, designs that are inferior can be locked in to the market through a historically path-dependent process in which "circumstantial events determine the winning alternative" (Carrillo-Hermosilla, 2006, p. 718).

Arthur referred to scale economies as one of four major issues that potentially lead to the lock-in of one new technology over another. Although new technologies are initially costly, these costs will decrease the more of the technology is produced (Arthur, 1989). However, significant barriers to entry exist from upfront investment costs, given that immediate cost savings cannot always be guaranteed. Furthermore, the fixed costs previously used to set up and place the dominant technology on the market (sunk costs) exist for technologies already in use, including early investments, which means that the incentives to invest or choose a new technology or alternative are reduced. This adds to the effect of scale economies, whereby cost advantages accrue to the producer that first entered the market. A superior alternative might not be chosen if the expected costs to switching to an alternative outweigh the efficiency gains of facilitating such a transition, which in turn engenders a barrier to adoption and entry (Woerdman, 2015).

Knowledge and experience accumulated over time generally lead to higher returns if you continue along the same production path as before (Kuokkanen et al., 2017). Thus, learning effects usually improve the quality of technologies, while reducing costs, which will in turn intensify the benefits of adopting one technology over another. This means that when two relatively young technologies are competing for the same market, the one that is initially leading in the market share will push it further all along the learning curve; this is because technicians and users will already have acquired skills to take it into use, which will make it more attractive to future adopters (Cowan and Gunby, 1996). In this sense, learning is path-dependent and the early success of lowering running costs contributes to the condition of lock-in (Woerdman, 2015).

An important indicator of lock-in mechanisms is the notion of adaptive expectations, and more generally, the effect that uncertainty plays on the expected uptake of technologies. Broadly speaking, the theory sees that adoption will increase as uncertainty decreases. This can be attributed to manufacturers or users that consider it too costly to experiment with alternative technologies, given that their expected benefits are not well known, and if some *are* recognised, they do not provide a decent enough justification for experimentation (Brekke, 2003). This means that the increased prevalence of a technology on the market in itself enhances beliefs of future prevalence on the market. In this sense, the expectation held by consumers and end-users that a product will hold a large share of the market redirects demand and induces producers to place significant proportions of a product on the market.

The fourth and final aspect present in locked-in markets is the advantages that benefit those adopting the same technologies as others: network effects (Katz and Shapiro, 1985). Network