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Supply-Side Regulation: An Effective Tool to Accelerate Clean Vehicle Deployment

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Executive Summary

As part of meeting economic and environmental policy goals, numerous jurisdictions have accelerated clean vehicle markets through supply-side regulations. These policies require automakers to produce cleaner or more efficient vehicles.

This paper seeks to explain why policymakers are choosing this policy approach by examining the evidence and theory underpinning them and the design strategies that have helped to address industry challenges. Among the key reasons, supply-side regulations can:

- ensure that automakers invest in new clean technologies over incumbent technologies;
- create market certainty to accelerate growth in clean technologies;
- encourage the development of supportive fueling infrastructure;
- create self-financing markets without reliance on public funding;
- support global competitiveness of local industry; and
- reduce fossil fuel dependency.

Follow-up research will incorporate anonymized insights from interviews with regulators who have adopted and implemented these policies.

Keywords: Electric Vehicles, Plug-in Hybrid Vehicles, Hybrid Electric Vehicles, Fuel Cell Electric Vehicles, Public Policy & Promotion

1. Introduction

Governments around the world are increasingly using supply-side regulations to accelerate the adoption of cleaner and more efficient vehicle technologies.[1] These regulations include fuel economy standards, emission standards, and zero-emission vehicle sales requirements,[2] typically paired with credit and/or credit trading systems. Policymakers have chosen supply-side regulations as a mechanism to meet myriad goals, including to reduce greenhouse gas emissions, improve air quality,[3] and decrease fuel consumption.

This paper seeks to answer the question of why supply-side regulations are a preferred policy tool[4] for meeting these environmental and economic objectives. It defines what supply-side regulations are and cites examples and then maps out which jurisdictions have adopted them. Finally, it details the arguments supporting their adoption that may be persuasive to policy makers.

2. What are Supply-Side Regulation for Vehicles?

"Supply-side regulations" in the context of transportation are government requirements on automakers to produce cleaner or more efficient vehicles to improve air quality and public health, meet climate goals, and/or support economic development. These regulations often include a credit trading system that gives manufacturers some market-based flexibility for compliance. Examples of regulatory supply-side regulations include: [5]

- Fuel economy/efficiency standards, which require automakers to meet fleet-wide fuel efficiency targets, measured in miles per gallon (mpg) or liters per 100 km, in order to promote lower fuel options.
- Greenhouse gas (GHG) or carbon dioxide (CO2) emission standards, which set performance-based limits on GHGs or CO2 tailpipe emissions. These standards are functionally equivalent to fuel efficiency requirements because they also increase the production of more fuel-efficient vehicles.
- Zero-emission vehicle (ZEV) sales requirements, which mandate that a growing percentage of a manufacturer's annual vehicle sales must be zero-emission vehicles (ZEVs), including battery-electric (BEVs), fuel-cell-electric (FCEVs), and plug-in hybrids (PHEVs, which sometimes can count toward meeting these requirements, even though they may burn some petroleum fuel).

3. Which Jurisdictions Have Adopted Supply-Side Regulations?

Jurisdictions around the globe have adopted supply-side regulations. Below is a non-exhaustive overview.

Table 1: *Example of jurisdictions around the globe have adopted supply-side regulations*

Type of supply-side regulation	Example Jurisdictions
Fuel economy/efficiency standards	Brazil,[6] Chile,[7] China,[8] India,[9] Japan,[10] United States (federal).[11]
Greenhouse gas (GHG) or carbon dioxide (CO2) emission standards	Australia,[12] Brazil,[13] Canada,[14] China,[15] European Union (supranational),[16] India,[17] United States. (federal[18] and state-level).[19]
Zero-emission vehicle (ZEV) sales requirements	Canada (federal[20] and province-level),[21] China,[22] United States (state-level),[23] United Kingdom.[24]

Every jurisdiction has a different vehicle market, and policymakers have tailored each of these supply-side

regulations to fit the nuances of their local policy goals as well as vehicle stock, consumer profiles, economy, auto industry, and import/export profile, among other factors.[25]

4. Arguments and Evidence Supporting Supply-Side Regulations to Accelerate Clean Vehicle Deployment

Supply-side regulations can be powerful instruments with key advantages over alternative policy approaches, such as fiscal and demand-side policy levers (i.e. zero-emission vehicles manufacturing incentives[26] and government financing).[27] Depending on their structure, they do not require government funding and can be relatively straightforward to manage and inexpensive to administer. For example, zero-emission vehicle sales requirements primarily involve tracking sales. Emissions or fuel economy standards can also be low cost to implement, although they often require more extensive testing or simulation of new vehicle emissions or fuel efficiency to ensure automaker compliance.

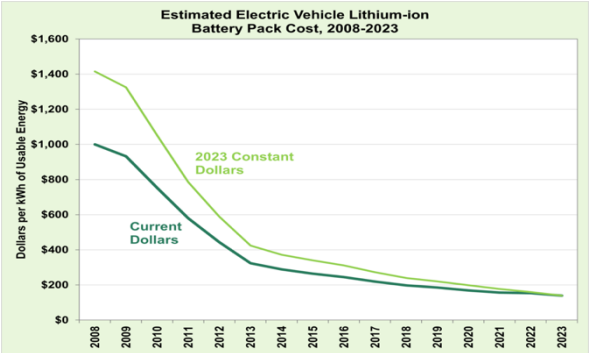
While further research can confirm why policy makers in specific jurisdictions decide to adopt them, this section explores some of the most persuasive arguments in support of supply-side regulations, which help explain their appeal to policymakers around the world.

4.1. Supply-side regulations ensure that automakers invest in new clean technologies when market forces otherwise favor incumbent technologies[28]

Producing and selling internal combustion engine vehicles remains the lower-cost option for most automakers today, while investing in innovation and new manufacturing for fuel-efficient and zero-emission vehicles typically involves higher upfront costs. Policy makers are willing to inflict these higher upfront costs on industry because more fuel efficient (and most electric) vehicles save consumers money over their lifetime due to reduced fuel consumption.

Policy makers can also observe evidence that these higher industry costs are often short-term. As production increases, economies of scale improve and learning curves accelerate, causing these upfront costs to decline.[29] Over time, these cleaner technologies are expected to become cheaper to produce and purchase than internal combustion engine vehicles.[30] For example, global battery manufacturing increased dramatically following increased zero-emission vehicle sales and related requirements, which drove down battery prices nearly tenfold. Specifically, battery pack costs dropped from ~$1,415 per kilowatt hour (kWh) in 2008 to ~$139 per kWh by 2023, a 90% decline.[31] This cost drop was partly due to technological improvements in battery technologies and chemistries, as well as improvements in manufacturing and increases in production volumes.[32] But increased scale and learning-by-doing as cumulative production rose into the millions of units played a large role as well. Supply-side zero-emission vehicle mandates were a key driver of that scale, especially in China, the world's largest electric vehicle producer.[33]

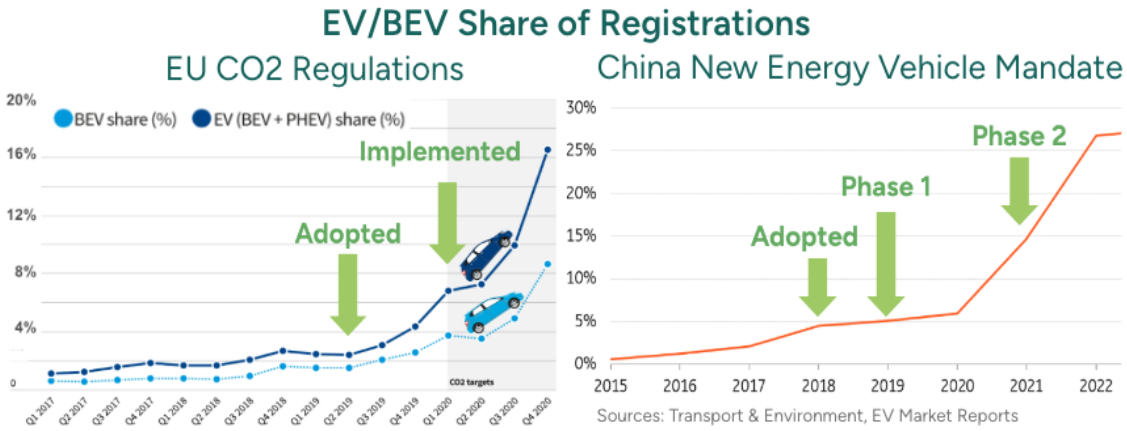
Fig. 1: *Plunging Battery Costs with Scale. Electric vehicle lithium-ion battery pack costs fell by ~90% from 2008 to 2023, from ~$1,415/kWh to ~$39/kWh (2023 USD)*[34]



In addition, supply-side regulations create a "level playing field" for the auto industry.[35] They set uniform standards that require all producers to invest in cleaner vehicle technologies. This industry-wide requirement prevents companies from undercutting the long-term market by chasing short-term profits from internal combustion engines, which can discourage broader investment in cleaner technologies and ultimately leave automakers less competitive as the market trends towards cleaner vehicles.

Recent evidence of increased zero-emission vehicle sales around the world suggests that the more ambitious and consistent the regulations, the more they accelerate the clean transport market. For example, the United Kingdom (UK) experienced more clean vehicle deployment compared to other European countries that did not have an annual sales targets from 2024 to 2030 like the UK.[36] Similarly, in 2023, the share of electric vehicle sales in states with zero-emission vehicle requirements (excluding California) was approximately 12%, double the 6.1% market share in states without zero-emission vehicle regulation.[37] In addition, when the European Union adopted the second round of carbon dioxide regulations for new cars, the market share of battery-electric vehicles and fuel-cell electric vehicles and plug-in hybrid electric vehicles jumped from 3% in 2019 to 19% in 2021. Similarly, in China, the electric vehicle market share jumped from 5% to 24% between 2019 and 2022 as the New Energy Vehicle requirements came into effect.[38]

Fig. 2: *The charts below show sales increasing noticeably following the implementation, strengthening, or reinstatement of supply-side regulations.*[39]



When facing a stringent supply-side standard that current technology cannot meet at acceptable cost, firms have a strong incentive to innovate in order to reduce compliance costs.[40] For this reason, experts call them "technology-forcing policies."[41] They can drive technological innovation for two key reasons: first, they explicitly aim to stimulate progress in environmental control technologies;[42] second, they establish a competitive dynamic where regulators and companies actively influence each other's decisions and behaviors and thus increase spending on research and development.[43] A classic example is the U.S. Clean Air Act tailpipe emissions standards of 1970. The law mandated that the federal Environmental Protection Agency achieve 90% reductions in tailpipe emission over a four-to-five year period.[44] In response, automakers developed the catalytic converter in 1975[45] and the three-way catalyst in 1981,[46] dramatically cutting emissions of hydrocarbons, carbon monoxide and nitrogen oxides between 1975 and 1985.[47] This innovation further spurred the availability and increased supply of unleaded gasoline.[48] Similarly, U.S. fuel economy standards led to widespread adoption of efficiency technologies[49] that might have been delayed or less prevalent without the supply-side requirements.

California presents another example of the technology-forcing nature of supply-side regulations. For over 20 years, zero-emission mandates in the state have spurred entrepreneurial and research activity in the field of electric vehicle components and materials. For instance, research from University of California, Davis linked the supply-side Low Emission Vehicle I standard in California in 1990 (which required zero-emission vehicles to account for 2% of new vehicle sales in 1998, rising to 5% in 2001, and 10% in 2003)[50] to a

subsequent increase in electric vehicle patenting.[51]

Examples from other sectors emphasize the power of supply-side regulations to force development of new technologies. For instance, the Renewable Portfolio Standards,[52] which set minimum requirements for the share of electricity supply (generation or sale) from designated energy resources by a specified date, created new wind and solar energy markets and helped reduce the cost of these technologies. Specifically, China increased production in response to these policies and new markets and drove costs down.[53] Another example includes U.S. refrigerator standards in the 1980s, which forced manufacturers to innovate and develop products that used a fraction of the energy without any cost increase.[54]

4.2. Supply-side regulations create market certainty, which accelerates growth in clean technologies

By setting gradually increasing requirements for new vehicles, supply-side regulations create a predictable deployment timeline that provides market certainty[55] (assuming the jurisdiction is not subject to rapid and widespread policy change). This long-term predictability allows industry leaders to plan their investments around a steadily growing market for clean vehicles,[56] which in turn:

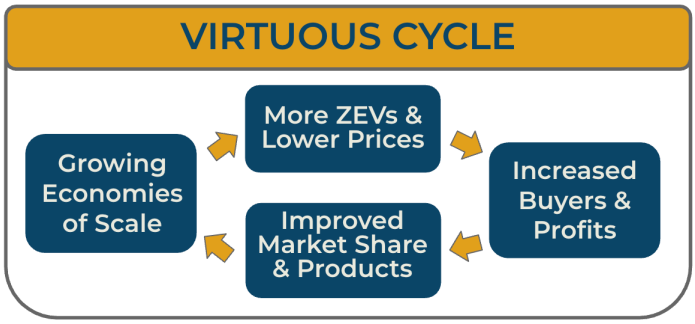
- Facilitates cost reductions by allowing manufacturers and suppliers to anticipate higher sales volumes, accelerating learning curves, and achieving economies of scale for clean vehicle products, services, and supply chains.

- Strengthens domestic industry and job growth by signaling long-term demand and encouraging investment in local manufacturing, infrastructure, and workforce development throughout the supply chain.

- Drives private investment and innovation[57] by reducing market risk, increasing investor confidence, and enabling the development of innovative financing and business strategies that help overcome high capital costs and unlock cost savings.

Moreover, most policymakers in this context want to increase the market faster, so that zero-emission vehicle purchase prices decrease and become affordable for more consumers.[58] Evidence of such affordability exists particularly in the smaller, entry-level electric vehicles, such as those now available in the UK.[59] Policymakers anticipate that near-term compliance costs yield much larger long-term payoffs, both in environmental terms and in lower vehicle operating costs and technology maturity.

Fig. 3: *The virtuous cycle of supply-side regulations illustrates how policy makers can achieve market certainty and lower costs*[60]



4.3. Supply-side regulations encourage the development of supportive fueling infrastructure, such as electric vehicle chargers and hydrogen stations

Supply-side regulations send clear market signals about the type of infrastructure needed to support cleaner vehicles, such as electric vehicle charging stations and related grid enhancements and hydrogen fueling stations for fuel cell vehicles. This certainty prompts further infrastructure investment and research and development. Supply-side regulations can also force coordination among supportive investments that lower costs globally. Developers will increasingly deploy charging infrastructure in jurisdictions with supply-side regulations to meet demand. Evidence from the UK indicates that the certainty created by the zero-emission vehicle mandate and phase-out of internal combustion engine sales enabled the commitment of its national charging industry coalition to invest £6 billion by 2030.[61]

This policy synergy resolves the "chicken and egg" problem[62] of lack of charging due to insufficient numbers of electric vehicles, but insufficient demand due to lack of infrastructure. By contrast, jurisdictions with supply-side regulations often see increased deployment of charging infrastructure and battery production facilities, which reduce "soft" costs[63] and convenience barriers. An analysis of U.S. states showed zero-emission vehicle mandate states have roughly two-to-three times more charging stations per capita than non-zero-emission vehicle states,[64] as public and private investment followed the policy-driven electric vehicle rollout. This charging network effect means the total cost of electric vehicle ownership drops (i.e. less range anxiety and more efficient use of infrastructure), which further encourages consumer adoption. In essence, supply-side regulations send a signal that galvanizes the entire industry ecosystem to invest, creating positive feedback loops.

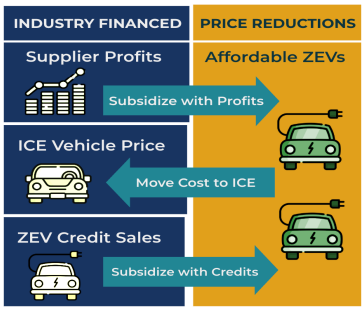
4.4. Supply-side regulations can create self-financing markets without reliance on public funding

Supply-side regulations motivate an industry-funded transition by prompting automakers to redirect private capital–both internally and across the sector–toward investments in affordable clean vehicle production:

- Automakers must increase sales of cleaner vehicles to meet supply-side regulation targets. In order to ensure sufficient consumer and business demand for cleaner vehicles, they can lower prices by investing in production expansion and cost-reduction strategies.[65]
- A well-designed supply-side regulation credit mechanism can generate revenue for automakers that exceed targets and have credits to sell, assuming every electric vehicle sold receives credits determined by its electric range. Automakers that under-deliver clean vehicles—by selling internal combustion engine ones—will have to purchase those credits from companies that exceed the mandate.

For example, Tesla's early success was due in part to the revenue the company earned from the sale of zero-emission vehicle credits, accounting for 5-10% of the firm's total revenue most years.[66] Credit revenues were crucial in allowing Tesla and Nissan—two early electric vehicle companies—to weather the initial high costs of bringing pure zero-emission vehicles to market.[67] The credit system also allowed other companies to comply with the rules without needing to sell electric vehicles, potentially lowering their compliance costs by letting these firms buy credits from others.[68]

Fig. 4: *Visualization of how self-financing clean vehicle markets can work*[69]



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4.5. Supply-side regulations can support the global competitiveness of local industry

As supply-side regulations expand worldwide, more automakers and vehicle markets are shifting towards cleaner technologies. But for markets without such regulations, automakers will continue to sell older, more polluting, less efficient vehicles.[70] This dynamic not only limits local environmental and economic benefits but also puts these local automakers at a competitive disadvantage globally.[71] As other regions adopt stricter standards, markets that fail to make this transition risk being excluded from international trade, as many countries will not accept or have lower demand for outdated, high-emission vehicles.

In both regulated and unregulated markets, automakers that fail to increase clean vehicle production risk losing market share to international competitors that are moving faster on more efficient or electric vehicles.[72] The competitive nature of the market may also benefit customers at a local level and increase the supply of clean vehicles they can choose from.[73] By requiring investment in cleaner technologies, supply-side regulations can therefore secure both domestic benefits and maintain local manufacturer competitiveness in the evolving global automotive market.[74]

Many countries seek to be leaders in the growing electric vehicle industry (batteries, power electronics, new vehicle design, etc.). For example, China's aggressive electric vehicle mandates and subsidies were arguably due to industrial strategy (dominating electric vehicle and battery production) rather than a desire to reduce greenhouse gas emissions. Similarly, the EU's stringent standards aimed to push carmakers toward electrification to stay competitive vis-à-vis international rivals.[75]

Supply-side regulations can ultimately enhance global competitiveness by encouraging industries to invest in clean vehicle research and development. These policies in major markets also stimulate investment not only in vehicle manufacturing but also in upstream industries like mining, battery recycling, and power sector upgrades,[76] which can contribute to increasing the local economy. Ultimately, regulators can assist this investment by reducing information gaps through transparent technical assessments and by prompting firms to share knowledge.

4.6. Supply-side regulations reduce fossil fuel dependency, generating savings for consumers and improving energy security

More efficient and zero-emission vehicles reduce oil consumption[77] and therefore improve energy security. Countries that import oil have benefitted from fuel economy standards that cut demand. As an example, the U.S. adopted the Corporate Average Fuel Economy standards during the 1970s oil crisis to reduce dependence on foreign oil. Shifting to electricity (or hydrogen) as a fuel for transport through zero-emission vehicle requirements can improve energy independence,[78] especially if paired with clean power generation. For example, the cumulative savings from vehicle efficiency in the U.S. ($5 trillion in saved fuel costs) demonstrate huge economic benefits and reduction in foreign oil imports that likely would not have occurred

without regulation forcing the saving.[79]

Consumers ultimately save by purchasing an electric vehicle, spending about 60% less each year on fuel costs compared to internal combustion engine vehicles.[80] In every state in the U.S. it is cheaper to fuel an electric vehicle than an internal combustion engine.[81]

5. Conclusion: Supply-side regulation and the environment

Supply-side vehicle regulations have proven to be popular options for policymakers seeking to transform the transportation sector in the public interest. By mandating cleaner and more efficient vehicles, supply-side regulations can align automakers' incentives with societal goals, leveraging private capital and innovation to deliver cleaner air, lower consumer costs, and progress toward climate targets. While this paper seeks to answer the question of why supply-side regulations are popular policy tools, further research and outreach can help explain why specific jurisdictions adopted them and what political and other factors may have been influential.

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