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Essays on Energy Transition in a Developing Country: The Case of Argentina

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Summary

The concentration of greenhouse gases (GHG) in the atmosphere has increased sharply in recent decades, affecting human health, economic performance, and societal functioning. According to Olivier et al. (2020), electricity and heat generation (35.8%), transport (19.5%), and industrial activities (16.7%) are the largest CO2 emitters, primarily due to fossil fuel consumption. A transition to cleaner energy systems is necessary, particularly in how energy is produced and used. According to Meng et al. (2023), developing countries contributed 43.2% of cumulative global CO2 emissions between 1995 and 2015. The energy transition must therefore be integrated into the development agenda: the goal is to decarbonize economic activity while supporting sustainable development (Fay et al., 2015).

This thesis explores the energy transition from the perspective of energy and environmental economics, focusing on Argentina as a case study. It is divided into three chapters, each addressing a different dimension of the energy transition while contributing to policy-oriented insights. Chapters 1 and 2 examine transport-related issues, including biofuel mandates and electric vehicle (EV) promotion, while Chapter 3 focuses on the power sector and the role of energy storage. All chapters provide economy-wide, policy-oriented analyses of impacts on prices, output, welfare, income distribution, and fiscal balances, highlighting trade-offs relevant for energy-transition strategies.

1. Chapter 1 examines Argentina's mandatory biofuel blend policy using a Recursive Computable General Equilibrium (CGE) model calibrated with a 2018 energy-oriented Social Accounting Matrix. The analysis compares mandatory blending with full market flexibility and evaluates alternatives to induce a given blend such as fossil fuel taxes. Results indicate that mandatory blending reduces economic activity, affects income distribution and energy affordability, but lowers emissions. A special tax on fossil fuels performs better in the short run, while the mandatory blend has longer-term benefits. Market flexibility improves resilience to international price shocks.

2. Chapter 2 develops a dynamic automobile market model including primary and secondary markets, charging infrastructure investment, and network effects. Three policy scenarios are examined: EV subsidies, welfare-maximizing subsidies, and a ban on new internal combustion engine vehicles. Subsidies increase EV penetration to 11.88% under a 30% subsidy, but network effects can reduce adoption. Emissions decrease moderately, while battery waste rises. Policy funding affects equity outcomes, and charging infrastructure subsidies alone have limited impact. EV bans require significant price reductions to preserve welfare. They fully electrify the fleet but generate substantial battery waste.

3. Chapter 3 evaluates economic and environmental effects of deploying energy storage in Argentina using a two-step approach: optimal electricity dispatch to estimate cost

reductions, and a recursive CGE model for macroeconomic and sectoral effects. Storage capacities of 5% and 7% of total generation reduce electricity costs by 1.9–3.36%, with larger benefits under projected 2030 conditions. GDP grows by 0.47–1.11 percentage points, unemployment falls, fiscal revenues rise, and welfare improves across all households, reducing inequality. Emissions decline, and electricity-intensive industries benefit most. Social benefits exceed investment costs, highlighting the need for public support to foster energy storage.

Keywords: Energy transition; Public policies; Developing countries; Climate change; Fuels; Electrification.

Résumé

La concentration des gaz à effet de serre dans l'atmosphère a fortement augmenté au cours des dernières décennies, affectant la santé humaine, la performance économique et le fonctionnement de la société. Selon Olivier et al. (2020), la production d'électricité et de chaleur (35,8 %), les transports (19,5 %) et l'industrie (16,7 %) constituent les principales sources d'émissions de CO2, principalement en raison de l'utilisation de combustibles fossiles. Une transition vers des systèmes énergétiques plus propres est donc nécessaire, tant du côté de la production que de la consommation. Selon Meng et al. (2023), les pays en développement ont contribué à 43,2 % des émissions cumulées mondiales entre 1995 et 2015. La transition énergétique doit ainsi être intégrée à l'agenda du développement afin de concilier décarbonation et croissance durable (Fay et al., 2015).

Cette thèse analyse la transition énergétique en Argentine sous l'angle de l'économie de l'énergie et de l'environnement. Elle se compose de trois chapitres, chacun abordant une dimension spécifique avec une perspective orientée vers les politiques publiques. Les chapitres 1 et 2 portent sur le secteur des transports, en étudiant les biocarburants et les véhicules électriques (VE), tandis que le chapitre 3 se concentre sur le secteur électrique et le rôle du stockage d'énergie. L'ensemble propose une analyse à l'échelle de l'économie des effets sur les prix, la production, le bien-être, la distribution des revenus et les équilibres fiscaux, en mettant en évidence les arbitrages associés aux politiques de transition.

1. Le chapitre 1 étudie la politique de mélange obligatoire de biocarburants à l'aide d'un modèle d'équilibre général calculable récursif (CGE) calibré sur une matrice de comptabilité sociale orientée énergie pour 2018. Il compare cette politique à une situation de flexibilité totale du marché et évalue des alternatives, notamment la taxation des combustibles fossiles. Les résultats montrent que le mélange obligatoire réduit l'activité économique et modifie la distribution des revenus, tout en diminuant les émissions. Une taxe apparaît plus efficace à court terme, tandis que le mélange présente des avantages à long terme. La flexibilité du marché améliore la résilience face aux chocs internationaux de prix.

2. Le chapitre 2 développe un modèle dynamique du marché automobile intégrant les marchés primaire et secondaire, l'investissement dans les infrastructures de recharge et les effets de réseau. Trois politiques sont analysées : subventions aux VE, subventions maximisant le bien-être et interdiction des ventes de véhicules thermiques. Les subventions portent la part des VE à 11,88 %, mais les effets de réseau peuvent freiner leur diffusion. Les émissions diminuent modérément, tandis que les déchets de batteries augmentent. Le financement influence les résultats en termes d'équité, et les subventions aux seules infrastructures ont un impact limité. Les interdictions nécessitent des baisses de prix importantes : elles électrifient le parc, mais génèrent des déchets significatifs.

3. Le chapitre 3 évalue les effets économiques et environnementaux du déploiement du stockage d'énergie en Argentine à partir d'une approche en deux étapes : un

modèle de dispatch optimal pour estimer la réduction des coûts électriques, puis un modèle CGE récursif pour analyser les effets macroéconomiques et sectoriels. Des capacités de stockage de 5 % et 7 % de la production réduisent les coûts de l'électricité de 1,9 à 3,36 %, avec des gains plus élevés dans le scénario 2030. Le PIB augmente (0,47 à 1,11 point), le chômage diminue, les recettes fiscales et le bien-être s'améliorent, et les inégalités se réduisent. Les émissions diminuent et les industries électro-intensives en bénéficient le plus. Les bénéfices sociaux dépassent les coûts d'investissement, soulignant la nécessité d'un soutien public.

Mots clés: Transition énergétique; Politiques publiques; Pays en développement; Changement climatique; Carburants; Électrification

Resumen

La concentración de gases de efecto invernadero (GEI) en la atmósfera ha aumentado significativamente en las últimas décadas. Este fenómeno no solo afecta la salud de la población, sino también el desempeño económico y el funcionamiento de la sociedad. Olivier et al. (2020) estiman que entre las actividades que más emisiones de CO2 generan se encuentran la producción de electricidad y calor (35,8%), el transporte (19,5%) y las actividades industriales (16,7%). Los autores también destacan que estas emisiones están estrechamente relacionadas con el consumo de combustibles fósiles. Por lo tanto, es necesario que las economías transiten hacia un sistema más limpio, especialmente en la forma en que se produce y se utiliza la energía: la transición energética. Según Meng et al. (2023), los países en desarrollo representaron el 43,2% de las emisiones globales acumuladas de CO2 entre 1995 y 2015. En este contexto, la transición energética debe integrarse a la agenda del desarrollo: el objetivo no es solo descarbonizar la actividad económica a cualquier costo, sino descarbonizar el desarrollo (Fay et al., 2015), lo que plantea un desafío más complejo.

Esta tesis explora temas en la intersección de la economía de la energía y la economía ambiental. Tiene como objetivo profundizar en los debates actuales sobre la transición energética, centrándose en el caso de un país en desarrollo: Argentina. Se estructura en tres capítulos independientes, aunque con denominadores comunes. Los tres capítulos de esta tesis están unidos por una lógica coherente: cada uno explora una dimensión distinta de la transición energética en Argentina y todos comparten el objetivo de informar la toma de decisiones orientada a políticas en los mercados de energía. Los capítulos 1 y 2 abordan temas de transición energética relacionados con el transporte (analizando mandatos de biocombustibles y políticas de promoción de vehículos eléctricos), mientras que el capítulo 3 se adentra en el sector eléctrico al evaluar el impacto de la introducción de infraestructura de almacenamiento de energía eléctrica. A pesar de sus diferentes áreas de enfoque, los tres emplean un marco de análisis de alcance económico y orientación política que traza cómo cada intervención impacta en precios, producción, bienestar, distribución del ingreso y balances fiscales. En conjunto, estudian los trade-offs y retroalimentaciones relevantes que forman parte de las estrategias de transición energética. A continuación, se presenta un breve resumen de cada uno de los capítulos incluidos en esta tesis.

- **Capítulo 1.** *¿Cuáles son los costos de la rigidez? Un estudio de Equilibrio General del mercado de combustibles en Argentina:* La política más aplicada en el mundo para fomentar el uso de biocombustibles es el corte obligatorio. Esta política establece un nivel mínimo de biocombustible por unidad de combustible mezclado. Este capítulo estudia los costos y beneficios de dicha política. Para ello, se desarrolla un modelo de Equilibrio General Computable (CGE) recursivo calibrado con una nueva Matriz de Contabilidad Social, con identificación de sectores energéticos, para Argentina en 2018. Este modelo se extiende incorporando explícitamente un modelo de mezcla de combustibles con restricciones. Este capítulo aborda las siguientes preguntas: ¿Cuáles son los costos y beneficios de un corte obligatorio con respecto a un escenario con total flexibilidad? ¿Es preferible inducir el uso de biocombustibles mediante un impuesto a los combustibles fósiles o una restricción de mezcla? ¿Cuál es el impacto de los shocks internacionales de precios bajo diferentes

regímenes de mezcla? Esta investigación encuentra que el corte obligatorio tiene un impacto negativo sobre la actividad económica, la pobreza, la distribución del ingreso y la asequibilidad energética, pero un efecto positivo sobre las emisiones. Al analizar la conveniencia de un impuesto especial a los combustibles fósiles en lugar de un régimen obligatorio, se observa que los costos y beneficios de cada política se distribuyen de manera distinta a lo largo del tiempo. El impuesto especial resulta más eficiente en el corto plazo, mientras que el corte obligatorio lo es en el largo plazo. Finalmente, se concluye que la flexibilidad del mercado de combustibles mejora el desempeño del país frente a shocks internacionales de precios.

- **Capítulo 2.** *Impulsando el cambio: Evaluando el impacto de las políticas de promoción de vehículos eléctricos en Argentina:* Para evaluar el impacto de las políticas de promoción de vehículos eléctricos (VE), estimo un modelo dinámico y tratable del mercado automotor que incorpora tanto el mercado primario como el secundario, un sector de inversión en servicios de carga y efectos de red indirectos, utilizando datos de Argentina. Evalúo tres regímenes contrafactuales: (i) subsidios a la compra de VE nuevos y a la infraestructura de carga, (ii) el subsidio óptimo a los VE que maximiza el bienestar bajo configuraciones alternativas de externalidades y de impuestos, y (iii) una prohibición de ventas de nuevos vehículos con motor de combustión interna (ICE). Bajo subsidios a la compra y precios base de los VE, la participación residencial de VE aumenta hasta 11.88% con un subsidio del 30%. Los efectos de red pueden reducir la penetración hasta en 10.63 p.p. para un subsidio del 30%. Las emisiones caen de 12.99 a 10.84 $MTCO_2eq$, mientras que el descarte de baterías aumenta hasta 27.09 mil unidades por año. Los resultados muestran que el régimen impositivo utilizado para financiar la promoción de VE no es neutral desde el punto de vista distributivo. Los subsidios a la infraestructura de carga por sí solos tienen un impacto despreciable. El subsidio óptimo a los VE es del 29% bajo el statu quo, del 24% en ausencia de externalidades ambientales, del 20% sin efectos de red, del 17% cuando no se consideran los impuestos a los automóviles y del 25% cuando se elimina el IVA. Una prohibición de las ventas de nuevos ICE requiere que los precios de los VE caigan un 37% para preservar el bienestar (44% para mantener la proporción de hogares sin automóvil), electrificando completamente la flota, reduciendo las emisiones a 2.72 $MTCO_2eq$, pero incrementando el descarte de baterías hasta 127 mil unidades.

- **Capítulo 3.** *Impactos Económicos Amplios del Almacenamiento de Energía: El Caso de Argentina:* Las energías renovables ofrecen una vía para descarbonizar los sistemas eléctricos, pero enfrentan desafíos derivados de su naturaleza intermitente. El almacenamiento de energía puede mitigar este problema al desplazar la oferta a lo largo del tiempo, estabilizando la oferta de electricidad y otorgando más flexibilidad al sistema. Este trabajo estudia los impactos económicos y ambientales del desarrollo de infraestructura de almacenamiento de energía en Argentina mediante un enfoque en dos etapas: un modelo de despacho óptimo de electricidad para estimar reducciones en los costos de generación eléctrica, y un modelo de equilibrio general recursivo para evaluar los efectos macroeconómicos, sectoriales y distributivos. Se simulan capacidades de almacenamiento equivalentes al 5% y 7% de la capacidad total de generación, tanto bajo las condiciones actuales (2021) como en un sistema proyectado para 2030, caracterizado por una mayor demanda y una expansión significativa de la generación renovable. En todos los escenarios, los costos promedio

de la electricidad disminuyen entre 1,9 y 3,36%, con los mayores beneficios en el sistema de 2030, donde el almacenamiento adquiere mayor valor a medida que aumenta la penetración de renovables. Estas reducciones de costos generan beneficios económicos generalizados. El PIB aumenta entre 0,47 y 1,11 puntos porcentuales a lo largo de una década, el desempleo se reduce entre 0,07 y 0,19 p.p., y los ingresos fiscales aumentan entre 0,43 y 1,13 p.p. El bienestar mejora para todos los hogares, con efectos particularmente fuertes entre los hogares de menores ingresos, lo que contribuye a una reducción de la desigualdad. Las emisiones disminuyen entre 1,9 y 3,02 p.p. y se reduce la intensidad de emisiones de la economía. Los resultados sectoriales muestran que las industrias intensivas en electricidad, como la Construcción, los Minerales No Metálicos y la Extracción, son las principales beneficiarias, mientras que los sectores de Combustibles y actividades Primarias resultan perjudicados. Una comparación entre las ganancias anuales del PIB y los costos de inversión muestra que los beneficios sociales del almacenamiento superan sus costos de capital en todos los escenarios. Estos resultados resaltan el sólido argumento a favor del apoyo público para fomentar la inversión en almacenamiento de energía y capturar plenamente sus beneficios económicos, ambientales y distributivos para Argentina.

Palabras clave: Transición energética; Políticas públicas; Países en desarrollo; Cambio climático; Combustibles; Electrificación.

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Introduction

The concentration of greenhouse gases (GHG) in the atmosphere has increased dramatically in recent decades. According to the World Bank database[1], between 1990 and 2020, annual global GHG emissions grew by 50.57%, reaching 46.12 million KTCO2eq[2]. This phenomenon has a significant impact not only on the environment, but also on society as a whole. Watkiss et al. (2005) point out that the main consequences of climate change include rising sea levels, heat waves, forest fires, intense hurricanes, changes in rainfall patterns leading to floods or droughts, and degradation of air quality. All this not only affects people's health (Borchers-Arriagada et al., 2024; García-Witulski et al., 2023), but also impacts economic performance and the functioning of society (Tol, 2018; Carleton and Hsiang, 2016). Therefore, climate change must be contained and mitigated.

In this context, mitigating climate change requires reducing net GHG emissions to zero. Emission reductions must happen quickly because, as long as more greenhouse gases are emitted than nature can absorb through its sinks (such as oceans, forests, and other vegetation) the concentration of these gases in the atmosphere will continue to rise, and the planet will continue to warm. According to the World Bank database, approximately 73% of the 46.12 million KTCO2eq of GHGs emitted in 2020 are carbon dioxide (CO2) emissions. Olivier et al. (2020) estimate that among the activities that emit the most CO2, those that stand out are electricity and heat generation (35.8%), transport activities (19.5%) and industrial activities (16.7%). The authors also point out that these emissions are mainly associated with the consumption of fossil fuels. It is therefore necessary for economies to move towards a cleaner system, particularly in terms of the way energy is produced and used. Sgouridis and Csala (2014) define energy transition as a process that leads a society to replace the main fossil energy sources with renewable and sustainable resources while ensuring the provision of energy per capita.

Kaya Identity (Kaya et al., 1997) states that carbon emissions depend on four factors: 1) Population, 2) Gross Domestic Product (GDP) per capita, 3) Energy intensity (amount of energy used per unit of GDP) and 4) the carbon intensity of energy supply. Therefore, taking demographics as a given, the energy transition must delve into the latter three factors and how they interact. In this context, the Kaya Identity leads us to think about technological change, energy efficiency, recycling, decarbonization of power generation and many other possible actions to reduce emissions and mitigate climate change.

However, the energy transition is not without obstacles. According to Schubert (2017), fossil energy sources have been part of the everyday functioning of economies since the beginning of the industrial revolution. Therefore, productive activities have specialized in the use of fossil fuels, generating deep and complex problems for their decarbonization. In this line, the incorporation of new clean technologies and alternative forms of energy implies getting rid of the capital already installed and making investments to replace it (Lennox and Witajewski-Baltvilks, 2017; Azomahou et al., 2012). This also implies facing new challenges. A paradigmatic example of these challenges is the case of

[1]Link: World Bank Database

[2]Kilo-Tons of CO2 equivalent.

renewable electricity generation, where the possibility of exploiting these technologies depends significantly on weather conditions (Petersen et al., 2024). Therefore, the massive incorporation of these technologies could create problems of intermittency in electricity generation, leading to imbalances between supply and demand (Mazo et al., 2020; Ambec and Crampes, 2021).

According to Meng et al. (2023), developed countries contributed in 56.8% to cumulative global CO2 emissions between 1995 and 2015, while developing countries contributed the remaining 43.2%. However, developing economies generally face multiple challenges in moving rapidly towards a low-carbon economy such as: lack of financing, technology gaps, uncertainty about the future, and institutional problems, among others (Fauceglia, 2015; Álvarez and Labra, 2014; Aghion et al., 2010; Acemoglu et al., 2003). Also, poverty, welfare and inequality represent particularly pressing concerns in developing countries (Alvaredo and Gasparini, 2015; Haddad et al., 2024). In this context, the energy transition plays a crucial role, as many energy market policies have direct effects on low-income households, which are the most exposed to changes in energy availability and affordability (Cavallo et al., 2024; Hodok and Kozluk, 2024; Brown et al., 2025).

Therefore, the process of moving towards a cleaner economy in these countries must be carefully analyzed. In this context, the quest for an energy transition must be integrated into the development agenda: the objective is not just to decarbonize economic activity at any cost, but to decarbonize development (Fay et al., 2015; Fodha, 2024), which is a more challenging goal.

Purpose of the Thesis and Presentation of the Chapters

This thesis aims to deepen the current topics of energy transition and to provide an updated and creative perspective to analyze these problems. Moreover, this thesis also seeks to elaborate tools that allow the study of the energy transition process in the context of developing economies. Particularly, for the construction of the chapters, Argentina will be taken as a case study.

Argentina provides a compelling case for studying the energy transition in a developing-country. It is a middle-income country with a vast territory and long distances, which make automobile use and road transportation essential (World Bank, 2023). The country also holds substantial potential for renewable energy generation (Ruggeri and Garrido, 2021), particularly solar power in the northwest and wind power in the Patagonia. In addition, Argentina possesses large oil and gas reserves in Vaca Muerta (Coremberg, 2019), strong comparative advantages in the production of biofuel inputs (Torroba and Orozco Montoya, 2023), and significant lithium reserves in the northwest (Orihuela and Serrano, 2024). Despite these advantages, Argentina faces severe infrastructure constraints in both transportation and electricity systems (World Bank, 2023), alongside persistent challenges related to productivity, income inequality, and poverty (Ahumada et al., 2024; Gasparini et al., 2019). According to INDEC (2025), 24.1% of households are below the poverty line, representing 31.6% of the population. Of these, 5.6% of households fall below the extreme poverty line, accounting for 6.9% of the population. These features make Argentina an especially relevant case for evaluating how the energy transition agenda can align with broader debates on economic growth and development. Moreover, the insights and evidence from this study are relevant for informing other countries facing similar structural conditions.

The general objectives of this work are:

1. To raise and study problems that are relevant to understand the energy transition in developing countries, taking the Argentine case as a reference, and to propose or analyse policies that help to overcome them.

2. To link the state of the art in the field of economic sciences with the challenges presented by this transition in order to frame them in the current literature.

3. To develop databases and methodological tools to study and quantify various aspects related to the energy transition and the impact associated with the implementation of public policies. In this way, the aim is not only to carry out an exhaustive analysis of a particular problem, but also to make policy recommendations for the country studied that will also be illustrative for other similar cases.

This thesis is structured in three chapters, each one corresponding to independent research, although with common denominators. The three chapters of this thesis are bound together by a coherent logic: each one explores a different dimension of Argentina's energy transition and all of them share the common goal of informing policy-oriented decision-making in energy markets. Focusing on these topics is crucial not only for economic performance (since energy underpins every value chain) but also for enhancing welfare and reducing GHG emissions.

One of the most important dimensions of the energy transition is the transformation of transportation activities, which account for a large share of global greenhouse gas emissions. According to the World Resources Institute[3], transportation activities accounted for nearly 14% of total GHG emissions in 2021 (approximately 18% of CO2 emissions). As a result, research on the energy transition must pay particular attention to this sector. Chapters 1 and 2 address this challenge from two complementary perspectives. Chapter 1 analyzes the costs and benefits of a biofuel support policy: the mandatory blend. This policy sets a minimum share of biofuels in a unit of blended fuel (De Gorter and Just, 2009; Serra and Zilberman, 2013) reducing its carbon intensity. This policy, widely implemented across countries, aims to increase biofuel demand by making their use compulsory (Torroba and Orozco Montoya, 2023). Mandatory blending reshapes fossil fuel markets, affects sectoral performance, and alters emissions from fuel consumption. Chapter 2 examines the electrification of the automobile fleet. Although electric vehicles (EVs) offer substantial potential to reduce transport-sector emissions, most developing countries, including Argentina, have not yet achieved significant EV adoption (Li et al., 2021). Two main barriers hinder EV adoption. First, EVs involve higher upfront costs relative to internal combustion engine vehicles (Sheldon et al., 2023). Second, limited charging infrastructure constrains their diffusion (Luo et al., 2023). According to Li et al. (2017a), the EV market exhibits indirect network effects arising from the interdependence between vehicle adoption and investment in charging stations. In this context, Chapter 2 evaluates the impact of alternative policy scenarios that promote EV adoption on market penetration, emissions, battery disposal, household welfare, and fiscal revenues.

Another key dimension of the energy transition is the decarbonization of electricity generation. According to the World Resources Institute[4], electricity and heat generation accounted for nearly 40% of global CO2 emissions in 2021. Renewable energy sources can

[3]https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors
[4]https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors

provide low-cost, zero-emission electricity, but their output is intermittent and weather-dependent (Petersen et al., 2024). Energy storage has therefore emerged as a critical enabler for integrating renewables (Andrés-Cerezo and Fabra, 2023). Chapter 3 studies the microeconomic and macroeconomic impacts of deploying energy storage capacity, identifying which sectors and stakeholders benefit (and which may incur losses) as electricity systems adopt this technology.

All chapters of this thesis deliver a comprehensive, economy-wide analysis. They trace how targeted interventions (in biofuel blending, vehicle electrification, or energy storage) ripple through prices, output, welfare, income distribution and fiscal balances across the entire Argentine economy. In doing so, the thesis not only quantifies direct policy effects but also uncovers the broader economic feedbacks and trade-offs inherent in any energy transition strategy.

The following is a brief summary of each one of the chapters included in this thesis.

The **first chapter**, called *What are the costs of rigidity? A General Equilibrium study of the fuel market in Argentina* focuses on the Argentine fuel market. Particularly, it focus on the role of first-generation biodiesel and bioethanol, and studies the costs and benefits induced by the mandatory blend. This policy has been widely applied to regulate how those fuels are mixed and to incentivize the use of biofuels. It sets a minimum level of biofuels that must be present in a unit of blended fuel. Argentina is a biofuel-producing country with proven comparative advantages in the production of the primary inputs for biofuels (Timilsina et al., 2013). Therefore, the conclusions from this work may be illustrative for other producing countries. Torroba and Orozco Montoya (2023) report that biofuel mandates are present, with varying rates and setups depending on the country. Thus, the modelling of this policy and the conclusions from this analysis relate to other countries applying this regulation. This research addresses the following questions: (i) What are the costs and benefits of a mandatory blend compared to a full flexibility scenario? (ii) Which policy is better to induce the use of biofuels: a blending constraint or a tax on fossil fuels? And, finally, (iii) what is the impact of international price shocks when considering different blending regimes?

To explore these questions, this paper develops a Computable General Equilibrium (CGE) model calibrated using a new own-developed 2018 Social Accounting Matrix of Argentina, with a focus on energy sectors. The modelling of the fuel and biofuel supply, together with an explicit representation of the blending constraint, are the most relevant methodological aspects of this paper. The model was recursively estimated from 2019 to 2030. There are three blocks of counterfactual exercises. The first one evaluates the cost and benefits of the mandatory blend with respect to a full flexibility scenario. The second one evaluates the best alternative to induce biofuel use by comparing previous mandatory blends with a scenario involving an additional fossil fuel tax to achieve equivalent blending levels. Finally, the third one measures the performance of the mandatory blend when the international price of oil and the international prices of agricultural commodities increase. This paper finds that, if there is a shift from a mandatory blend regime to a flexible one, although upon calibration relative prices are in favour of fossil fuels, biofuels remain in the economy, and over time their share in the blend increases. It also finds that the mandatory blend presents a trade-off between efficiency and environmental outcome. Particularly, there are costs in terms of activity, welfare, income distribution, and energy affordability compared to the full flexibility scenario. However, in terms of environmental outcomes,

the mandatory blend is an effective policy. As for the more convenient policy to induce a certain blend, this paper finds that the costs and benefits of a fossil fuel tax versus a mandatory blend are distributed differently over time. For the fossil fuel tax, benefits are derived in the short run while for the mandatory blend, in the long run. Finally, this paper finds that flexibility in the fuel market improves the country's performance when there are shocks on international prices.

The **second chapter**, called *Driving Change: Assessing the Impact of EV-promoting Policies in Argentina* assess the impact of different policy scenarios on EV penetration, emissions, battery disposals, household welfare, and fiscal revenue. The research questions are: (i) What is the impact of subsidizing new EVs and new charging infrastructure on adoption, emissions, battery disposals, welfare, and fiscal outcomes? (ii) What is the welfare-maximizing subsidy for new EVs, and how does it change when environmental externalities, network externalities, and tax policies change? (iii) If banning new ICE vehicle sales is considered, by how much should EV prices decrease to maintain pre-ban household welfare? In this chapter, I develop and estimate a dynamic structural model that considers trading patterns in the primary and secondary automobile markets of the type described in Gillingham et al. (2022). There are two distinctive aspects of this model: First, the modelling of a battery charging service market characterized by an optimal investment problem. Second, the introduction of indirect network effects arising from the interdependence between EV adoption and investment decisions regarding charging infrastructure. These effects can limit EV adoption and erode the effectiveness of the EV-promoting policies.

I evaluate three blocks of counterfactual scenarios. In the first block, I quantify the effects of subsidies to new EVs ($s \in [0, 0.3]$) and charging infrastructure ($s_c \in [0, 0.3]$), both with and without network effects. To account for price dynamics, I consider three EV price scenarios: (i) baseline, (ii) a 7% reduction, and (iii) a 15% reduction (IEA, 2025b). I find that subsidies to new EVs substantially encourage adoption: the residential EV share rises from 0.32% in the baseline to 11.88% at a 30% subsidy, while the share of households without a car falls from 60.41% to 58.09%. Network effects become more important as the subsidy increases. When network effects operate and households care about infrastructure availability, EV market penetration falls by up to 10.63 percentage points at a 30% subsidy with respect to the no network effects situation. Charging costs and the number of charging stations both increase significantly with the subsidy. Carbon emissions decline, while battery disposals increase from 0.97 to 27.09 thousand per year. Fiscal revenues remain stable, and average household welfare increases from 4.25 to 4.32 thousand USD. The results also show that the tax regime used to finance EV promotion is not distributionally neutral and plays a central role in shaping the policy's equity implications. By contrast, subsidies to charging infrastructure alone have negligible effects. These results indicate that the primary barrier to EV adoption is the high upfront cost of vehicles and that charging infrastructure responds mainly to increases in EV adoption rather than to direct subsidies.

In the second block, I estimate the welfare-maximizing subsidy to new EVs. The optimal subsidy equates marginal social benefits with marginal social costs. Benefits include (i) reduced noise and local pollution and (ii) lower travel costs due to EVs' higher efficiency in cost per kilometer. Social costs arise from the tax burden required to fund the subsidy. Under the status quo, the optimal subsidy equals 29%, yielding an EV share of 9.36% and a no-car share of 58.62%. Excluding environmental externalities reduces the

optimal subsidy to 24%, with an EV share equal to 4.05%. Excluding network externalities further reduces the subsidy to 20%. Estimating the optimal subsidy jointly with the elimination of car taxes or VAT yields optimal subsidies of 17% and 25%, respectively. Eliminating car taxes generates the highest EV penetration, with an EV share of 29.33% and a no-car share of 53.86%. In the third block, I simulate a ban on new ICE vehicle sales by imposing prohibitively high transaction costs. To preserve pre-ban household welfare, EV prices must fall by 37%, which fully electrifies the fleet and raises the no-car share to 74.35%. Alternatively, to maintain the pre-ban share of carless households, EV prices must decline by 44%.

Finally, the **third chapter** called *Wide Economic Impacts of Energy Storage: The Case of Argentina* (written with Exequiel Romero-Gomez) focus on the impact of energy storage for the case of Argentina. The objective of this article is to study the wide-economic and sectorial impacts of installing energy storage capacity for the case of Argentina. Particularly, I discuss the following research questions: (i) How does the cost of electricity change under different levels of energy storage capacity? (ii) Given these new electricity costs, relative profitability between sectors changes: who are the winners and losers? (iii) What are the effects on aggregate variables and household welfare? (iv) Are the social benefits of installing this infrastructure greater than its costs? To answer this questions, I develop a stylized dynamic model of the power market in Argentina. This model accounts for optimal dispatch of electricity to satisfy hourly demand. There are two ways to smooth the prices curve: Either by managing a given charging infrastructure or by managing water reservoirs for hydroelectric production. I use hourly data on local supply and demand for Argentina 2021 provided by CAMMESA to estimate our model. The main objective of this model is to estimate how different level of storage infrastructure changes the average cost of electricity. Also, I develop a recursive General Equilibrium model that I use to evaluate the previous cost reductions in terms of aggregate and sectorial activity, fiscal variables, welfare, income distribution and emissions. To estimate this model we used an owned-developed Social Accounting Matrix (SAM) for Argentina 2021 with focus on energy activities.

I use the dispatch model to simulate four alternative storage scenarios: storage representing 5% and 7% of total generation capacity under current system conditions (year 2021), and the same storage shares in a projected 2030 system based on the National Secretariat of Energy's report, which incorporates a 22% increase in electricity demand and substantial expansions in renewable, hydro, nuclear, and combined-cycle capacity, consistent with Law 27,191. The analysis shows that expanding storage capacity reduces the average cost of electricity. Across all scenarios, electricity costs fall between 1.9% and 3.36% relative to the baseline. The smallest reduction corresponds to the 5% storage scenario under the 2021 system configuration, while the largest reduction occurs in the 7% storage scenario within the projected 2030 generation structure. These cost reductions become stronger in a system with higher renewable penetration: by 2030, the same storage shares yield the largest cost reductions, confirming that storage becomes more valuable as variability in supply grows.

Reductions in the cost of electricity translate into improved macroeconomic performance. GDP increases in every scenario, with gains ranging from 0.47 to 1.11 percentage points over the ten-year horizon. Unemployment rate declines consistently as well, with reductions between 0.07 and 0.19 percentage points. The trade balance strengthens proportionally to overall economic activity, reflecting greater competitiveness from lower

energy costs. Fiscal revenues also grow, rising between 0.43 and 1.13 percentage points, driven by higher production and household income. Altogether, these results point to a clear macroeconomic dividend from reducing electricity costs through energy storage. Welfare and distributional indicators reinforce the positive outlook. Every income group benefits, and gains are systematically larger for low-income households. Environmental outcomes improve as well. Total emissions decline between 1.9 percentage points and 3.02 percentage points, while the emissions intensity of the economy also falls, indicating a cleaner and more efficient production structure. The sectoral results show a clear pattern aligned with electricity intensity and input–output linkages. Besides the electricity sector, Construction, Non-Metallic Minerals, and Extraction are the main winners. These sectors are highly electricity-intensive and closely linked through input-output relationships. Gains in one sector create positive spillovers in others. By contrast, the Fuels sector and Primary activities are the main lossers. Lastly, comparing the annualized macroeconomic gains with the annualized capital expenditure required to deploy energy storage shows that the social benefits exceed the investment costs in every scenario. This means that, even when private profitability remains uncertain due to financing conditions or technology costs, the net social return is positive. These results underscore a role for public policy in fostering the adoption of storage technologies, ensuring that their broad economic and environmental benefits can be captured.

Institutional Context of the Thesis

This doctoral thesis is conducted within the framework of a cotutelle agreement between the University of Buenos Aires (UBA) and the École des Hautes Études en Sciences Sociales (EHESS). The agreement was signed by both institutions on April 7, 2022. At the UBA, the research is based in the Department of Economics (FCE, by its acronym in Spanish), while at EHESS, the affiliated institution is the Paris School of Economics (PSE). This thesis is carried out under the regulations of the UBA Doctoral Program and the Doctoral School No. 465 Économie Panthéon-Sorbonne (UMR 8545).

List of Activities, Presentations and Achievements

Activities Completed

By the thesis submission date, the doctoral student completed the following activities:

1. **Mandatory activities at EHESS/PSE:** The doctoral student completed all mandatory doctoral activities at EHESS/PSE, including:
    - Completion of the following doctoral courses: Environmental Economics (Professors Katrin Millock and Hélène Ollivier), Industrial Risk (Professors Jean-Philippe Tropeano and Stéphane Gauthier), Taxation (Professor Stéphane Gauthier), Recursive Methods in Economic Theory (Professor Nikhil Vellodi), and Inequality (Professor Facundo Alvaredo).
    - Participation in two seminar series per year for two years: the Seminar on Regulation, Environment and Markets (REM seminar) and the Seminar on Applied Economics (Applied Economics Lunch Seminar).
    - Fulfillment of the EHESS research-stay requirement abroad; under the cotutelle agreement, the doctoral student's research years at the University of Buenos Aires satisfy this requirement.

- Annual presentations to the Thesis Committee, composed of Professor Facundo Alvaredo, Professor María Priscila Ramos, and Professor Katheline Schubert. These meetings also included the presentation of all the corresponding reports.
- Annual meetings with the CSI (*comité de suivi individuel*), composed of Professor Facundo Alvaredo, Professor María Priscila Ramos, Professor Gabriel Palazzo, and Professor Katheline Schubert. These meetings also included the presentation of all the corresponding reports.

2. **Mandatory activities at the UBA:** The doctoral student met all UBA requirements by completing the following courses: Topics in Macroeconomics (Professor Saúl Keifman, Professor Danilo Trupkin, and Professor Daniel Heymann), Impact Evaluation (Professor Juan Pablo González), and by validating the Inequality course taken at PSE/EHESS (Professor Facundo Alvaredo) for the Problems section. By doing so, the doctoral student satisfied the Problems, Theory, and Quantitative course requirements. The doctoral student also completed the doctoral seminar and validated his Thesis Plan.

Presentations and Achievements

1. **Chapter 1:** The doctoral student has discussed this work privately with Professor Omar Chisari (UBA/UADE), Professor Carlos Romero (UBA), Professor Gustavo Ferro (UCEMA), and Professor Stéphane Gauthier (PSE) and present it to his first Thesis Committee. The doctoral student presented this chapter at the UBA-IIEP seminar (UBA, December 2022), the Applied Economics Seminar (EHESS-PSE, October 2022), the workshop on Sustainable Energies in the Post-COVID-19 Scenario: Environmental and Socioeconomic Impact (MESi/UBA, March 2023), and the Fifth Workshop on Environmental Economics and Climate Change (UCA, August 2023). The doctoral student also presented it at the 2024 IIOA Conference (ECLAC, Santiago de Chile, July 2024). The conference committee awarded the paper with the Leontief Memorial Prize 2024 as the best young-author paper. In 2024, Elsevier published a version of this chapter in *Energy Economics*. Reference: Mercatante, J. I. (2024). What are the costs of rigidity? A general equilibrium study of the fuel market in Argentina. *Energy Economics*, 138, 107874.

2. **Chapter 2:** The doctoral student presented the second chapter to the Thesis Committee at EHESS/ PSE (Professor Facundo Alvaredo, Professor María Priscila Ramos, Professor Katheline Schubert) at EHESS/PSE in January 2024. The doctoral student then presented it privately to Professor Omar Chisari (UBA/UADE), Professor Stéphane Gauthier (PSE), Professor Nicolas Astier (PSE), Professor Sebastián Galiani (Maryland University), Professor Gustavo Ferro (UCEMA), Professor Gabriel Palazzo (University of Sussex), and Professor Mariana Conte Grand (UCEMA). The doctoral student also presented it at the UBA Annual Thesis Seminar (April 2024) and at the LACEA-LAMES Conference 2024 (Montevideo, November 2024), both in the main sessions and in the PhD Student Workshop, where Professor Sebastián Galiani served as advisor.

3. **Chapter 3:** The doctoral student presented the third chapter to the Thesis Committee (Professor Facundo Alvaredo, Professor María Priscila Ramos, Professor Katheline Schubert) at EHESS/PSE in March 2025 and at the UBA/IIEP seminar (UBA, March 2025). He also discussed it privately with Professor Omar Chisari (UBA) and Professor Carlos Romero (UBA). The doctoral student presented the paper at the LACEA Conference 2025 (Recife, November 2025).

Chapter 1: What are the costs of rigidity? A General Equilibrium study of the fuel market in Argentina

A version of this chapter has been published in *Energy Economics*

Abstract

The policy that is most widely applied to the biofuel market in the world is the mandatory blend. This policy aims to induce the use of biofuels by setting a minimum level of biofuel per unit of blended fuel. This paper studies the costs and benefits of such a policy. To do so, a Recursive Computable General Equilibrium model (CGE), calibrated with a new own-developed energy-oriented Social Accounting Matrix of Argentina for 2018, has been developed. Such a model is extended by explicitly embedding a constrained fuel blending model into the CGE setup. This research addresses the following questions: What are the costs and benefits of a mandatory blend compared to a full flexibility scenario? Is it better to induce the use of biofuels through a tax on fossil fuels or a blending constraint? What is the impact of international price shocks when considering different blending regimes? This paper finds that the mandatory policy has a negative impact on the economic activity, poverty, income distribution, and energy affordability, but a positive one on emissions. When analysing the convenience of a special tax on fossil fuels instead of a mandatory regime, this paper finds that the cost and benefits of each policy are distributed differently over time. The special tax on fossil fuels performs better in the short run while the mandatory blend does so in the long run. Finally, this paper finds that flexibility in the fuel market improves the country's performance when there are shocks on international prices.

Keywords: Biofuels, Mandatory Blend, Welfare, General Equilibrium
JEL Codes: C68, D50, D61, L91, O13.

1.1 Introduction

The energy transition is part of a global transition towards a more inclusive and sustainable world. Not only does this transition have a direct impact on the environmental features of the economy, but it also interacts with conditions of energy security and welfare. Fuels, as well as the policies affecting them, play a vital role in this context. Biofuels have been supported as they are an additional source of combustion, they are less pollutant per unit burned and they contribute to rural development (La Rovere et al., 2011). However, their production is often associated with changes in the use of land and water, deforestation, and increases in the volatility of food prices (Sant'Anna, 2024; Guo and Tanaka, 2022). Also, according to the US Department of Energy[5], these fuels often generate less energy than traditional fossil fuels when burned. The main application of biofuels is to blend them with fossil fuels to decrease the latter's carbon intensity. In this sense, the mandatory blend is one of the most widely applied policies to regulate how those fuels are mixed and to incentivize the use of biofuels [6]. To do so, this policy sets a minimum level of biofuels that must be present in the mix (Torroba and Orozco Montoya, 2023).

This paper focuses on first-generation biodiesel and bioethanol, and studies the costs and benefits induced by the mandatory blend [7]. The country under study is Argentina, a biofuel-producing country with proven comparative advantages in the production of the primary inputs for biofuels (Timilsina et al., 2013). Therefore, the conclusions from this work may be illustrative for other producing countries, such as Brazil, Germany, Indonesia, and the USA, among others. Also, Torroba and Orozco (2023) report that biofuel mandates are present, with varying rates and setups depending on the country, in the European Union, the majority of Latin and North America, China, India, Japan, among others. Thus, the modelling of this policy and the conclusions from this analysis relate to other countries applying this regulation. Even though there are many types of fuels in the fuel market, this paper defines the relevant market as that which contains: (i) Gasoil, (ii) Gasoline, (iii) Biodiesel, and (iv) Bioethanol. Therefore, references to *fuel market* throughout this text will include those fuels.

This research addresses the following questions: What are the costs and benefits of the mandatory blend in terms of activity level, household welfare, income distribution, and the environmental performance of the economy? How does this policy impact energy affordability? Which policy is better to induce the use of biofuels: a blending constraint or a tax on fossil fuels? And, finally, what is the impact of international price shocks when considering different blending regimes?

To explore these questions, I develop a Computable General Equilibrium (CGE) model calibrated using a new own-developed 2018 Social Accounting Matrix of Argentina, with a focus on energy sectors. I rely on this methodology because the fuel market interacts with multiple value chains (Kretschmer and Peterson, 2010). As a result, the evaluation of fuel-market policies must account for their effects on other activities and economic agents, capturing both direct and indirect impacts. Computable General equilibrium

[5] https://afdc.energy.gov/fuels/properties

[6] Link: Alternative Fuels Data Center

[7] In terms of the blending regimes, bioethanol is blended with gasoline and biodiesel is blended with gasoil.

offers a consistent methodological framework to provide a good assessment of fuel and biofuel related policies (Kretschmer and Peterson, 2010). This model has 5 representative households differentiated by income quintiles, 47 productive sectors, one government, and the rest of the world. The modelling of the fuel and biofuel supply, together with an explicit representation of the blending constraint, are the most relevant methodological aspects of this paper. The model was recursively estimated from 2019 to 2030.

There are three blocks of counterfactual exercises. The first one evaluates the cost and benefits of the mandatory blend with respect to a full flexibility scenario. The second one evaluates the best alternative to induce biofuel use by comparing previous mandatory blends with a scenario involving a fossil fuel tax to achieve equivalent blending levels. Finally, the third one measures the performance of the mandatory blend when the international price of oil and the international prices of agricultural commodities increase.

This paper contributes to different strands of the literature. First, it contributes to the literature using CGE models to study biofuel policies (Doumax et al., 2014; Wianwiwat and Asafu-Adjaye, 2013; Timilsina et al., 2013) by explicitly embedding a constrained fuel blending model into a CGE setup. Second, it contributes to the literature that relates energy policy to energy affordability and consumption conditions (Guo and Tanaka, 2022; To and Grafton, 2015) by estimating the impact of different blending regimes on those indicators. Third, it contributes to the literature on environmental fiscal and regulatory policy (De Gorter and Just, 2009; Marron and Toder, 2014) by assessing the impact of different mandatory blend regimes on economic and social indicators and by comparing the performance of the mandatory blend with respect to a fossil fuel tax. Finally, it contributes to the literature on international price shocks (Cheng et al., 2023; Thorbecke, 2019; Gelos and Ustyugova, 2017) by evaluating the impact of an increase in the international price of oil and agricultural commodities under different blending regimes.

This paper finds that, if there is a shift from a mandatory blend regime to a flexible one, although upon calibration relative prices are in favour of fossil fuels, biofuels remain in the economy, and over time their share in the blend increases. It also finds that the mandatory blend presents a trade-off between efficiency and environmental outcome. Particularly, there are costs in terms of activity, welfare, income distribution, and energy affordability compared to the full flexibility scenario. However, in terms of environmental outcomes, the mandatory blend is an effective policy. As for the more convenient policy to induce a certain blend, this paper finds that the costs and benefits of a fossil fuel tax versus a mandatory blend are distributed differently over time. For the fossil fuel tax, benefits are derived in the short run while for the mandatory blend, in the long run. Finally, this paper finds that flexibility in the fuel market improves the country's performance when there are shocks on international prices.

This paper is organized as follows. Section 2 presents a literature review and the policy background. Section 3 presents the model and data. Section 4 presents the simulations and their results. Section 5 concludes. The appendices provide additional information that complements the content of the article.

1.2 Policy Background and Literature Review

Biofuels are liquid or gaseous fuels produced from biomass (Bochtis et al., 2020) and can be differentiated into liquid and non-liquid. According to IRENA (2022), there are three generations of liquid biofuels: (i) first generation: derived from primary products such as soybeans or corn; (ii) second generation: derived from cellulose, hemicellulose, and lignin; and, finally, (iii) third generation: derived from aquatic organisms such as algae [8]. This paper will focus on those that take the largest share of the market: first-generation biodiesel and bioethanol.

Biofuels have been promoted for their contribution both to the energy transition as they are non-fossil fuels whose combustion emits fewer greenhouse gases (GHG), and to rural development (La Rovere et al., 2011). However, their production may have negative consequences. First, their development changes the use of land and water and increases deforestation (Sant'Anna, 2024; Witcover et al., 2013; Laborde and Valin, 2012). Secondly, biofuels generate new demands for primary inputs that could be used, alternatively, in food production (Guo and Tanaka, 2022; To and Grafton, 2015). Finally, there are significant differences in efficiency between fossil fuels and biofuels in terms of energy per unit burned[9]. Thus, biofuel policies are not neutral in terms of energy efficiency, poverty, activity levels, and environmental outcomes.

Two types of policies usually involve these markets: incentive policies and regulatory policies (Saravanan et al., 2020). On the incentive side, depending on the country, it is possible to find tax exemptions or subsidies, taxes on fossil fuels, and investment and development funds (De Gorter and Just, 2010; Castiblanco et al., 2015; Grigolon et al., 2018). In terms of regulatory policies, the most common regulation is the mandatory blend of fossil fuels and biofuels. This regulation usually sets a minimum share of biofuels that must be respected in a unit of final blended fuel (De Gorter and Just, 2009; Serra and Zilberman, 2013). This policy is one of the most widely applied and aims at increasing the demand for biofuels by making them mandatory.

In Argentina, the blending policy was first applied through Law No. 26,093 (2006) and Decree No. 109/07. For bioethanol, the law established an initial blend of 5%, and subsequently raised it to 10% (Resolution No. 44/14) in 2014, and to 12% in 2016 (Resolution No. 37/2016). Finally, with the new regulatory framework for biofuels (Law No. 27,640), the blend remains at 12% until today. For biodiesel, the legislation of 2006 and 2007 established an initial blend of 5% of biodiesel in the mix to be achieved in 2010. From then onwards, the 5% blend rose to 7% in the same year (Resolution No. 554/10). In 2013, it increased to 8% (Resolution No. 450/13) and, in the same year, to 10% (Resolution No. 1125/13). Finally, under the new legislation of 2021, the blend of biodiesel with gasoil went back to 5% and, from June 2022, it is 7.5%. Additionally, Argentina has a set of policies aimed at subsidizing biofuels and taxing fossil fuels.

To place Argentina's biofuel policy in an international context, it is useful to compare it with those of other countries. According to Torroba and Orozco Montoya (2023), Indonesia (35%), Brazil (12%), and Colombia and Malaysia (10%) are the countries with

[8] Although not considered in this classification, another way to generate biofuels is decomposing organic waste.

[9] According to the US Department of Energy, the difference in efficiency amounts to 30% for bioethanol and 7% for biodiesel. This means that, for example, burning one unit of biodiesel produces 7% less energy than burning one unit of diesel. Alternative Fuels Data Center. https://afdc.energy.gov/fuels/properties.

the highest mandates on biodiesel. In comparison, Argentina (7.5%) has similar levels to countries like Greece (7%) and Germany (8%). For bioethanol, Brazil (27%), Paraguay (25%), and Argentina (12%) have the highest mandates, followed by a group of countries that round a level of 10%. It is noteworthy that some countries have introduced overall mandates[10] on biofuel use. For example, Norway, Finland, and the Netherlands have established overall mandates of 24.5%, 18.9%, and 13.5%, respectively.

Blending policies are not the only ones affecting the fuel market. In this regard, Argentina has a long tradition of fuel price regulation through the local price of the barrel of oil. According to Romano (2017), export taxes are the most widely used tool to regulate the domestic price of oil. There is a similar approach to biofuels, where exports of raw primary inputs, such as soy or corn, are taxed. The price of fuels is also affected by taxes that seek to internalize the environmental damage caused by fuels or to fund investment in infrastructure. According to OECD (2019), the 2017 Argentine Tax Reform simplified the taxation of energy use by replacing an ad valorem tax system with a specific tax based on physical units. The reform also introduced a carbon tax of USD 10 per tCO2eq on fossil fuels, in force since March 2018. Although the fuel tax is established by law, the government retains discretion to update its level, which makes its effective application highly dependent on the political cycle (Argentine Secretariat of the Treasury, 2025). For biofuels, there are tax exemptions and subsidies affecting their price. Appendix A describes those policies, as well as the institutional background of Argentina.

The policies linked to the fuel market do not only have an impact on the biofuel market itself, but also on related markets and households. Therefore, those policies cannot be studied separately from the rest of the economy, since multiple domestic and/or international indirect effects would be omitted. According to Kretschmer and Peterson (2010), CGE models are a suitable tool to study energy (and bioenergy) related problems. Those models have been widely used to represent shocks associated with energy, fuel, and biofuel prices (Timilsina and Mevel, 2013; Timilsina et al., 2013). Arndt et al. (2012) develop a CGE model for Tanzania to assess different biofuel production options and to estimate their impact in terms of growth and poverty. Wianwiwat and Asafu-Adjaye (2013) develop a CGE model for Thailand with a focus on the energy sector and analyse the government's sustainable development plan with a focus on biofuels. Doumax et al. (2014) develop a CGE model for France to study the impact of incentive schemes for biodiesel based on the high prices of fossil fuels.

The CGE models applied to study the impact of biofuels generally assume that fuels and biofuels are mixed according to a CES function (Phomsoda et al., 2021; Timilsina et al., 2013; Wianwiwat and Asafu-Adjaye, 2013; Timilsina and Mevel, 2013). Therefore, the blend of both types of fuels will be significantly affected by the elasticity of substitution. This paper departs from these works, assuming that both types of fuels are substitutes, and studies cases with and without a blending constraint. The CGE model developed for this paper differs in the sense that it provides an explicit representation of the blending constraint for regulated scenarios.

[10]The concept of overall mandates refers to set general goals of bioenergy use in the total use of fuels instead of fuel specific mandates

1.3 Methodology and Data

1.3.1 The Computable General Equilibrium Model for Argentina

CGE models are an algebraic representation of the economy designed to assess the impact of changes in its structural parameters (Burfisher, 2021). Each agent in this model is represented by its budget constraints and its behaviour equations derived from an optimization process. The global consistency of the model is given by the market clearing equations. The CGE model in this paper was calibrated with an own-developed 2018 Social Accounting Matrix for Argentina. Finally, the model runs from the calibration year to 2030.

1.3.2 The Blending Problem

Assume that there are blenders that, given fuel prices, want to minimize the cost of producing one unit of the mix. In this case, there are two possible scenarios for these blenders: (i) they are free to choose any combination of fuel and biofuel that they want, or (ii) there is a regulation that sets the blending policy. The situation with no regulatory constraint will be presented first. The blend will be formed by mixing Fossil Fuels (F) and Biofuels (B). Both fuels are modelled as perfect substitutes, but there are differences in efficiency. Therefore, considering prices and efficiency, the blenders will choose the mix that minimizes the cost (c) of producing y units of the product. The cost minimization problem for those blenders is:

$$\min_{\{F,B\}} C = P_B B + P_F F \quad \text{s.t.} \quad y = \alpha F + \gamma B$$

Note that, since both inputs are perfect substitutes, the production function is linear. The rate of substitution between fuels is dominated by α and γ. Those parameters account for the difference in efficiency where the greater the efficiency gap is, the greater the difference between α and γ will be. This means that an extra unit of B contributes less to the final mix than one unit of F. Therefore, depending on α, γ and the prices, the blenders will choose the optimal mix. The solution for these types of problems is such that the blenders use only fossil fuels ($F = {}^{y}/_{\alpha}$ and $C = P_F F$) if ${}^{\alpha}/_{\gamma} > {}^{P_F}/_{P_B}$ and only biofuels ($B = {}^{y}/_{\gamma}$ and $C = P_B B$) if ${}^{\alpha}/_{\gamma} < {}^{P_F}/_{P_B}$. Finally, the blenders are indifferent ($y(F,B) : F \in [0; {}^{y}/_{\alpha}]$ and $B \in [0; {}^{(y-\alpha F)}/_{\gamma}]$ and $C = P_F F + P_B B$) if ${}^{\alpha}/_{\gamma} = {}^{P_F}/_{P_B}$.

Considering the blending regulation, the optimization problem is the same, but, in this case, there is an additional constraint that fixes the minimum blend (θ). Under this setup, the problem of the blenders is:

$$\min_{\{F,B\}} C = P_B B + P_F F \quad \text{s.t.} \quad \text{(a)} \quad y = \alpha F + \gamma B \quad \text{(b)} \quad \frac{B}{B+F} \geq \theta$$

Now, the blenders cannot freely choose the mix that they want. There are two possible cases: (i) the relationship between marginal productivities and prices is such that ${}^{\alpha}/_{\gamma} > {}^{P_F}/_{P_B}$ and the blenders prefer fossil fuels, and (ii) ${}^{\alpha}/_{\gamma} \leq {}^{P_F}/_{P_B}$ where the blenders prefer biofuels, or they are indifferent. Note that, in the former case, the blending constraint will be binding while, in the latter, it will not. Therefore, the solution will be such that, if $({}^{\alpha}/_{\gamma} > {}^{P_F}/_{P_B})$, then the blending constraint will hold as equality, and $F = {}^{y}/_{[\alpha + \gamma \frac{\theta}{1-\theta}]}$ and $B = {}^{(y-\alpha F)}/_{\gamma}$. However, if ${}^{\alpha}/_{\gamma} \leq {}^{P_F}/_{P_B}$, the constraint will not be operative, and the results will be the same as in the non-regulated scenario.

Proposition 1. *Define the level of inefficiency (IN) of the blend as the ratio between the average cost of the mix with a mandatory blend (AC_{wb}) and the average cost when no blending policy is imposed (AC_{nb}). Thus, $IN = {}^{AC_{wb}}/_{AC_{nb}}$. Under this definition, the level of inefficiency is equal to:*

$$IN = \begin{cases} \frac{1+\frac{P_B}{P_F}\frac{\theta}{1-\theta}}{1+\frac{\gamma}{\alpha}\frac{\theta}{1-\theta}} & if \quad {}^{\alpha}/_{\gamma} > {}^{P_F}/_{P_B} \\ \\ 1 & if \quad {}^{\alpha}/_{\gamma} \leq {}^{P_F}/_{P_B} \end{cases}$$

Proof in Appendix B.

In this framework, inefficiencies are explained by the relation between relative prices and relative marginal productivities. For example, in the case where ${}^{\alpha}/_{\gamma} > {}^{P_F}/_{P_B}$, inefficiencies increase with ${}^{P_B}/_{P_F}$. In other words, given that fossil fuels are preferred, the greater the difference between the cost of biofuels and fossil fuels, the greater the inefficiency generated by the mandatory blend. However, such inefficiency may be eroded if relative productivity changes in favour of biofuels. In other words ${}^{\gamma}/_{\alpha}$ increases. In the case where biofuels are preferred, or the blenders are indifferent between fuels, there is no inefficiency. In this line, understanding the inefficiencies caused by choosing a blending policy is important for the whole economy since, from a general equilibrium point of view, those inefficiencies are negative externalities over other markets and institutions.

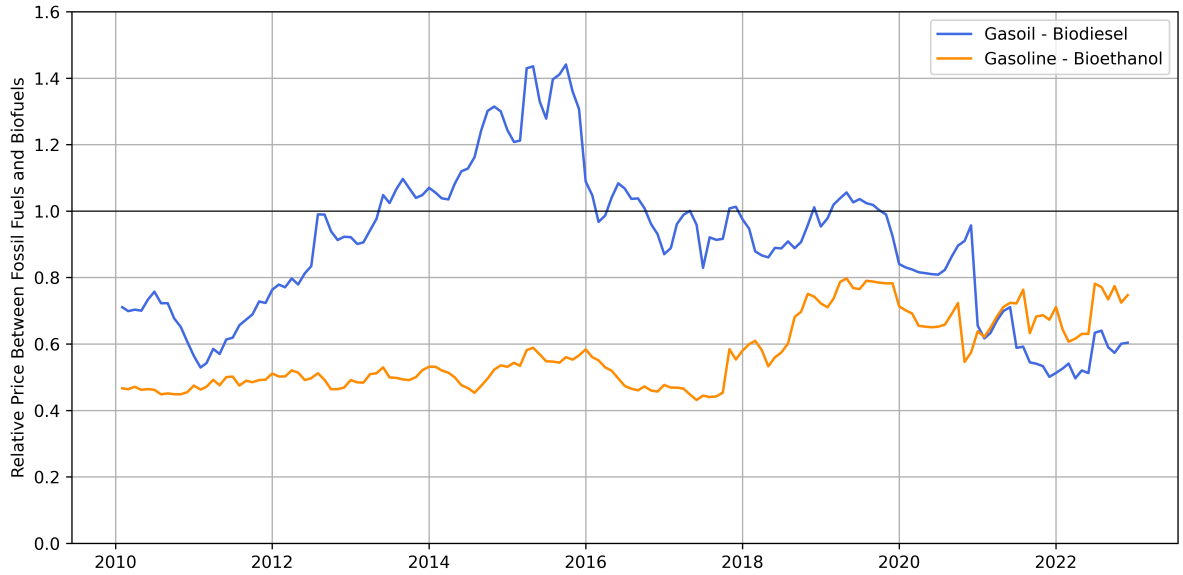
Proposition 2. *Define SK as the level of specific capital installed in the biofuel industry. In a flexible scenario (no blending constraint), given SK, there will always be a minimum level of biofuel production and ${}^{\alpha}/_{\gamma} = {}^{P_F}/_{P_B}$.*

Proof in Appendix B.

Preposition 2 states that, although there is substitutability between both types of fuels, in general equilibrium and considering the specific capital already installed in both industries that cannot be reallocated to other activities, there are no corner solutions. In this line, the nonpreferred fuel industry will still produce a minimum quantity and will sell it at the minimum price possible. That means that the owner of a firm will reduce the return of the activity to keep on producing with the already installed capital. Therefore, the price of that fuel will go down until relative prices equalize the relative marginal productivities and the blenders are indifferent.

Note that the blending problem turns around the relative prices between both types of fuels and their relative productivities. However, relative marginal productivity is usually fixed since it is a technical characteristic. Figure 1.1 presents the evolution of relative prices between gasoil and biodiesel, and gasoline and bioethanol.

Figure 1.1 – Argentina. Relative prices: ratio between the prices of fossil fuels and biofuels corrected for taxes and efficiency.



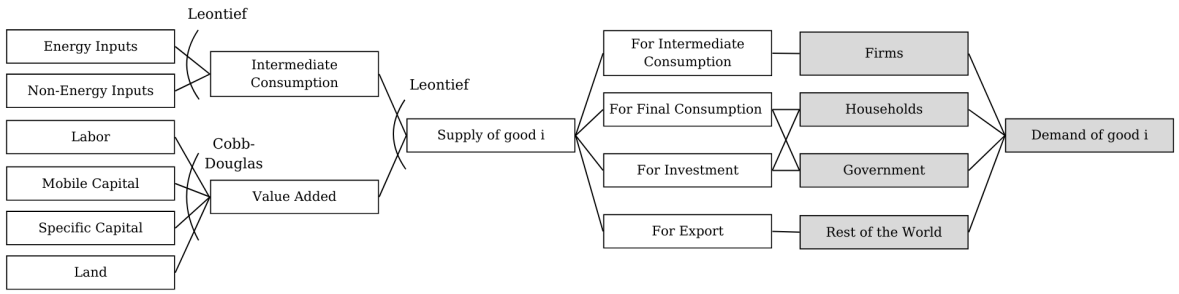
Source: Prepared by the author using data from the Argentine Secretariat of Energy. Note: Relative prices are calculated as the quotient between fossil fuel price (numerator) and biofuel price (denominator). Both prices consider taxes and differences in energy efficiency. Based on the US Department of Energy, this paper considers a 30% difference in energy efficiency for bioethanol and a 7% for biodiesel.

As can be seen, relative prices have changed over the years and, in some periods, biofuels became more convenient than fossil fuels. However, the blending mandates do not change with those prices.

1.3.3 General Structure of the Model

Figure 1.2 describes the general structure of the CGE model. In this model, goods are produced using value added and intermediate consumption, with the former modelled using a Cobb-Douglas function between productive factors and the latter modelled as perfect complements between the energy and non-energy consumption. The final supply of goods and services has four main destinations: intermediate consumption, final consumption (private and public), investment (private and public), and export.

Figure 1.2 – Supply and demand structure of the general equilibrium model.



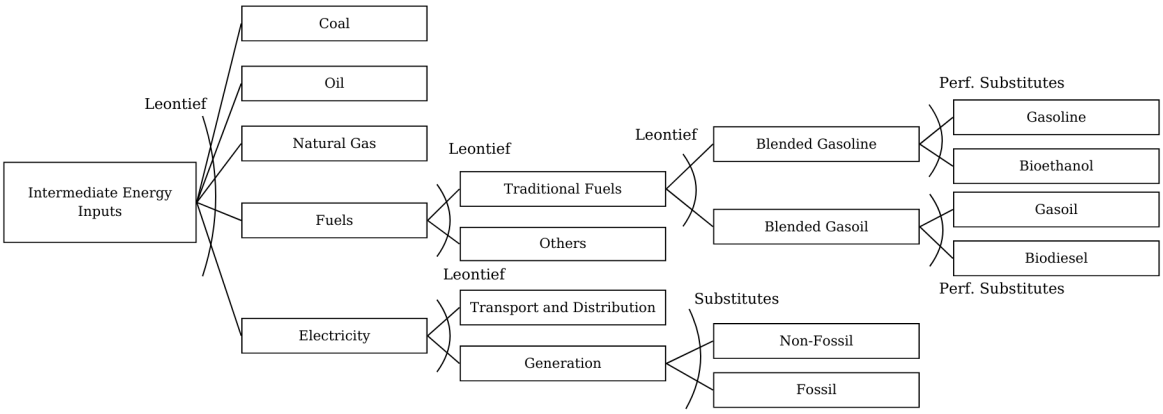
Note: Figure 1.2 illustrates the structure of demand and supply in the CGE model.

For all the activities, an elasticity of substitution equal to zero is used at the level of intermediate consumption. In other words, the sectors cannot replace energy inputs with non-energy inputs. Regarding the composition of value added, four productive factors

are modelled: labour, mobile capital, specific capital, and land. Labour is mobile across sectors and there is unemployment arising from the assumption of wages fixed in real terms. Specific capital is only demanded from the sector to which it belongs, and it is fully employed. Mobile capital can be reallocated among sectors. This kind of capital is allocated endogenously according to the relative returns between activities, and it is reallocated until the marginal benefit of the capital is the same across industries. Finally, land is included as a separate factor as it is a relevant input in the value chain of biofuels.

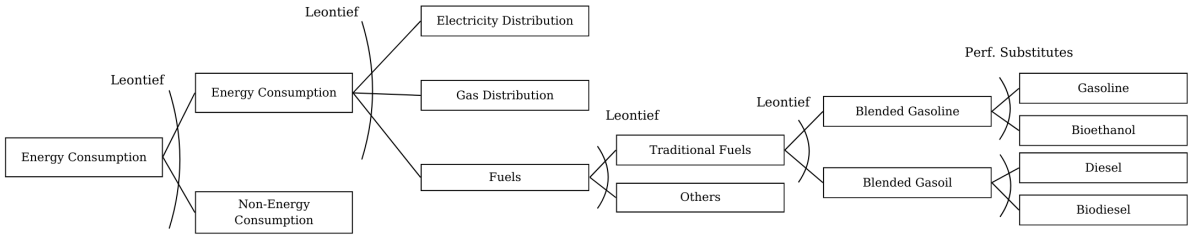
Figure 1.3 shows the composition of intermediate energy consumption and Figure 1.4 shows the composition of residential energy demand.

Figure 1.3 – Structure of energy demand from firms.



Note: Figure 1.3 shows the structure of energy demand from firms in different branches. Note that, even though all the sectors share the same structure, the demand for each energy service will depend on firm-specific parameters calibrated with the SAM. Note: T&D: Transport and Distribution.

Figure 1.4 – Structure of the residential energy demand.



Note: Figure 1.4 shows the structure of residential energy demand across different branches. Note that households in the model are differentiated by income level; therefore, each household has a specific energy demand that follows this structure, with household-specific parameters.

For the energy supply to firms, in all the initial nodes an elasticity of substitution equal to zero is used. In other words, the sectors cannot replace one type of energy with other energy sources at the same level. This is not the case of different electricity generation technologies. In this case, a perfect substitute production function is considered since all sources generate the same product.

In the model, the activities of producing and selling fuels are separated into two: the sectors that produce fuels and biofuels, and the sectors responsible for blending and selling

them. The former will sell the production to the latter, who blends the fuels and sells the final product. With this setup both the production and blending decisions are included in the model. In this context, the blending constraint is applied to the sectors responsible for blending. This model introduces two different blending problems. First, the blend between gasoil and biodiesel and, second, between gasoline and bioethanol. For both cases, the blending constraint will be simulated (except for the full flexibility scenario). Note that there is a 7% difference in fuel efficiency between gasoil and biodiesel and 30% between gasoline and bioethanol[11]. This means that burning one unit of gasoil (gasoline) generates 7% (30%) more energy than burning one unit of biodiesel (bioethanol). Biofuel prices are corrected to account for the efficiency gap between fossil fuels and biofuels.

Figure 1.4 reports the relationship between residential energy consumption and the demand for other goods. This relation is modeled using a Leontief function. Within energy consumption, the main household expenses are electricity transmission and distribution, gas distribution, and fuels, which are grouped using a perfect complements function.

For primary products and extractive activities, which are the beginning of the value chain of fossil fuels and biofuels, prices are determined internationally. The domestic price would be equal to the international price corrected for the corresponding international trade taxes applied to each product. All types of fuels are produced domestically. However, this model allows for the possibility to substitute domestic goods with imported goods. Therefore, consumers will increase the share of domestic fuel when the domestic price of the good is lower than the international price and will increase imports in the opposite case. This paper considers Armington elasticities between international and domestic products of 0.9 (Tourinho et al., 2010). Appendix H presents a sensitivity analysis of the Armington elasticity.

Note that this model is recursive-dynamic, which means that, by iterating the static model, endowments are updated period by period generating a dynamic simulation. Agents decide how much to save in period t using information from that period only while, in the next period $(t+1)$, those savings are transformed into new capital, which is mobile across sectors. Thus, it is allocated while returns and prices are defined in the model. In this line, the final allocation of the new capital is endogenously determined by sectoral relative productivities, and it is reallocated until the marginal benefit of new capital is the same in all industries. Therefore, the final industrial scale in the next period depends on market incentives determined by the model. Note that, on the one hand, new capital enters the model, and, on the other, depreciation diminishes the stock of capital. Finally, labour endowment evolves according to the population growth rate (1.09%).

1.3.4 Database: MCS Argentina 2018

This paper develops a SAM of Argentina for the year 2018. This matrix has 47 productive sectors, 5 households differentiated by income quintile, a consolidated government, and the rest of the world. The structure of the matrix is a fundamental aspect of this research since it will set the limits of the model. This section is not intended to describe the matrix in detail, but to explore some aspects relevant to this work. Appendix D displays a sectoral opening with 47 sectors and Appendix E presents the main sources of information consulted. Finally, Appendix F reports the main results for the SAM.

[11] https://afdc.energy.gov/fuels/properties

Table 1.1 characterizes the sectors included in this model. Although the original sectoral opening covers 47 sectors, Table 1.1 shows data for the relevant indicators with a reduced sectoral opening emphasizing the sectors relevant to this analysis.

Table 1.1 – Argentina 2018. Sectoral indicators from the 2018 Argentine SAM. Percentage.

Sector	Value Added	Gross Value of Prod.	Incidence Fuels	Incidence Rest of energy	Low-Income Households	High-Income Households	Share of National Supply	Share of Mobile Capital in VA
Soy	1.23	1.47	3.54	0.26	0.35	0.28	85.27	29.64
Maize	0.91	1.19	3.33	0.14	0.74	0.58	100.00	28.16
Sugar cane	0.03	0.04	3.84	0.52	0.00	0.00	100.00	22.49
Rest of Primary	3.18	3.37	2.13	0.87	2.07	1.46	97.14	19.87
Oil	2.67	2.35	0.70	5.09	0.33	0.27	99.35	4.08
Rest of extractive	1.86	1.51	1.18	5.67	0.05	0.02	79.84	7.27
Soy oil	0.30	0.60	0.10	0.73	0.04	0.00	99.98	15.10
Rest of food and beverage	5.32	10.51	0.09	1.04	27.33	13.58	98.28	10.90
Light industry	2.73	3.34	0.27	3.35	3.95	2.97	86.69	11.85
Diesel	0.15	0.78	4.60	53.89	–	–	79.70	9.38
Gasoline	0.13	0.69	4.19	49.29	–	–	91.72	9.38
Biodiesel	0.10	0.21	0.00	0.75	–	–	100.00	13.25
Bioethanol	0.05	0.09	0.00	1.04	–	–	100.00	10.59
Rest of fuels	0.31	0.92	0.00	55.55	2.28	0.62	88.84	11.49
Chemicals	1.81	2.89	1.40	2.27	3.64	2.97	70.86	11.52
Heavy industry	5.71	8.81	0.42	9.24	4.15	4.81	69.00	16.17
Blender Diesel–Biodiesel	1.11	1.60	60.22	0.00	1.46	1.86	100.00	18.01
Blender Gasoil–Bioethanol	0.88	1.26	60.09	0.00	2.48	2.81	100.00	18.01
Transport	4.65	7.03	5.74	1.75	13.71	11.24	90.71	4.43
Services	66.88	51.34	0.96	3.47	37.40	56.52	97.28	7.80
Total	**100.00**	**100.00**	**3.25**	**4.93**	**100.00**	**100.00**	**91.64**	**9.45**

Note: Table 1.1 reports the sectoral share in Value Added and Gross Value of Production, the incidence of fuels and the rest of energy inputs in the average cost, the household consumption basket, the share of national supply in total supply, and the share of mobile capital in value added. Appendix E reports the sources consulted to construct the SAM. The values from Table 1.1 are derived from the SAM.

In terms of value added, without considering blending and selling activities, the relevant fuels occupy 0.43% of Argentine value added in 2018, where 0.15% and 0.13% correspond to gasoil and gasoline respectively, and 0.10% and 0.05% correspond to biodiesel and bioethanol. In terms of gross value of production, those fuels account for 1.77% of the total, where 0.78% and 0.69% are gasoil and gasoline, and 0.21% and 0.09% are biodiesel and bioethanol. However, the significance of those fuels can be greater if the incidence on the average cost of other products is considered. Although fuels have a significant logical impact on the cost of blending activities, they also have a significant impact on the average cost of transport activities (5.74%), the production of gasoil (4.60%) and gasoline (4.19%), and primary products (ranging between 2.13% for the rest of primary products and 3.84% for sugar cane). Many of these products have a direct or indirect impact on the consumption basket of low-income households, particularly for transportation services, which account for 13.71% and 11.24% of the total consumption of low-income households and high-income households, respectively. Finally, nearly all the supply of fossil fuels and biofuels is national. It is important to highlight that biofuels have a greater share of mobile capital in value added (13.25% for biodiesel and 10.59% for bioethanol) than fossil fuels (9.38%). Considering both national and imported fuels, the SAM estimates an effective blending rate of 9.8% for biodiesel and 12.2% for bioethanol.

Table 1.2 shows the cost structure of the relevant sectors in the value chain of fossil fuels and biofuels.

Table 1.2 – Argentina 2018. Composition of national intermediate consumption of the relevant sectors of the value chain of fossil fuels and biofuels. Percentage.

Sector	Soy	Crop	Sugar cane	Oil	Soy oil	Gasoil and Gasoline	Biodiesel	Bioethanol	Blending
Soy	22.63	2.66	2.43	-	57.27	-	0.06	0.06	-
Crop	0	17.13	0	-	0	-	0	22.63	-
Sugar cane	-	-	1.04	-	-	-	-	16.38	-
Rest of Primary	4.98	8.85	20.95	0	0.57	0	0.27	0.28	-
Oil	-	-	-	0.04	0	59.31	0	0	-
Rest of extractive	0.01	0	0.01	0.86	0.02	14.27	0.12	0.12	-
Soy oil	-	0	0	0	0.48	0.01	40.03	0	-
Rest of food and beverage	0.09	0.02	0.15	0.42	7.34	0.24	1.32	1.37	-
Light industry	0.42	0.1	0.75	4.24	1.37	0.25	1.05	1.1	-
Gasoil	-	-	-	-	-	2.47	-	-	50.14
Gasoline	-	-	-	-	-	2.81	-	-	38.98
Biodiesel	-	-	-	-	-	-	-	-	5.8
Bioethanol	-	-	-	-	-	-	-	-	5.08
Rest of fuels	0	0	0	1.49	0.14	3.42	1.64	1.71	-
Chemicals	24.41	22.06	20.04	0.6	0.66	6.75	32.61	29.82	-
Heavy industry	2.01	0.44	3.71	23.07	2.76	1.54	1.08	2.95	-
Blended Diesel	6.44	5.55	5.78	1.07	0.09	-	-	-	-
Blended Gasoil	-	-	-	0.59	0.07	-	-	-	-
Transport	18.51	22.12	19.99	14.26	1.95	2.96	1.88	2.94	-
Services	20.51	21.06	25.15	53.36	27.3	6	19.94	20.64	-
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Note: Table 1.2 reports the sectoral distribution of the national intermediate consumption of the relevant sectors in the value chain of fossil fuels or biofuels.

Considering the cost structure of primary products, Table 1.2 reports that self consumption, chemicals, transportation, general services (mainly business and financial activities), and gasoil are the most relevant inputs. In the case of oil production, the greatest expenses are concentrated in the heavy industry and services consumption. Note that those services include infrastructure services such as electricity, gas, and water. In the case of soy oil, 57.27% of intermediate costs are related to soy consumption. For both fossil fuels, the cost structure is similar, and the most relevant consumption is oil. In the case of biodiesel, the main inputs are soy oil and chemicals. For bioethanol, crop and sugar cane account for 39.01% of the total intermediate expenses while chemicals account for 29.82%. Finally, blending activities only consume fossil fuels and biofuels, and mix them.

1.4 Counterfactual Exercises, Results, and Discussion

1.4.1 Counterfactual Exercises

There are three blocks of counterfactual exercises. The first block evaluates the cost and benefits of different mandatory blends with respect to a scenario without blending constraints. The following scenarios are simulated: (i) MB05: A 5% mandatory blend. (ii) MB10: A 10% mandatory blend. (iii) MB15: A 15% mandatory blend. (iv) MB20: A 20% mandatory blend. (v) FF: The Full Flexibility scenario. This last scenario represents a situation where regulatory constraints are lifted. This situation is equivalent to a 0% mandatory blend. The range of values to simulate ($0\% - 20\%$) is in line with those applied by the vast majority of countries around the world (Torroba and Orozco Montoya, 2023).

The second block is fiscal-policy oriented and evaluates the convenience of a fossil fuel tax over a mandatory blend to induce the use of biofuels. Particularly, this block of simulation assesses the fossil fuel tax that generates the same mix between fossil fuels and biofuels as in different mandatory blend cases, and the costs and benefits of inducing

this outcome with a tax instead of a constraint. The MB05, MB10, MB15, and MB20 scenarios were simulated in two variants: (i) with a blending constraint, and (ii) with the equivalent tax on fossil fuels.

The third block studies the performance of the mandatory blend under different increases in international prices. Two types of scenarios are considered: (i) IPO: An 18% increase in the growth rate of the international price of oil and (ii) IPC: A 12% increase in the growth rate of the price of agricultural commodities. Both scenarios will be considered under two regimes: First, the mandatory regime in the year of calibration (10% for biodiesel and 12% for bioethanol). Second, the same shock will be replicated, but under a flexible regime. This would make it possible to assess the differential impact across regulatory contexts. The magnitude of those scenarios was calibrated with the IMF time series data. Appendix H provides information on this estimation. A limitation of this approach is that it does not capture the effects of international price volatility; instead, it only simulates the impact of isolated price increases. Because the model is deterministic, it cannot account for this stochastic feature. However, price volatility may play an important role in this setting. In particular, depending on whether the blending mandate binds, international price volatility may transmit to the production costs of blended fuels.

Table 1.3 shows the indicators that will be considered to carry out the simulations. Appendix G details the estimated baselines for the model.

Table 1.3 – Indicators reported for each simulation.

Indicator	Measure	Formula
GDP growth index	Percentage	$\left(\frac{GDP_t}{GDP_{base}} - 1\right) 100$
Household h welfare index	Equivalent Var. (%)	$\left(\frac{EV_t^h}{EV_{base}^h} - 1\right) 100$
Unemployment rate	Percentage	$\frac{UL_t}{TL_t} 100$
Gini index	[0-100]	$\frac{1}{n}\left(n + 1 - 2\frac{\sum_{i=1}^{n}(n+1-i)y_i}{\sum_{i=1}^{n}}\right) 100$
GHG emissions index	Percentage	$\left(\frac{GHG_t}{GHG_{base}} - 1\right) 100$
Consumption index of goods s	Percentage	$\left(\frac{c(s)_t}{c(s)_{base}} - 1\right) 100$
Affordability index of goods s	[0;∞)	$\frac{\sum_s c(s)_{base}\Delta p(s)}{y\Delta y} 100$
Activity index of sector j	Percentage	$\left(\frac{GDP_{j,t}}{GDP_{j,base}} - 1\right) 100$
Export index	Percentage	$\left(\frac{X_t}{Xbase} - 1\right) 100$

Note: GDP: Gross Domestic Product; EV: Equivalent Variation; UL_t: Unemployed labor; TL_t: Total labor; n: Number of households; y_i: Income of household i; GHG: Greenhouse Gas Emissions; $C(s)$: Household consumption of goods s; $\Delta P(s)$: Price variation of goods s; Δy: Income variation; X: Exports.

A GDP indicator will be used to measure the impact on the aggregate activity level. This paper uses the equivalent variation to measure the impact on household welfare. This indicator represents the change in income that would have the same effect (that is, equivalent) on the household's utility as that of the simulated scenario (Guerra and Sancho, 2018). To measure the impact in terms of income distribution, the Gini Index is estimated. To assess the effect in terms of emissions, an emissions index is built using the GHG emissions resulting from the model. Aspects regarding energy access are measured in two dimensions. First, the variation in the consumption of energy goods is measured by building a consumption index. Second, to assess the impact on affordability conditions, an index comparing the evolution of income with respect to the cost of energy is created.

The cost indicator is constructed as a Laspeyres index where amounts are fixed in the base year.

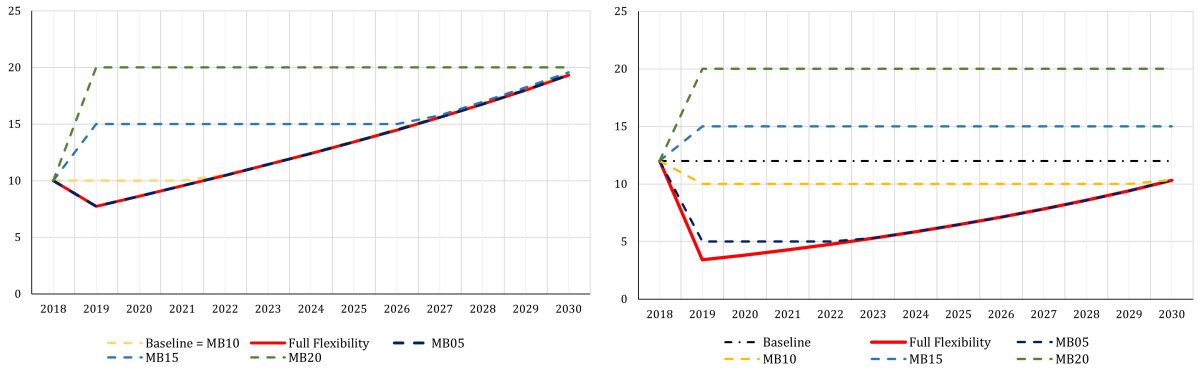
The tables in this section should be read as follows: for each simulation, there are two columns (2019 shows the results of the first year simulated and 2030 shows the last year simulated). The values in the tables are calculated as the difference between the values in the simulations and in the reference scenario. For example, in Block 1 in Table 1.4, the result for the GDP index in 2019 for the MB05 scenario is equal to 0.12 percentage point (p.p.), meaning that GDP increases 2.13% in the simulation and 2.25% in the baseline. Appendix G presents the complete dynamic simulations for each indicator and simulation.

1.4.2 Results and Discussion

Block 1. *The costs of rigidity.*

Figure 1.5 presents the estimated trajectories for the blend under different blending regimes for the period 2018–2030 for each type of fuel. The year 2018 contains the mandatory blend levels upon calibration and the simulation runs from 2019 until 2030. The dashed lines plot the trajectory of the blend under each mandatory regime while the red line plots the blend in the Full Flexibility scenario.

Figure 1.5 – Simulated trajectories for the Biodiesel-Gasoil and Bioethanol-Gasoline blend under different blending policies.



(a) Gasoil - Biodiesel **(b)** Gasoline - Bioethanol

Note: Figure 1.5 shows the simulated trajectory for the Gasoil-Biodiesel blend (a) and for the Gasoline-Bioethanol blend (b) for the period 2019–2030 under six different regimes: (i) Baseline mandatory blend: 12% for bioethanol and 10% for biodiesel; (ii) Full flexibility scenario: no mandatory blend; (iii) MB05: 5% mandatory blend; (iv) MB10: 10% mandatory blend; (v) MB15: 15% mandatory blend; and (vi) MB20: 20% mandatory blend. The year 2018 reports the mandatory blend levels corresponding to the calibration and the simulation runs starting in 2019.

Figure 1.5 shows that there are two situations where the original blending constraint is relaxed (MB05 and Full Flexibility). First, there is a drop in the share of biofuels per unit of blended fuel, and second, biofuels increase their share in the blend. When the mandatory regime is relaxed, relative prices become the measure that, together with technology, determines how much of each fuel to consume. Hence, blenders would choose to increase the share (demand) of the cheaper fuel in the mix and to reduce the stake of the expensive one. Since the initial relative prices are in favour of fossil fuels when the flexible policy is applied (due to differences in efficiency and cost), the blend initially falls. For the Full Flexibility scenario, the Gasoil-Biodiesel mix initially drops from 10% to 7.73% while,

for the Gasoline-Bioethanol blend, it drops from 12% to 3.41%. For the 5% mandatory blend, the constraint is never binding for the Gasoil-Biodiesel market since the optimal blend (Full Flexibility) is above 5%, and, for the Gasoline-Bioethanol market, it is only binding for the first four years. Logically, for the greatest levels of the mandatory regime (20%), the constraint is always binding for both types of fuels.

Since there is specific capital already installed in the biofuel industry, production will not drop to zero (see proposition 2). In this case, biofuel plants would allow for reductions in the price (and therefore in its return rate) to produce and remain in the market, assuring a minimum level of production. Hence, the existence of specific capital that cannot be reallocated to other activities explains why there is no corner solution in spite of the substitutability between fossil fuels and biofuels. In this case, the price of biofuel would fall until the relative prices of fuel and biofuels equalize the relative productivities and the blenders are indifferent (see section 4).

The upward trend in the blend after the initial shock is explained by the fact that the demand for blended fuel grows faster than the capacity of the fossil fuel industry to satisfy it. In other words, fossil fuels have reached their capacity, and, at that point, new capital enters more slowly than the speed at which the demand grows. Note from Table 1.1 that refineries have a greater share of fixed capital than the average of the economy, meaning that increasing production in these activities requires, at some point, an increase in sector-specific capital. On the other hand, the biofuel industry has capital that is already installed, and, in this context, it becomes more profitable to use it rather than to install new capital on the fossil fuel industry. The mechanism by which blenders start using biofuels is the following: when fossil fuels become scarce, their price goes up and blenders start to incorporate biofuels. In this model, importing fossil fuels is an option. For those markets, there is an Armington elasticity between domestic and imported goods of 0.9[12], which is in line with the literature (Tourinho et al., 2010). However, the demand growth is also satisfied using biofuels. In terms of the evolution of each blend, for lower levels of the mandatory policy, the Gasoline-Bioethanol blend always remains below the initial policy. However, for the Gasoil-Biodiesel blend, after four periods, it converges to the original policy.

Table 1.4 shows the results of comparing different blending regimes. For more information, Appendix G presents the complete dynamic simulations for each indicator.

[12]Appendix C reports a sensitivity analysis of the Armington elasticity for fuels and biofuels, setting the parameter value to 2. The results are robust to this change.

Table 1.4 – Results for each blending regime. Differences with respect to the Full Flexibility scenario.

Indicator	Measure	M. blend 5%		M. blend 10%		M. blend 15%		M. blend 20%	
		2019	2030	2019	2030	2019	2030	2019	2030
GDP index	Percentage	-0.12	-0.00	-0.49	-0.04	-0.89	-0.47	-1.24	-0.89
Welfare index Q1-Q2	EV	-0.15	-0.00	-0.64	-0.04	-1.18	-0.50	-1.67	-0.95
Unemployment rate	Percentage	0.17	-0.00	0.71	0.01	1.32	0.43	1.88	0.82
GINI index	[0-100]	0.01	0.00	0.03	0.03	0.05	0.08	0.07	0.15
Emission index	Percentage	-0.19	-0.02	-1.04	-0.23	-2.21	-1.21	-3.37	-2.74
Energy demand index	Percentage	-0.11	-0.01	-0.48	-0.06	-0.90	-0.44	-1.29	-1.14
Affordability index	[0;∞)	0.10	-0.00	0.38	-0.02	0.65	0.24	0.90	0.39
Activity index-Primary	Percentage	-0.13	-0.02	-0.57	-0.15	-1.11	-0.89	-1.63	-1.93
Activity index–Industry	Percentage	-0.04	0.00	-0.15	-0.02	-0.25	-0.20	-0.34	-0.47
Activity index-Services	Percentage	-0.09	0.00	-0.39	-0.02	-0.75	-0.33	-1.09	-0.69

Note: Table 1.4 shows the simulated results for each indicator under four blending regimes: (a) MB05: 5 % mandatory blend; (b) MB10: 10% mandatory blend; (c) MB15: 15% mandatory blend; and (d) MB20: 20% mandatory blend. All values are expressed as the difference with respect to the Full Flexibility scenario (no blending constraint). For more information, Table 1.3 reports the definition of each indicator. Note: EV stands for Equivalent Variation and M. Blends stands for Mandatory Blend.

In terms of activity, there are always costs compared to the Full Flexibility scenario, which increase with the mandatory blend level. For the 5% mandatory blend, this cost equals 0.12 p.p. of GDP in 2019. For 2030, since both markets converged (blending constraints are not binding (see Figure 1.5), there is no cost in terms of GDP. However, for the 20% mandatory blend, losses could amount to 1.24 p.p. of GDP in 2019 and 0.89 p.p. in 2030. This effect is mainly explained by the cost of the blended fuel. In a flexible context, blenders can freely optimize the cost of the mix while, in a constrained scenario, they are forced to comply with the law. For the 5% mandatory blend, the affordability indicator for energy goods worsens by 0.10 p.p. in 2019. Note that the initial negative effects of the lower mandatory blends disappear by 2030 when the blend converges to the non-regulated level. However, for high levels of the mandatory blend, this cost is preserved. For the case of the 20% mandatory regime, the cost in terms of energy affordability is 0.90 p.p. and 0.39 p.p. in 2019 and 2030, respectively. This policy has a greater impact on fuel-intensive activities that must deal with higher fuel prices. These results are related to the outcome of the energy consumption index, which shows, for the greatest mandatory policy (20%), a fall of 1.29 p.p. in 2019 and 1.14 p.p. in 2030.

In terms of welfare, a higher level of blending policy has a negative impact on the welfare of the lowest quintiles of income, which are more exposed to the cost of energy. Moreover, it also has costs in terms of income distribution. For the 20% mandatory blend, losses in terms of welfare of the poorest deciles equal 1.67 p.p. in 2019 and 0.95 p.p. in 2030. There is also an effect of 0.07 and 0.15 in terms of the Gini index in 2019 and 2030, respectively. Additionally, the unemployment rate increases by 1.88 p.p. in 2019 and 0.82 p.p. in 2030. These results are maintained for lower regimes but with smaller sizes.

In terms of sectoral activity, primary activities are the most affected by the blending constraint since a significant share of their costs are attributed to gasoil consumption. Ad-

ditionally, service activities are also significantly affected since, within this group, there are activities such as road transportation, which is intensive on gasoil and gasoline, or fossil electric generation. Industrial activities are the least affected group.

As regards emissions, the mandatory blend seems to be an effective policy. The scenario with lower emissions is the 20% mandatory blend, which decreases emissions by 2.74 p.p. by 2030, amounting to 9.78 MTCO2eq. The accumulated gain in terms of avoided emissions during the whole period 2019–2030 is equal to 135.28 MTCO2eq. Logically, this environmental gain decreases with the mandatory blending policy.

Note that, when considering additional investments in installed capacity to produce biofuels, the supply of biofuels would increase and its price decrease, thereby reducing the costs associated with an active blending constraint. Therefore, considering new investments in biofuel-specific capital is a viable option to mitigate the costs of the blending policy. This model considers, in each dynamic simulation, the evolution of the stock of capital. In this context, past investment enters each sector as new capital according to the sectoral rate of return. Thus, capital will not enter the sector unless it is sufficiently profitable. Additionally, this model does not include efficiency investments. However, the mandatory blend could stimulate investments in R&D, especially if the price gap between fossil fuels and biofuels is high enough. In such a scenario, firms would find it profitable to invest in developing new technologies to increase efficiency and lower costs. This response would enhance the penetration rate of biofuels and reduce the costs associated with the blending constraint.

A relevant dimension in the Argentine case is the impact on exports, as Argentina is a net exporter of oil, soybeans, and corn. Table 1.5 compares the export index of those three commodities under different mandatory blending scenarios with respect to the full flexibility scenario. The results show that higher mandatory blending rates generate larger positive effects on oil exports, while the opposite pattern emerges for soybeans and corn. The underlying mechanism is a reallocation of productive resources. Higher mandatory blending reduces domestic demand for oil, which releases resources from the oil sector and allows the economy to redirect productive capacity toward exports. In contrast, mandatory blending increases domestic demand for agricultural commodities, which reduces the economy's export capacity in soy and corn. Depending on international price levels, this effect may translate into costs in terms of the current account.

Table 1.5 – Impact on exports under alternative mandatory blending levels

Commodity	**M. Blend 5%**		**M. Blend 10%**		**M. Blend 15%**		**M. Blend 20%**	
	2019	**2030**	**2019**	**2030**	**2019**	**2030**	**2019**	**2030**
Oil	0.03	0.01	0.20	0.09	0.42	0.27	0.63	0.57
Soy	-0.00	-0.02	-0.04	-0.15	-0.08	-0.35	-0.04	-0.15
Corn	-0.01	-0.01	-0.05	-0.08	-0.09	-0.21	-0.05	-0.08

Note: Table 1.5 shows the simulated results for the export index of three commodities (oil, soy and corn) under four blending regimes: (a) MB05: 5% mandatory blend; (b) MB10: 10% mandatory blend; (c) MB15: 15% mandatory blend; and (d) MB20: 20% mandatory blend. All values are expressed as the difference with respect to the Full Flexibility scenario (no blending constraint). Note: M. Blends stands for Mandatory Blend.

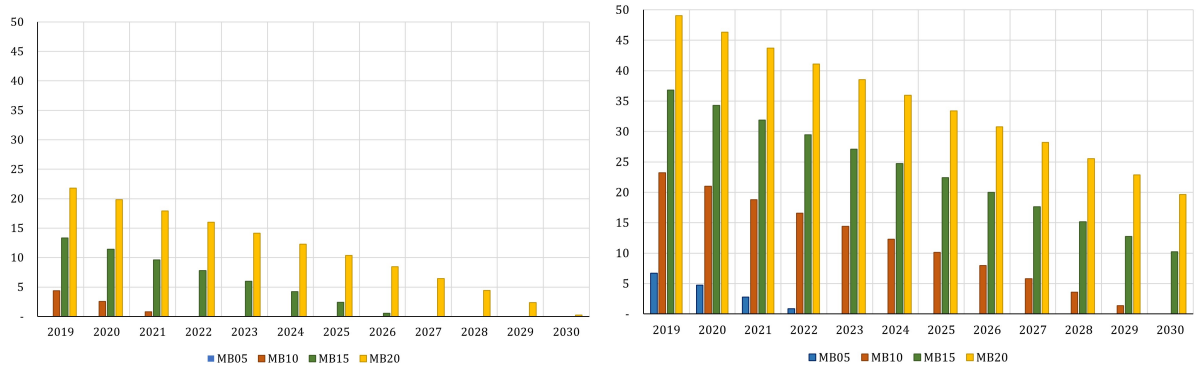
Appendix C presents a sensitivity analysis of the model. It addresses uncertainty regarding the elasticity of substitution among productive factors in value added and the

Armington elasticities. In addition, I consider the 10% and 15% mandatory blending scenarios and perform a sensitivity analysis in which I increase the Armington elasticity for fuels and biofuels to 2 to assess the robustness of the results with respect to this parameter. The results show no changes in the direction of the effects, and the magnitude of the changes remains small.

Block 2. *Fiscal Policy*

From the fiscal point of view, the allocations arising from the blending constraint could be induced by applying an additional tax on fossil fuels. This tax would modify relative prices and, therefore, the decision of the blenders. However, there is a difference between introducing a blending constraint and a tax. In the first case, a quota in the fossil fuel market is introduced. Thus, the owners of refineries sell less but at a higher price. This is equivalent to a tax that is collected by the owners of those firms. However, when there is no constraint and the government introduces a tax, the funds are collected by the government itself. Therefore, even though the same allocations are induced, the collection of those resources is spent differently. In this line, it is possible to ask which policy is better: a blending constraint or a tax on fossil fuels. Figure 1.6 shows the special taxes on fossil fuels required to induce the same results as in the previous simulations.

Figure 1.6 – Equivalent Blending: Tax on fuels achieving the same blend with respect to the Mandatory Blending Regime. Percentage.



(a) Gasoil - Biodiesel

(b) Gasoline - Bioethanol

Note: Figure 1.6 illustrates the additional tax on fuels needed to attain an equivalent blend between Gasoil and Biodiesel or Gasoline and Bioethanol, as induced by a mandatory blend. Note: MB: Mandatory Blend.

Figure 1.6 shows that, whenever the blending constraint is binding in the mandatory blend scenario, the tax is positive, but, if the constraint is not binding, no tax is required. For both markets, there is an initial increase in the tax and, by 2030, this value decreases. The greater the distance between the mandatory blend and the optimal blend (Full Flexibility), the greater the tax that is required to induce the constrained allocation. That is why, for the greatest levels of mandatory blend, a greater tax is required. However, as was mentioned in the previous subsection, by 2030, the demand for blended fuel increases faster than the capacity of the fossil fuel sector. In this context, a lower tax is required to induce the constrained allocation. Finally, note that the required tax in the gasoline market is always greater than in the case of gasoil. This is because of differences in efficiency between fossil fuels and biofuels.

Table 1.6 presents the results of indicators for different blending levels. The results in

Table 1.6 should be read as the cost or benefits of inducing the blend with a tax instead of a blending constraint.

Table 1.6 – Impact of each scenario in the relevant indicators. Difference between the equivalent tax scenario and the blending constraint scenario.

Indicator	Unit of measure	M. Blend 5%		M. blend 10%		M. blend 15%		M. blend 20%	
		2019	2030	2019	2030	2019	2030	2019	2030
GDP index	Percentage	0.01	-0.03	0.06	-0.20	0.11	-0.38	0.15	-0.58
Welfare index Q1-Q2	EV	0.07	-0.03	0.30	-0.18	0.54	-0.22	0.72	-0.29
Unemployment rate	Percentage	-0.05	0.02	-0.20	0.15	-0.35	0.21	-0.47	0.30
GINI index	[0-100]	-0.01	0.00	-0.06	0.01	-0.10	0.00	-0.14	0.00
Emission index	Percentage	-0.02	-0.07	-0.07	-0.47	-0.11	-0.97	-0.14	-1.43
Energy demand index	Percentage	-0.01	-0.03	-0.02	-0.20	-0.03	-0.41	-0.04	-0.59
Affordability index	[0;)	-0.00	0.00	-0.02	0.01	-0.03	0.01	-0.04	0.02
Activity index-Primary	Percentage	-0.02	-0.06	-0.07	-0.39	-0.11	-0.80	-0.15	-1.18
Activity index–Industry	Percentage	-0.00	-0.03	-0.01	-0.19	-0.02	-0.39	-0.02	-0.59
Activity index-Services	Percentage	0.03	-0.03	0.12	-0.18	0.21	-0.31	0.29	-0.45

Note: Table 1.6 has four columns: (a) 5% mandatory blend; (b) 10% mandatory blend; (c) 15% mandatory blend; and (d) 20% mandatory blend. Each column contains, for the initial year (2019) and the last year (2030), the result of the simulation of the additional tax on fossil fuels which induces the corresponding blend. Results in each column are expressed as the difference with respect to the mandatory blend scenario. For more information, Table 1.3 reports the definition of each indicator. Note: EV stands for Equivalent Variation.

In terms of GDP, for all the scenarios, there is an initial increase in 2019 and, by 2030, the result turns into a loss. These results are driven by the propensity of the government to consume and of the owners of refineries to invest. The government has a greater propensity to consume and makes transfers. Therefore, in the short run, the economy receives more stimulus. However, the owners of refineries have a greater propensity to invest. Therefore, in the long run, the scenario with the blending constraint performs better. The magnitude of these gains/losses depends on the funds collected. There is a similar result for the welfare of the poorest households, which benefit in the short run from the increased activity (the unemployment rate falls) and from social transfers by the government but, in the long run, they are negatively affected by the lower investment, which negatively impacts economic activity and unemployment. The energy demand always falls with the special tax on fossil fuels. That is because the government's demand is concentrated in services such as health or education while the richest households (owners of refineries) have a more energy-intensive demand. In terms of emissions, the result is always in favour of the special tax on fuels, as this policy has a negative differential impact on primary and industrial production.

Block 3. *The flexible blend in context*

This subsection aims to explore how the economy reacts under different regimes when there are shocks to international prices. Two shocks are assessed in this analysis. First, an 18% increase in the growth rate of the international price of oil (IPO) is simulated. Second, a 12% increase in the growth rate of the international price of agricultural commodities (IPC) is simulated. Appendix H reports the data sources and the methodology used to estimate these increases. Table 1.7 presents the differential impact of facing the shock in the Full Flexibility scenario versus facing the same shock with the original Mandatory Blend (Gasoil-Biodiesel = 10% and Gasoline-Bioethanol = 12%).

Table 1.7 – Differential impact of each international price scenario on relevant indicators under different blending regimes. Difference between the impact of the shock in the Full Flexibility scenario and the impact with the original mandatory blend.

Indicator	Unit of measure	IPO		IPC	
		2019	2030	2019	2030
GDP index	Percentage	-0.02	-0.11	0.01	0.12
Welfare index Q1-Q2	EV	-0.03	-0.12	0.01	0.12
Unemployment rate	Percentage	0.03	0.12	-0.01	-0.13
GINI index	[0–100]	0.00	0.00	-0.00	-0.03
Emission index	Percentage	-0.00	-0.00	0.00	0.00
Energy demand index	Percentage	-0.02	-0.08	0.01	0.09
Affordability index	[0,∞)	0.01	0.10	-0.01	-0.07
Activity index–Primary	Percentage	-0.02	-0.13	0.01	0.10
Activity index–Industry	Percentage	-0.01	-0.03	0.00	0.03
Activity index–Services	Percentage	-0.02	-0.08	0.01	0.08

Note: Table 1.7 reports two main columns: (a) IPO: International Price of Oil, and (b) IPC: International Price of Agricultural Commodities. Each column displays results for the initial year (2019) and the last year (2030). The results show the differential impact of confronting a shock in international prices with Full Flexibility versus doing so with the original mandatory blend. The results are expressed as the difference between the impact of the increase in international prices in the Full Flexibility scenario and the impact of the same price shock with the original mandatory policy. Note that, even though the table reports negative values, the indicators may still be improving in absolute terms. For more information, Table 1.3 provides the definition of each indicator. EV stands for Equivalent Variation.

For the IPO scenario, Table 1.7 shows that the gains from an increase in the international price of oil with the original mandatory blend are 0.02 p.p. and 0.11 p.p. greater than those with Full Flexibility for the years 2019 and 2030, respectively. This result is explained by the fact that, when no flexibility is considered, the economy starts from a suboptimal allocation. The increase in the international price of oil impacts the relative prices in favour of biofuels, thereby decreasing the costs associated with the blending constraint. This implies a significant gain in terms of GDP. However, when the shock occurs in a flexible context, the economy starts from an optimal allocation and moves to another one depending on the relative prices. In other words, when the mandatory blend is considered, the economy starts from a worse situation than with a flexible regime, and the shock helps it to catch up. This same reasoning explains the results for the other indicators, which follow the same pattern. However, the flexibility is dominant in absolute terms.

For the IPC scenario, in terms of GDP, the flexible regime presents greater gains than the mandatory blend. In this scenario, there are extra gains in terms of the GDP index of 0.06 p.p. in 2019 and 0.12 p.p. in 2030 when confronting the shock with a flexible regime. There are two channels driving these results. First, the optimal reaction to a positive shock in the international price of agricultural commodities would be to increase exports. However, with an active blending constraint, the economy continues producing biofuels with primary inputs to comply with the mandatory policy instead of exporting them. This results in blenders receiving biofuels at a higher cost, increasing the overall cost of fuels. Second, the increased cost of fuels worsens the country's international competitiveness, negatively affecting the trade balance and the activity level. In terms of welfare, poor households are better in a flexible scenario, with improvements in the welfare index of 0.01 p.p. in 2019 and 0.12 p.p. in 2030. This improvement is accompanied by better income distribution and a decrease in unemployment.

1.5 Conclusions

This paper studies the impact associated with the application of mandatory blends on the fuel market for the case of Argentina. It seeks to answer the following questions: What are the costs of rigidity in terms of activity, household welfare, income distribution, and the environmental performance of the economy? Which policy is better: a blending constraint or an additional tax on fossil fuels? And, finally, what is the impact of international price shocks when considering different blending regimes?

This paper finds that the mandatory blend presents a trade-off between efficiency and environmental outcome. In this line, costs in terms of activity, income distribution and energy affordability are increasing with the mandatory blend, as well as environmental benefits. This paper also studies the consequences of inducing allocations of a certain mandatory blend through an additional tax on fossil fuels. In this regard, this paper finds that the magnitude of the tax and its evolution are associated with the relative prices between fossil fuels and biofuels and their evolution. In terms of which policy is more convenient, this paper finds that the benefits of each policy are distributed differently over time. For the special tax on fossil fuels, benefits are derived in the short run while for the mandatory blend, in the long run. Finally, this paper finds that flexibility in the fuel market improves the country's performance when there are shocks on international prices.

To conclude, rigidity is linked to the poorest outcomes in terms of economic activity. It is noteworthy that the most vulnerable households consistently react negatively to exposure to rigidity. Likewise, this measure has negative impacts on the conditions of affordability of energy and, therefore, on its consumption. However, there are benefits in terms of emissions. Hence, the application of this policy will depend on how much the regulator values the environmental benefits compared to the costs in terms of welfare, which poses a dilemma. This opens the door to discussing the introduction of new ways of combustion or the electrification of pollutant activities.

Appendix A. The Argentine Fuel Market

A.1. Policy backround of the fuel market in Argentina

The current Argentine legal background for the fuel market can be thought as divided in two. In the first place, the law No 17,319 (1967) which is called the Hydrocarbons' Law regulates aspects related to the extraction, storage, production, and commerce of hydrocarbons. In the second place, law No 27,640 (2021), also called the Regulatory Framework of Biofuels, establishes a legal framework for the elaboration, storage, and sales of biofuels. Over the years, these laws were modified by different decrees, provisions, and administrative decisions. This is particularly important for the Hydrocarbons Law which is the oldest one. The spirit of both laws is to regulate the conditions under which those markets perform, to rule the rights of property, and to give the national government, represented by the Secretariat of Energy, the power to regulate those markets. The criteria under which such authority performs its role is not clear and it is highly dependent on the political cycle.

Regarding the blending policy, it was first applied in Argentina with the law No 26,093 (2006) and the decreet No 109/07. However, it took until 2010 to be effective. The evolution of the blending policy has been changing over the years together with the availability of fuels and their prices.

For the case of bioethanol, although the initial blend of 5% of bioethanol in gasoline was established, at the beginning of the implementation period, the blend achieved only 2%. This is mainly explained by fuel availability. However, between 2006 and 2012, conditions changed: (i) more sugarcane bioethanol plants were installed, (ii) the production of corn bioethanol increased, and (iii) there were modifications in the procedures for determining the purchase price of bioethanol differentiating by main input (Resolution No 170/14 and Provision No 1/15 of the Subsecretariat of Fuels) (Romano, 2017). Under these improvements, the blend was gradually raised to 10% (Resolution No 44/14) in 2014 and then, to 12% in 2016 (Resolution No 37/2016). Finally, with the new regulatory framework for biofuels (law No 27,640), the blend remains at 12%.

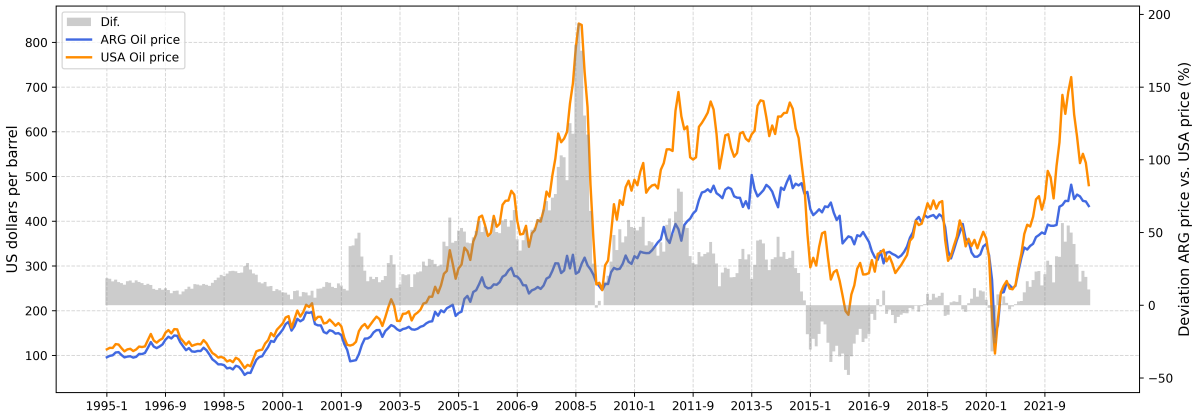
For the case of biodiesel, the legislation of 2006 and 2007 established an initial blend of 5% of biodiesel in the mix in 2010. Even though the Argentine Republic is one of the main producers in the world, it was not able to implement the blend. According to (Romano, 2017), this was because, up to that date, the legislation with the procedure for determining the retail price of biodiesel had not been promulgated. This was solved through Resolution No. 7/10 (2010). From then on, the 5% blend began, rising the same year to 7% (Resolution No. 554/10). In 2013, it increased to 8% (Resolution No. 450/13) and, in the same year, to 10% (Resolution No. 1125/13). Finally, under the new legislation of 2021, the blend of biodiesel with gasoline turned back to 5% and then to 7.5% in 2022.

However, the blending policies are not the only policies that affect the fuel market. In this regard, Argentina has a long tradition of price regulation of fuels through the local price of the barrel of oil. In the case of Argentine oil, there is no concrete legislation that sets its price. The most used tool to regulate the domestic price of oil is setting taxes on exports. Starting from 2002, decreet 310/2002, and 809/2002 fixed export taxes at 20% for oil and other derivatives. In 2004, Resolution 337/2004 increased this value to 25%. Resolution 532/2004 made the tax rate depending on the international price. Under

this new resolution, the tax rate would be 25% if the price of WTI was lower than 32 U$S/barrel. However, if the barrel was between 32 and 45 U$S/Barrel the tax rate would increase step by step until 45%. In 2007, resolution 394/2007 set a tax of 45% for oil and its derivatives if the international price of oil was between 45 and 60.89 U$S/Barrel. Resolution 1007/2014 changes the formula to estimate the threshold to pay the tax. Decreet 793/2018 reduces the tax to 12% and puts a maximum payment of $3 per dollar. In 2019, under law No 27,541 a maximum rate of 8% was established for hydrocarbons and mining. Finally, Decreet 488/2020 set a reference price for the value of oil, if the international price is below the reference, then the tax rate is 0% while if it is above that number the tax rate is 8%

Figure 1.7 shows the evolutions of the domestic price of oil and the international one.

Figure 1.7 – The domestic versus the international price of oil.



Source: FRED (WTI price) and Argentine Secretariat of Energy. Note: Figure 1.8 reports (lines) the price index of local and international price of oil for the period 1995–2022 and the gap between them (grey bars).

The price of fuels is also affected by taxes. Some taxes aim to internalize the environmental damages associated with fuel use, while others fund infrastructure investment. Prior to the 2017 Argentine tax reform, fuel taxation relied on ad valorem rates applied to fuel products (OECD, 2019). The system included the Special Tax on Liquid Fuels and Natural Gas and the Specific Tax on Diesel. In 2001, Decree No. 1381/2001 introduced the Hydric Infrastructure Tax, set at USD 0.05 per liter, to finance a fund aimed at flood prevention. Law No. 26,181 later modified this tax, redefining it as 5% of the gasoline value. According to OECD (2019), the 2017 Argentine Tax Reform simplified the taxation of energy use by replacing the ad valorem system with a specific tax based on physical units. The reform also introduced a carbon tax of USD 10 per tCO2eq on fossil fuels, in force since March 2018. Although these taxes are established by law, the government retains discretion to update their levels, which makes their effective impact highly dependent on the political cycle (Argentine Secretariat of the Treasury, 2025).

In terms of price regulation, there is a similar approach for the case of biofuels where the exports of raw primary inputs such as soy or corn are taxed. As an example, the export duties for soy and corn in 2002 were equal to 23.5% and 20% of the export transaction respectively (Resolution 35/02). In 2008, those values equal 35% and 25% respectively (Resolution 181 and 182/08). Between the period 2015–2019, the export duty for soy was on average equal to 28% while for corn there was no tax. Finally, from 2019 onward, the average duty for soy is 33% while, for corn, it is equal to 12%. As in the case of fossil fuels,

it lowers the domestic prices for consumers and for producers using those commodities as inputs.

The price of biofuels is also affected by Resolution No 170/14 and Resolution No 07/10. Resolution N°170/14 sets the price of bioethanol elaborated from sugar cane equal to the sum of the cost of diesel, the cost of labour, the cost of natural gas, and other costs required inputs to produce one litter of bioethanol. For the corn-based bioethanol, the price is set equal to the sum of the cost of corn, the cost of labour, the cost of steam, the cost of electricity, and other costs. In both cases, the law adds a rate of return equal to 31.3%. In the case of biodiesel, Resolution No 07/10 set its price equal to the sum of the cost of the soybean oil, the transaction cost to get the soybean oil, the transportation cost, the cost of methanol, other costs required to produce one ton of biodiesel. This Resolution recognizes an additional utility of 28 U$S per ton of biodiesel.

In the case of biofuels, these activities are benefited from the anticipated devolution of the VAT, accelerated amortization of the income tax, the exclusion of the goods that belong to the taxable base of the minimum presumed income tax, and the exclusion of the fuel taxes. Additionally, the export tax regime has differential advantages in favour of biofuels. Particularly, the focus is on biodiesel which is the product in which Argentina has a competitive advantage and is prone to export. As well as in other products, the tax on exports has changed over the years. For example, in 2013, according to the Secretary of Energy, the tax was 25%, in 2015 this value was 10%, in 2017 it was approximately 6%, and, in 2019, 15%. Finally, in 2022 the tax on exports of biodiesel reached 30%.

Appendix B. Proofs for Propositions

Proposition 1. *Define the level of inefficiency (IN) of the blend as the ratio between the average cost of the mix with a mandatory blend (AC_{wb}) and the average cost when no blending policy is imposed (AC_{nb}). Thus, $IN = {}^{AC_{wb}}/_{AC_{nb}}$. Under this definition, the level of inefficiency is equal to:*

$$IN = \begin{cases} \frac{1+\frac{P_B}{P_F}\frac{\theta}{1-\theta}}{1+\frac{\gamma}{\alpha}\frac{\theta}{1-\theta}} & if \quad {}^{\alpha}/_{\gamma} > {}^{P_F}/_{P_B} \\ 1 & if \quad {}^{\alpha}/_{\gamma} \leq {}^{P_F}/_{P_B} \end{cases}$$

To prove proposition 1, it is required to compare the average cost of the mix with and without regulation. The division of those magnitudes will characterize the inefficiency in which the blender incurred for choosing a mix that he does not prefer.

Note that when the blender is not regulated the average cost (AC) is:

$$AC_{nb} = \begin{cases} \frac{P_F}{\alpha} & if \quad {}^{\alpha}/_{\gamma} > {}^{P_F}/_{P_B} \\ \frac{P_F F + P_B B}{\alpha F + \gamma B} & if \quad {}^{\alpha}/_{\gamma} = {}^{P_F}/_{P_B} \\ \frac{P_B}{\gamma} & if \quad {}^{\alpha}/_{\gamma} \leq {}^{P_F}/_{P_B} \end{cases}$$

For the regulated case, note that in the situation where ${}^{\alpha}/_{\gamma} \leq {}^{P_F}/_{P_B}$ the constraint is not binding then the result of the regulated and non-regulated scenario is the same. Thus, the average cost is:

$$AC_{wb} = \begin{cases} \frac{P_F + P_B \frac{\theta}{1-\theta}}{\alpha + \gamma \frac{\theta}{1-\theta}} & if \quad \alpha/\gamma > P_F/P_B \\ \frac{P_F F + P_B B}{\alpha F + \gamma B} & if \quad \alpha/\gamma = P_F/P_B \\ \frac{P_B}{\gamma} & if \quad \alpha/\gamma \leq P_F/P_B \end{cases}$$

As previously stated, define the inefficiency (IN) incurred because of the regulation as the ratio between the regulated average cost and the non-regulated average cost. Logically, the greater this ratio the more inefficient the blend. After some math, the result for the inefficiency is:

$$IN = \begin{cases} \frac{P_F + P_B \frac{\theta}{1-\theta}}{P_f} \frac{\alpha}{\alpha + \gamma \frac{\theta}{1-\theta}} & if \quad \alpha/\gamma > P_F/P_B \\ 1 & if \quad \alpha/\gamma \leq P_F/P_B \end{cases}$$

By rearranging those factors and ordering the resultant terms it is possible to find:

$$IN = \begin{cases} \frac{1 + \frac{P_B}{P_F} \frac{\theta}{1-\theta}}{1 + \frac{\gamma}{\alpha} \frac{\theta}{1-\theta}} & if \quad \alpha/\gamma > P_F/P_B \\ 1 & if \quad \alpha/\gamma \leq P_F/P_B \end{cases}$$

Proposition 2. *Define SK as the level of specific capital installed in the biofuel industry. In a flexible scenario (no blending constraint), given SK, always it is going to be a minimum level of biofuel production and $\alpha/\gamma = P_F/P_B$.*

Market clearing conditions in the fossil fuel and biofuel markets require that demand and supply for both markets are equalized. Take Q_d^j as the quantity demanded of the fuel j and Q_s^j as the quantity supplied in the market j with $j \in [B, F]$. Market clearing conditions require that $Q_s^j = Q_d^j \; \forall j$.

In a flexible scenario, where no blending constraint is imposed, assume that $\alpha/\gamma > P_F/P_B$. In that case, the optimal choice would be to only use fossil fuels. Therefore, $Q_d^B = 0$ and, for the market clearing equation to hold, $Q_s^B = 0$ is required. However, there is specific capital installed in the biofuel industry (SK) that cannot be reallocated to other industries. Therefore, $Q_s^B = F(SK) > 0$. Which is a contradiction.

For the market clearing condition to hold, the equilibrium requires that $Q_s^B = F(SK) > 0$ and, therefore, $Q_d^B > 0$. Thus, the price of biofuels will adjust until there is a positive demand for biofuels. Therefore, it will go down until $\alpha/\gamma = P_F/P_B$. In other words, when there is specific capital already installed in the biofuel industry the system operates at the indifference prices and there are no corner solutions.

Appendix C. Sensitivity Analysis

For the sensitivity study, the uncertainty regarding the elasticity of substitution between productive factors in the value added and the Armington elasticities are addressed. Even though there are no estimations for Argentina of such parameters, values from the liter-

ature were taken. For each parameter, it will be performed a ±10% in the elasticities to assess how results change with those parameters. Table 1.8 presents the results for the elasticity of substitution between different productive factors in the baseline scenario.

Table 1.8 – Results of the sensitivity analysis of the elasticity of substitution among the components of value added in the baseline scenario.

Indicators	Sensitivity baseline scenario to value-added elasticity					
	2019			2030		
	(-) 10%	1	(+) 10%	(-) 10%	1	(+) 10%
GDP index	1.65	1.66	1.67	18.65	19.19	20.27
Welfare index Q1-Q2	0.48	0.50	0.51	8.76	9.48	10.63
Unemployment rate	9.36	9.36	9.37	8.66	7.75	6.03
GINI index	38.70	38.69	38.69	39.91	39.82	39.71
Emission index	103.34	103.31	103.28	131.01	128.62	125.12
Energy demand index	1.00	1.01	1.02	12.06	12.50	13.34
Affordability index	7.20	7.20	7.20	12.75	12.77	12.79
Activity index-Primary	3.95	3.95	3.95	37.00	37.24	38.69
Activity index–Industry	0.77	0.77	0.77	10.06	10.29	10.77
Activity index-Services	0.98	0.98	0.98	12.33	12.74	13.68

Note: Table 1.8 reports the results for the sensitivity analysis of the elasticity of substitution among the components of value added in the baseline scenario. This table presents the variation in the baseline scenario when the value-added elasticity of substitution is changed ±10%.

Table 1.9 – Results of the sensitivity analysis of the Armington elasticity in the baseline scenario.

Indicators	Sensitivity baseline scenario to Armington elasticity					
	2019			2030		
	(-) 10%	0.9	(+) 10%	(-) 10%	0.9	(+) 10%
GDP index	1.66	1.66	1.66	19.08	19.19	19.29
Welfare index Q1-Q2	0.5	0.5	0.5	9.37	9.48	9.58
Unemployment rate	9.36	9.36	9.37	7.83	7.75	7.68
GINI index	38.69	38.69	38.69	39.84	39.82	39.81
Emission index	103.3	103.31	103.33	128.25	128.62	128.98
Energy demand index	1.02	1.01	0.99	12.65	12.5	12.34
Affordability index	7.2	7.2	7.2	12.79	12.77	12.75
Activity index-Primary	3.92	3.95	3.98	36.66	37.24	37.83
Activity index–Industry	0.79	0.77	0.76	10.47	10.29	10.11
Activity index-Services	0.98	0.98	0.98	12.69	12.74	12.79

Note: Table 1.9 reports the results for the sensitivity analysis. This table presents the variation in the baseline scenario when the Armington elasticity is changed ±10%.

Table 1.10 – Sensitivity analysis of the Armington elasticity for the 10% and 20% mandatory blending scenarios.

Indicator	**Unit of measure**	**M. blend of 10%**		**M. blend of 20%**	
		2019	**2030**	**2019**	**2030**
GDP index	Percentage	-0.49	-0.06	-1.25	-0.99
Welfare index (Q1–Q2)	EV	-0.64	-0.07	-1.67	-1.09
Unemployment rate	Percentage	0.72	0.03	1.88	0.96
GINI index	[0–100]	0.03	0.03	0.08	0.15
Emission index	Percentage	-1.05	-0.27	-3.37	-3.17
Energy demand index	Percentage	-0.47	-0.07	-1.26	-1.07
Affordability index	[0,∞)	0.38	0.01	0.90	0.46
Activity index – Primary	Percentage	-0.57	-0.18	-1.64	-2.20
Activity index – Industry	Percentage	-0.15	-0.02	-0.34	-0.47
Activity index – Services	Percentage	-0.39	-0.03	-1.10	-0.79

Note: Table 1.10 reports the results of the sensitivity analysis for the 10% and 20% mandatory blending policies. The table shows deviations from the baseline scenario as the Armington elasticity for fuels and biofuels varies from 0.9 to 2. Note: M. blend stands for Mandatory Blend.

Appendix D. Sectoral Opening of the Social Accounting Matrix for Argentina 2018

Table 1.11 – Sectoral breakdown of the Argentine Social Accounting Matrix 2018.

Code	Sector	Aggregate Sector
1	Soybean	Agriculture
2	Corn	Agriculture
3	Sugar cane	Agriculture
4	Other Agriculture	Agriculture
5	Livestock and hunting	Cattle Rising
6	Deforestation	Rest of Primary Act.
7	Silviculture	Rest of Primary Act.
8	Fishing	Rest of Primary Act.
9	Oil	Extraction
10	Gas	Extraction
11	Coal	Extraction
12	Mining	Extraction
13	Soybean oil	Food and Beverages
14	Corn flours	Food and Beverages
15	Sugar	Food and Beverages
16	Food, Beverages, and Tobacco	Food and Beverages
17	Textiles, Clothing, and Leather	Light industry
18	Wood and wood products	Light industry
19	Paper, paper products, edits, and reproductions	Light industry
20	Gasoil	Fuels
21	Gasoline	Fuels
22	Other fossil fuels	Fuels
23	Biodiesel	Fuels
24	Bioethanol	Fuels
25	Chemical, plastic, and rubber	Heavy industry
26	Non-metallic minerals	Heavy industry
27	Metals and metal products	Heavy industry
28	Machinery and equipment	Heavy industry
29	Vehicles and transport equipment	Heavy industry
30	Rest of industry	Light industry
31	Fossil electricity generation	Electricity, Gas, and Water
32	Non-fossil electricity generation	Electricity, Gas, and Water
33	Transport and distribution of electricity	Electricity, Gas, and Water
34	Gas distribution	Electricity, Gas, and Water
35	Water distribution	Electricity, Gas, and Water
36	Construction	Construction
37	Commerce	Commerce
38	Blender Gasoil	Fuels
39	Blender Gasoline	Fuels
40	Hotels and Restaurants	Hotels and Restaurants
41	Road transportation	Transport
42	Rest of transportation	Transport
43	Communication	Other services
44	Financial intermediation, business, and real state	Other services
45	Public administration	Other services
46	Education and health	Education and health
47	Rest of services	Other services

Note: This table contains the sectoral breakdown of the Argentine Social Accounting Matrix for the year 2018.

Appendix E. Sources of Information for the Construction of the Social Accounting Matrix for Argentina 2018

This Appendix presents the primary sources of information used in the construction of the 2018 Social Accounting Matrix for Argentina. The preparation of such a matrix requires incorporating multiple sources into a single matrix. Among these sources, there is data on tax collection, government budgets, international trade, and sectoral production, among others. This matrix has managed to incorporate all the relevant information to represent the structure of the Argentine economy.

E.1. National accounts system

The main starting point for the preparation of this matrix is the national accounts system for Argentina 2018. It is published by the National Institute of Statistics and Census (INDEC, by its acronym in Spanish). This institution provides annual information for the following variables:

- Macroeconomic aggregates (GDP, public and private consumption, trade balance, composition of global supply and demand)
- Economic activity (Value of production, Value added, and Intermediate Consumption) by sector.
- Income generation account by factor and by sector.
- Supply and Use Tables Argentina 2018.

To better characterize the imports by sector and the commercialization and transport margins, the 1997 Argentine Input-Output Matrix (MIP, by its acronym in Spanish) and the 2004 Supply and Utilization Tables were used. It is necessary to mention that the 1997 Argentine MIP is the last matrix with estimates for the imports and margins.

The information necessary to characterize the government in budgetary terms was obtained from the Ministry of Treasury and Finance. In particular, the budgets for the consolidated government and the tax revenue tables were used. Additionally, for the sectoral characterization of national taxes, the databases of the Federal Administration of Public Funds (AFIP, by its acronym in Spanish) were used.

E.2. Household income and expenses in Argentina

The information regarding the structure of households was obtained from INDEC. This institution publishes the National Survey of Households' Expenditure (ENGHo, by its acronym in Spanish) 2017–2018 that accounts for households spending patterns. On the other hand, the Permanent Survey of Households (EPH, by its acronym in Spanish), which has quarterly information, was used to characterize household income. Additionally, the information by income decile was contrasted against data from the Center for Distributive, Labor, and Social Studies (CEDLAS, by its acronym in Spanish), which monitors income distribution in Latin American countries.

E.3. International accounting: balance of payments 2018

The data to characterize Argentina's relationship with the rest of the world in terms of the Social Accounting Matrix were obtained from the Argentine Balance of Payments

2018 published by INDEC.

E.4. Data used for sectoral openings

For the sectorial opening of the Oil, Gas, and Coal sector, the SESCO Tables provided by the Secretary of Energy (SENER, by its acronym in Spanish) of Argentina for the period were used. For the international trade data of these sectors, the Foreign Trade Consultation System prepared by INDEC was used. The price data comes from the Argentine Ministry of Energy. Additionally, data from the Tables of Supply and Use Argentina 2018 and the ENGHo 2017–2018 were used.

For the opening of fuels, the SESCO Tables, the National Energy Balance, and the SENER production data were used. The price data was taken from the National Energy Institute. Additionally, data from the 2018 Argentine Supply and Use Tables, the ENGHo 2017–2018, and the Foreign Trade Consultation System provided by INDEC were used.

For the Opening of biofuels, SENER's data on quantities produced and prices were used. Additionally, data from the Ministry of Agriculture, Livestock, and Fisheries (MAGYP, by its acronym in Spanish) were used. The cost data were obtained from the report by Epifanio and Ernst (2019) and FAO (2019) on the Biofuels value chain. Additionally, data from the 2018 Argentine Supply and Use Tables, the ENGHo 2017–2018, and the Foreign Trade Consultation System provided by INDEC were used.

For the opening of the electricity sectors, CAMESSA data was used for prices and quantities and data from balance sheets of companies in the sector to estimate cost structures.

For the opening of the primary sectors, MAGYP data, and the Value Chain Reports for each type of primary good (Ministry of Industry) were used. Additionally, the Agricultural Census were used. For the estimation of the value added by the primary sector, data from INTA (a body specialized in agricultural issues in Argentina) were used. Additionally, data from the Argentina 2018 Supply and Use Tables, the ENGHo 2017–2018, and the Foreign Trade Consultation System provided by INDEC and AFIP tax and sales data were used.

For the opening of Food and Beverages, the Value Chain Reports of the Ministry of Industry, and data from INTA and MAGYP were used. In this case, the 2018 COU was used at the product level to characterize the cost structure of these sectors. Additionally, data from the ENGHo 2017–2018 and the Foreign Trade Consultation System provided by INDEC were used.

E.5. The share of mobile capital in value added

This indicator was estimated from the Yearbook of Tax Statistics, which is published annually by the AFIP. This database contains tables with information about the composition of the assets of firms by main activity. In this context, fixed assets, such as buildings, or illiquid assets, such as long-term liabilities in favour of the firms, are considered to compute the share of fixed capital. Note that the share of mobile capital is the remaining part of the capital.

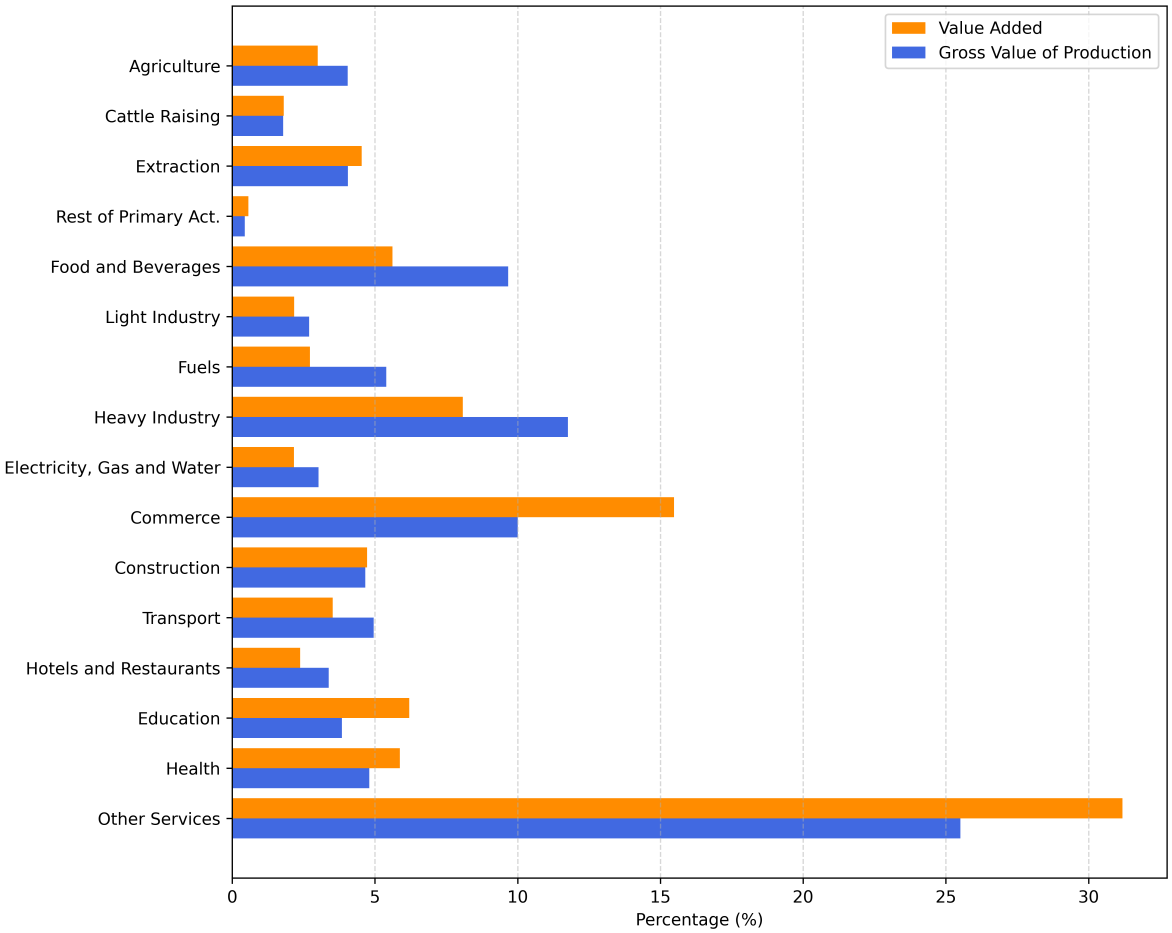
E.6. Emissions

The base emissions data come from the Inventory of Greenhouse Gas Emissions of Argentina for the sectoral composition and by type of gas. The whole dataset is available in the replication file.

Appendix F: The Social Accounting Matrix: Results

Figure 1.8 shows the contribution of the 15 activities to the Gross Production Value and the Value Added of the Argentine economy in 2018.

Figure 1.8 – Share of aggregated sectors in total Gross Value of Production and Value Added.



Note: This figure reports the share of each activity in total Value Added and Gross Value of Production.

Table 1.12 reports the composition of aggregate supply and demand in the Argentine economy according to the 2018 SAM.

Table 1.12 – Argentina 2018. Composition of aggregate supply and demand.

Concept	M$2018	%
GDP at market prices	14,744,811	86%
Imports	2,376,588	14%
Aggregate Supply	**17,121,399**	**100%**
Household Consumption	10,453,945	61%
Public Consumption	2,330,432	14%
Gross Domestic Investment	2,248,738	13%
Exports	2,088,285	12%
Aggregate Demand	**17,121,399**	**100%**

Note: Values are expressed in millions of 2018 Argentine pesos and in percentages.

To complement Table 1.12, Table 1.13 presents the composition of GDP at market prices.

Table 1.13 – Argentina 2018. Composition of GDP at market prices.

Concept	M$2018
GDP at basic prices	12,478,124
Taxes on products	2,564,104
Tariffs	107,178
Subsidies	404,595
GDP at market prices	**14,744,811**

Note: Values are expressed in millions of 2018 Argentine pesos.

Table 1.14 presents the composition of the consolidated government's expenditures and revenues. The difference between them determines the fiscal balance (deficit/surplus) for 2018.

Table 1.14 – Argentina 2018. Structure of consolidated government revenues and expenditures.

Concept	M$2018	% GDP
Revenues	**4,430,480**	**30.0%**
Tax revenues	3,473,738	23.6%
Social contributions	879,055	6.0%
Other	77,687	0.5%
Expenditures	**5,138,960**	**34.9%**
Public consumption	2,330,432	15.8%
Public investment	314,680	2.1%
Economic subsidies	404,595	2.7%
Household transfers	2,089,254	14.2%
Balance	**-708,480**	**-4.8%**

Note: Values are expressed in millions of 2018 Argentine pesos and as percentages. GDP at market prices was used to calculate the "% GDP" column.

Table 1.15 shows the composition of household income and expenditures by income quintile.

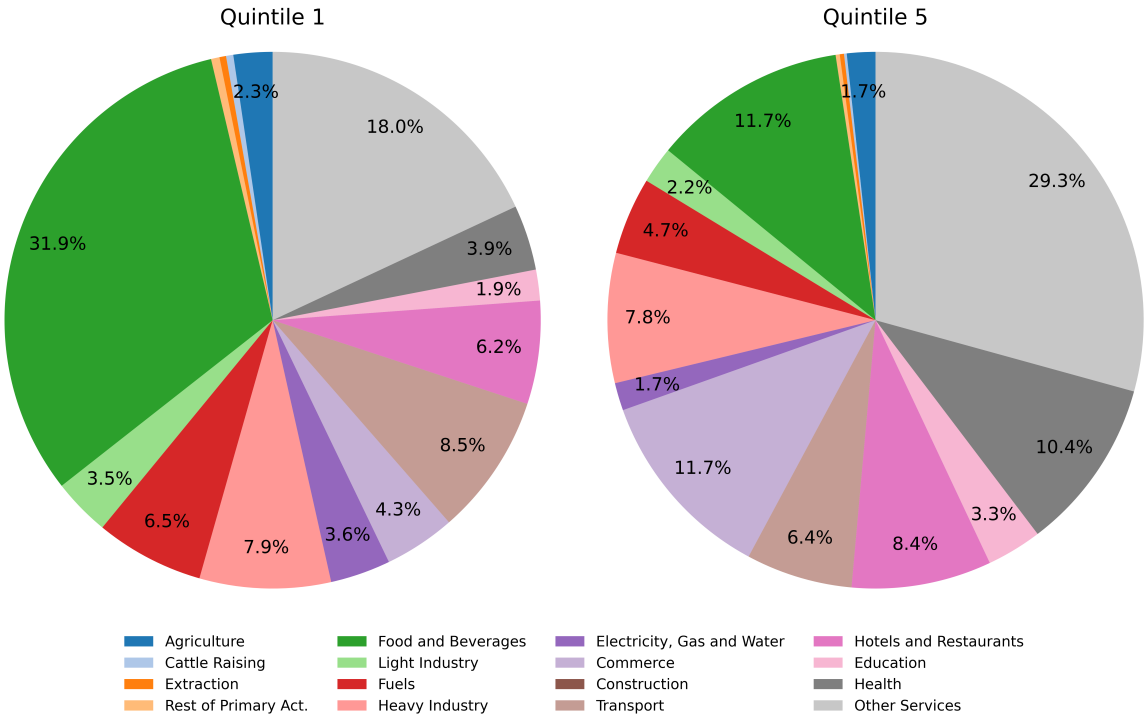
Table 1.15 – Argentina 2018. Structure of household income and expenditures by income quintile.

Concept	H1	H2	H3	H4	H5
Income	**647,857**	**1,278,705**	**1,810,645**	**2,712,921**	**5,878,281**
Labor	16.8%	30.7%	42.3%	51.9%	38.5%
Gross Mixed Income	20.3%	15.7%	13.5%	12.4%	9.2%
Capital	18.8%	16.4%	22.8%	20.4%	43.3%
Transfers	44.0%	37.2%	21.4%	15.4%	8.9%
Expenditures	**1,031,029**	**1,470,543**	**1,991,072**	**2,695,332**	**5,206,566**
Consumption	100.0%	100.0%	88.5%	88.6%	73.1%
Investment	0.0%	0.0%	11.5%	11.4%	26.9%
Balance	**-383,172**	**-191,838**	**-180,427**	17,589	**671,715**

Note: Values are expressed in millions of 2018 Argentine pesos and in percentages. GMI: Gross Mixed Income.

Figure 1.11 shows the composition of the national consumption basket for the poorest income quintile and for the richest income quintile. Although the matrix includes 47 productive sectors, the figure presents an aggregation into 15 sectors to simplify the presentation. The correspondence with the 47 sectors in the matrix is detailed in the previous subsection.

Figure 1.9 – Argentina 2018. Structure of residential consumption for the first and fifth income quintiles



Note: This figure shows the composition of the consumption basket for the poorest and richest households, identified by income per capita quintiles.

Table 1.16 shows the composition of Argentina's income and expenditures in its relations with the rest of the world.

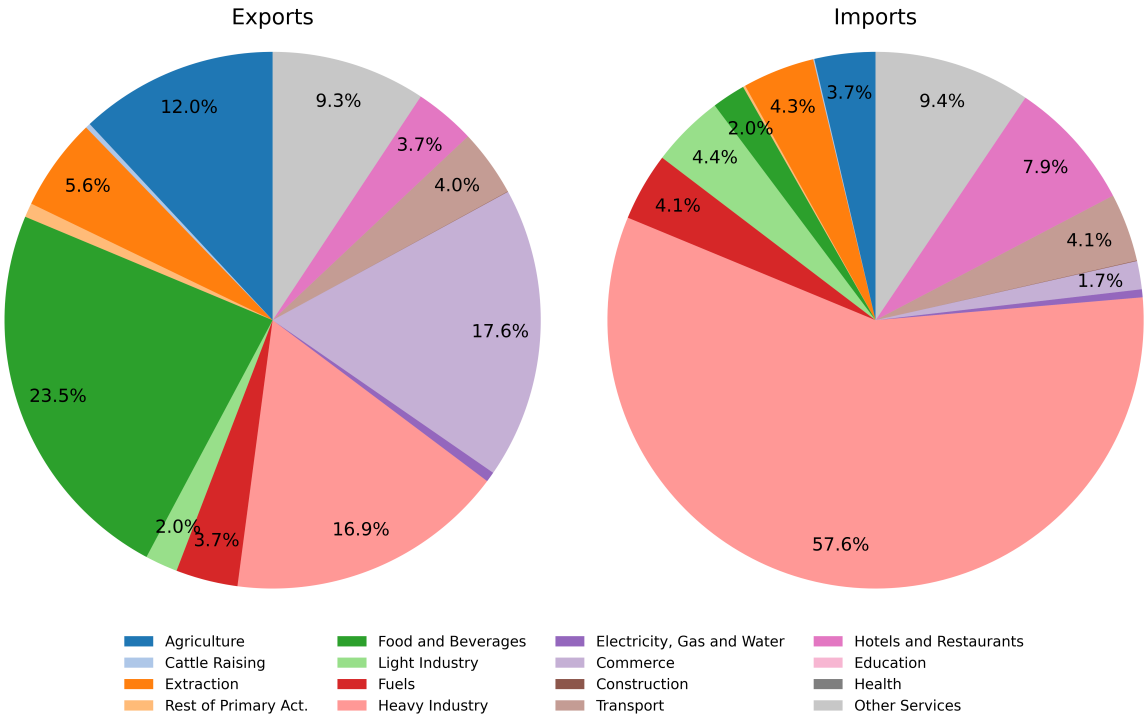
Table 1.16 – Argentina 2018. Foreign account of the economy (credits and debits).

Credit	**2,088,285**
Exports of goods	64.66%
Exports of services	35.34%
Debit	**2,862,897**
Imports of goods	62.38%
Imports of services	20.63%
Net compensation of employees	0.08%
Net investment income	16.91%
Balance	**-774,612**

Note: Values are expressed in millions of 2018 Argentine pesos and in percentages.

Figure 1.10 shows the composition of Argentina's export and import baskets, using the same sectoral breakdown as in the case of the household consumption basket.

Figure 1.10 – Argentina 2018. Structure of exports and imports per product



Note: This figure shows the composition of national exports and imports per activity.

To conclude, the following table presents an aggregated three-sector version of the 2018 Argentine Social Accounting Matrix, expressed in millions of 2018 dollars.

Table 1.17 – Argentina 2018. Social Accounting Matrix 3x3. Millions of current US dollars.

Argentina 2018	Primary	Industry	Services	VA	Taxes	Households	Government	Investment	Rest of the World	Total
Primary	8.742	40.998	9.790			10.622		8.029	13.895	**92.075**
Industry	11.421	39.249	65.910			108.923	54	7.478	34.218	**267.252**
Services	20.788	33.215	121.944			239.988	82.850	42.471	26.177	**567.432**
Value Added	36.837	62.773	284.707							**384.317**
Production Taxes	4.254	42.325	30.718			1.932		1.407		**80.636**
Factor Taxes	7.088	10.867	41.631							**59.586**
Direct Taxes						233				**233**
Households				364.253			74.324			**438.577**
Government				2.764	140.455					**143.219**
Investment						68.803	11.195			**79.998**
Rest of the World	2.945	37.825	12.732	17.300		10.429		20.614		**101.846**
NIB						-2.353	-25.204		27.556	**0**
Total	**92.075**	**267.252**	**567.432**	**384.317**	**140.455**	**438.577**	**143.219**	**79.998**	**101.846**	**0**

Note: This table presents a reduced version of the 2018 Argentina Social Accounting Matrix. The values of transactions between accounts are measured in millions of current US dollars from 2018. The original matrix contains 47 productive sectors, 5 household categories, a government account, and the rest of the world. This version is available as part of the thesis submission. Note: NIB: Net Income Balance.

Table 1.17 presents a macro-level version of the Social Accounting Matrix (SAM) used in this paper. It summarizes the main agents represented in the economy. Each agent is associated with an account, and each account appears as both a row and a column in the matrix: rows record the income received by each account, while columns record their corresponding expenditures. Thus, each cell in the matrix reflects a transaction between the row account (recipient) and the column account (payer). Unlike traditional input-output tables, SAMs capture not only transactions between productive sectors but also flows among all institutional agents in the economy. As such, Table 1.17 provides a comprehensive snapshot of the Argentine economy in 2018.

Appendix G. Dynamic Results for Each Variable Per Simulation

Table 1.18 – Results for the baseline and the first block of simulations.

Period	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Original policy												
GDP index	1.7	3.4	5.1	6.7	8.4	10.0	11.6	13.2	14.8	16.3	17.7	19.2
Welfare index Q1-Q2	0.5	1.3	2.1	3.0	3.8	4.6	5.5	6.3	7.1	7.9	8.7	9.5
Unemployment rate	9.4	9.1	8.8	8.5	8.3	8.1	8.0	7.9	7.8	7.8	7.8	7.8
GINI index	38.7	38.8	38.9	38.9	39.0	39.1	39.2	39.3	39.4	39.5	39.7	39.8
Emission index	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3
Energy demand index	1.0	2.2	3.4	4.6	5.7	6.8	7.9	8.9	9.9	10.8	11.7	12.5
Affordability index	7.2	7.5	7.9	8.2	8.7	9.1	9.6	10.2	10.7	11.4	12.0	12.8
Activity index-Primary	3.9	8.0	11.9	15.5	19.0	22.2	25.3	28.1	30.7	33.1	35.3	37.2
Activity index–Industry	0.8	1.7	2.7	3.6	4.5	5.4	6.3	7.2	8.0	8.8	9.6	10.3
Activity index-Services	1.0	2.2	3.3	4.5	5.6	6.7	7.8	8.8	9.8	10.8	11.8	12.7
Full flexibility												
GDP index	2.25	3.9	5.6	7.2	8.9	10.5	12.1	13.6	15.1	16.6	18.0	19.4
Welfare index Q1-Q2	1.3	2.0	2.8	3.6	4.4	5.2	6.0	6.7	7.5	8.2	9.0	9.7
Unemployment rate	8.5	8.3	8.1	7.9	7.7	7.5	7.5	7.4	7.4	7.4	7.5	7.6
GINI index	38.7	38.7	38.8	38.9	39.0	39.1	39.2	39.3	39.4	39.5	39.6	39.8
Emission index	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3
Energy demand index	1.6	2.7	3.9	5.0	6.2	7.2	8.3	9.3	10.2	11.1	11.9	12.7
Affordability index	6.7	7.1	7.5	7.9	8.3	8.8	9.3	9.9	10.5	11.2	11.9	12.7
Activity index-Primary	4.6	8.6	12.5	16.1	19.6	22.9	25.9	28.7	31.3	33.6	35.7	37.6
Activity index–Industry	1.0	1.9	2.9	3.8	4.7	5.6	6.5	7.3	8.1	8.9	9.6	10.4
Activity index-Services	1.5	2.6	3.7	4.9	6.0	7.0	8.1	9.1	10.1	11.0	12.0	12.9
MB05												
GDP index	2.13	3.8	5.5	7.2	8.9	10.5	12.1	13.6	15.1	16.6	18.0	19.4
Welfare index Q1-Q2	1.1	1.9	2.7	3.6	4.4	5.2	6.0	6.7	7.5	8.2	9.0	9.7
Unemployment rate	8.7	8.4	8.1	7.9	7.7	7.6	7.5	7.4	7.4	7.4	7.5	7.6
GINI index	38.7	38.7	38.8	38.9	39.0	39.1	39.2	39.3	39.4	39.5	39.6	39.8
Emission index	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3
Energy demand index	1.5	2.7	3.9	5.0	6.2	7.2	8.3	9.3	10.2	11.1	11.9	12.7
Affordability index	6.8	7.2	7.5	7.9	8.3	8.8	9.3	9.9	10.5	11.2	11.9	12.7
Activity index-Primary	4.5	8.5	12.4	16.1	19.6	22.8	25.9	28.7	31.3	33.6	35.7	37.6
Activity index–Industry	0.9	1.9	2.8	3.8	4.7	5.6	6.5	7.3	8.1	8.9	9.6	10.4
Activity index-Services	1.4	2.5	3.7	4.8	6.0	7.0	8.1	9.1	10.1	11.0	12.0	12.9
MB10												
GDP index	1.8	3.5	5.2	6.9	8.5	10.2	11.8	13.4	14.9	16.4	17.9	19.3
Welfare index Q1-Q2	0.6	1.4	2.3	3.1	4.0	4.8	5.6	6.5	7.3	8.1	8.9	9.6
Unemployment rate	9.2	8.9	8.6	8.3	8.1	7.9	7.8	7.7	7.6	7.6	7.6	7.6
GINI index	38.7	38.8	38.9	38.9	39.0	39.1	39.2	39.3	39.4	39.5	39.7	39.8
Emission index	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3
Energy demand index	1.1	2.3	3.5	4.7	5.9	7.0	8.0	9.1	10.0	10.9	11.8	12.6
Affordability index	7.1	7.4	7.8	8.2	8.6	9.0	9.5	10.1	10.6	11.3	11.9	12.7
Activity index-Primary	4.1	8.1	12.0	15.7	19.1	22.4	25.5	28.3	31.0	33.4	35.5	37.5
Activity index–Industry	0.8	1.8	2.7	3.7	4.6	5.5	6.4	7.2	8.1	8.8	9.6	10.3
Activity index-Services	1.1	2.2	3.4	4.6	5.7	6.8	7.9	8.9	10.0	10.9	11.9	12.8
MB15												
GDP index	1.4	3.0	4.7	6.4	8.0	9.7	11.3	12.9	14.5	16.0	17.4	18.9
Welfare index Q1-Q2	0.1	0.9	1.7	2.5	3.4	4.3	5.1	6.0	6.8	7.6	8.4	9.2
Unemployment rate	9.8	9.5	9.3	9.0	8.7	8.5	8.3	8.2	8.1	8.1	8.0	8.0
GINI index	38.7	38.8	38.9	39.0	39.1	39.1	39.2	39.3	39.5	39.6	39.7	39.9
Emission index	1.0	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.3
Energy demand index	0.7	1.9	3.1	4.2	5.4	6.5	7.6	8.7	9.6	10.6	11.4	12.2
Affordability index	7.4	7.7	8.1	8.4	8.9	9.3	9.8	10.3	10.9	11.5	12.2	12.9
Activity index-Primary	3.5	7.5	11.3	15.0	18.4	21.7	24.8	27.6	30.3	32.6	34.8	36.7
Activity index–Industry	0.7	1.6	2.6	3.5	4.4	5.3	6.2	7.0	7.9	8.7	9.4	10.2
Activity index-Services	0.7	1.9	3.0	4.2	5.3	6.4	7.5	8.6	9.6	10.6	11.6	12.5
MB20												
GDP index	1.0	2.6	4.2	5.9	7.5	9.1	10.7	12.3	13.8	15.3	16.8	18.5
Welfare index Q1-Q2	-0.4	0.3	1.1	1.9	2.7	3.6	4.4	5.2	6.1	6.9	7.7	8.7
Unemployment rate	10.4	10.1	9.9	9.7	9.4	9.2	9.1	8.9	8.8	8.7	8.7	8.4
GINI index	38.7	38.8	38.9	39.0	39.1	39.2	39.3	39.4	39.5	39.6	39.8	39.9
Emission index	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.3	1.3
Energy demand index	0.3	1.4	2.6	3.7	4.9	6.0	7.0	8.0	9.0	10.0	10.9	11.5
Affordability index	7.6	8.0	8.3	8.7	9.1	9.6	10.1	10.6	11.2	11.8	12.5	13.1
Activity index-Primary	3.0	6.9	10.6	14.2	17.6	20.8	23.7	26.5	29.1	31.5	33.7	35.7
Activity index–Industry	0.6	1.5	2.4	3.3	4.2	5.1	5.9	6.8	7.6	8.3	9.1	9.9
Activity index-Services	0.4	1.5	2.6	3.7	4.8	5.9	7.0	8.0	9.0	10.1	11.1	12.2

Table 1.19 – Results for the second block of simulations.

Period	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
TAX - MB05												
GDP index	2.1	3.8	5.5	7.2	8.9	10.5	12.0	13.6	15.1	16.5	17.9	19.3
Welfare index Q1-Q2	1.2	1.9	2.7	3.5	4.3	5.1	5.9	6.7	7.5	8.2	8.9	9.6
Unemployment rate	8.6	8.4	8.1	7.9	7.7	7.6	7.5	7.4	7.4	7.5	7.5	7.6
GINI index	38.6	38.7	38.8	38.9	39.0	39.1	39.2	39.3	39.4	39.5	39.6	39.8
Emission index	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3
Energy demand index	1.5	2.6	3.8	5.0	6.1	7.2	8.2	9.2	10.2	11.0	11.9	12.6
Affordability index	6.8	7.2	7.5	7.9	8.3	8.8	9.3	9.9	10.5	11.2	11.9	12.7
Activity index-Primary	4.5	8.5	12.4	16.1	19.5	22.8	25.8	28.6	31.2	33.6	35.7	37.5
Activity index–Industry	0.9	1.9	2.8	3.8	4.7	5.6	6.5	7.3	8.1	8.9	9.6	10.3
Activity index-Services	1.4	2.5	3.7	4.8	5.9	7.0	8.1	9.1	10.1	11.0	11.9	12.8
TAX - MB10												
GDP index	1.8	3.5	5.2	6.8	8.5	10.1	11.7	13.2	14.7	16.2	17.7	19.1
Welfare index Q1-Q2	0.9	1.7	2.5	3.2	4.0	4.8	5.6	6.4	7.2	8.0	8.7	9.4
Unemployment rate	9.0	8.8	8.5	8.3	8.1	8.0	7.8	7.8	7.7	7.7	7.7	7.8
GINI index	38.6	38.7	38.8	38.9	39.0	39.1	39.2	39.3	39.4	39.5	39.7	39.8
Emission index	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3
Energy demand index	1.1	2.3	3.5	4.6	5.7	6.8	7.9	8.9	9.8	10.8	11.6	12.4
Affordability index	7.1	7.4	7.8	8.1	8.6	9.0	9.5	10.1	10.6	11.3	11.9	12.7
Activity index-Primary	4.0	8.0	11.8	15.5	18.9	22.2	25.2	28.0	30.6	33.0	35.2	37.1
Activity index–Industry	0.8	1.7	2.7	3.6	4.5	5.4	6.2	7.1	7.9	8.7	9.4	10.1
Activity index-Services	1.2	2.3	3.4	4.6	5.7	6.7	7.8	8.8	9.8	10.8	11.7	12.7
TAX - MB15												
GDP index	1.5	3.1	4.7	6.3	7.9	9.5	11.1	12.6	14.2	15.6	17.1	18.5
Welfare index Q1-Q2	0.6	1.3	2.1	2.8	3.6	4.4	5.2	6.0	6.7	7.5	8.2	9.0
Unemployment rate	9.5	9.3	9.1	8.9	8.7	8.5	8.4	8.3	8.2	8.2	8.2	8.2
GINI index	38.6	38.7	38.8	38.9	39.0	39.1	39.2	39.3	39.4	39.6	39.7	39.9
Emission index	1.0	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.3	1.3
Energy demand index	0.6	1.8	2.9	4.1	5.2	6.3	7.3	8.3	9.3	10.2	11.0	11.8
Affordability index	7.4	7.7	8.0	8.4	8.8	9.3	9.8	10.3	10.9	11.5	12.2	12.9
Activity index-Primary	3.4	7.3	11.0	14.6	18.0	21.2	24.2	27.0	29.6	31.9	34.0	35.9
Activity index–Industry	0.7	1.6	2.5	3.4	4.2	5.1	5.9	6.7	7.5	8.3	9.0	9.8
Activity index-Services	0.9	2.0	3.1	4.2	5.3	6.3	7.4	8.4	9.4	10.3	11.3	12.2
TAX - MB20												
GDP index	1.2	2.7	4.2	5.8	7.4	8.9	10.4	11.9	13.4	14.8	16.3	17.9
Welfare index Q1-Q2	0.3	1.0	1.7	2.4	3.1	3.9	4.6	5.3	6.1	6.8	7.6	8.4
Unemployment rate	9.9	9.8	9.6	9.4	9.3	9.2	9.1	9.0	9.0	8.9	8.9	8.7
GINI index	38.6	38.7	38.8	38.9	39.0	39.1	39.2	39.3	39.4	39.6	39.7	39.9
Emission index	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Energy demand index	0.2	1.3	2.4	3.5	4.6	5.6	6.6	7.6	8.5	9.4	10.3	10.9
Affordability index	7.6	7.9	8.3	8.7	9.1	9.6	10.1	10.6	11.2	11.8	12.5	13.1
Activity index-Primary	2.9	6.6	10.3	13.7	17.0	20.1	22.9	25.6	28.1	30.4	32.5	34.5
Activity index–Industry	0.6	1.4	2.3	3.1	3.9	4.8	5.6	6.3	7.1	7.8	8.5	9.3
Activity index-Services	0.6	1.7	2.7	3.8	4.8	5.8	6.8	7.8	8.8	9.7	10.7	11.7

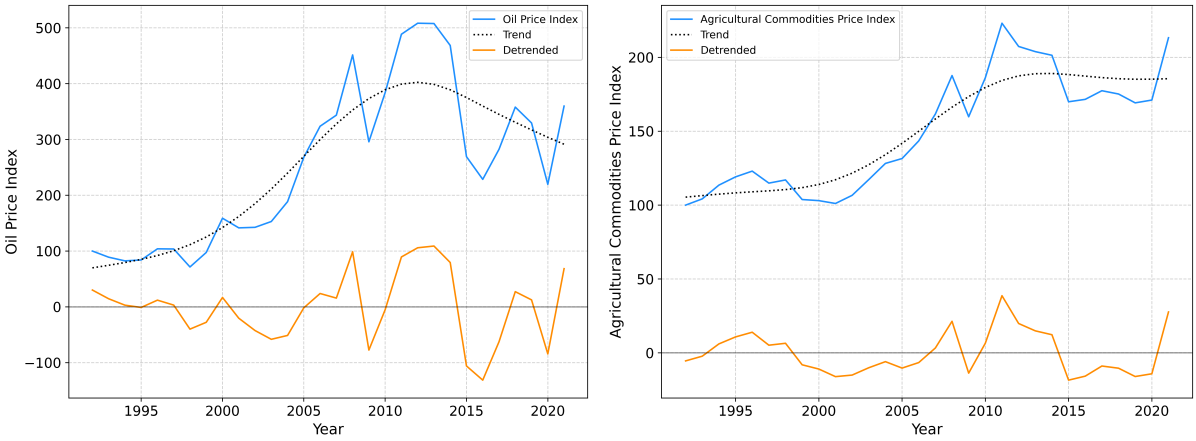
Table 1.20 – Results for the third block of simulations.

Period	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
PIP												
GDP index	1.7	3.4	5.2	6.9	8.5	10.2	11.8	13.4	15.0	16.5	18.0	19.4
Welfare index Q1-Q2	0.5	1.4	2.2	3.0	3.9	4.7	5.5	6.4	7.2	8.0	8.8	9.5
Unemployment rate	9.3	9.0	8.7	8.5	8.3	8.1	8.0	7.9	7.8	8.9	8.9	9.0
GINI index	38.7	38.8	38.9	39.0	39.1	39.2	39.3	39.4	39.5	39.7	39.9	40.1
Emission index	1.0	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.3	1.3
Energy demand index	1.0	2.2	3.4	4.6	5.7	6.8	7.8	8.8	9.7	10.6	11.5	12.2
Affordability index	7.2	7.5	7.9	8.3	8.7	9.2	9.7	10.3	10.9	11.5	12.2	13.1
Activity index-Primary	4.0	8.0	11.9	15.5	18.9	22.1	25.0	27.8	30.2	32.5	34.4	36.1
Activity index–Industry	0.8	1.7	2.7	3.6	4.5	5.4	6.3	7.1	7.9	8.7	9.4	10.2
Activity index-Services	1.0	2.2	3.4	4.5	5.6	6.7	7.8	8.8	9.8	10.8	11.8	12.7
PIP FLEX												
GDP index	2.3	4.0	5.6	7.3	9.0	10.6	12.2	13.7	15.2	16.6	18.1	19.5
Welfare index Q1-Q2	1.3	2.0	2.8	3.6	4.4	5.1	5.9	6.7	7.4	8.1	8.8	9.5
Unemployment rate	8.5	8.3	8.1	7.9	7.7	7.6	7.6	7.6	7.6	8.8	8.9	9.0
GINI index	38.7	38.8	38.8	38.9	39.0	39.1	39.2	39.4	39.5	39.7	39.8	40.0
Emission index	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.3
Energy demand index	1.6	2.7	3.8	4.9	6.0	7.1	8.1	9.0	9.9	10.8	11.6	12.3
Affordability index	6.8	7.1	7.5	8.0	8.4	9.0	9.5	10.1	10.8	11.5	12.3	13.1
Activity index-Primary	4.6	8.6	12.5	16.1	19.5	22.6	25.5	28.2	30.6	32.8	34.7	36.3
Activity index–Industry	0.9	1.9	2.8	3.7	4.7	5.5	6.4	7.2	8.0	8.8	9.5	10.2
Activity index-Services	1.5	2.6	3.7	4.8	5.9	7.0	8.0	9.0	10.0	10.9	11.8	12.7
PIC												
GDP index	1.7	3.4	5.2	6.9	8.6	10.2	11.8	13.3	14.8	16.3	17.6	19.0
Welfare index Q1-Q2	0.5	1.3	2.2	3.0	3.9	4.7	5.5	6.3	7.1	7.8	8.5	9.2
Unemployment rate	9.3	9.0	8.7	8.4	8.2	8.1	8.0	7.9	7.9	8.0	8.1	8.3
GINI index	38.7	38.8	38.9	38.9	39.0	39.1	39.2	39.3	39.5	39.6	39.8	40.0
Emission index	1.0	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2
Energy demand index	1.0	2.3	3.5	4.7	5.9	6.9	8.0	9.0	9.9	10.7	11.4	12.1
Affordability index	7.2	7.5	7.9	8.3	8.7	9.2	9.7	10.3	10.9	11.5	12.2	12.9
Activity index-Primary	3.7	7.5	11.0	14.3	17.3	20.1	22.6	24.8	26.7	28.3	29.6	30.7
Activity index–Industry	0.8	1.8	2.8	3.8	4.7	5.6	6.5	7.4	8.2	8.9	9.7	10.4
Activity index-Services	1.0	2.2	3.4	4.6	5.7	6.8	7.9	8.9	9.9	10.8	11.7	12.5
PIC FLEX												
GDP index	2.3	4.0	5.7	7.4	9.1	10.7	12.3	13.8	15.3	16.7	18.0	19.2
Welfare index Q1-Q2	1.3	2.1	2.9	3.7	4.5	5.3	6.1	6.8	7.6	8.2	8.9	9.5
Unemployment rate	8.5	8.2	8.0	7.8	7.6	7.5	7.4	7.4	7.5	7.6	7.8	8.0
GINI index	38.7	38.7	38.8	38.9	39.0	39.1	39.2	39.3	39.4	39.6	39.7	39.9
Emission index	1.0	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Energy demand index	1.6	2.8	4.0	5.2	6.3	7.4	8.4	9.3	10.2	11.0	11.7	12.4
Affordability index	6.7	7.1	7.5	7.9	8.4	8.8	9.4	10.0	10.6	11.3	12.0	12.8
Activity index-Primary	4.4	8.2	11.7	15.0	18.0	20.7	23.2	25.4	27.3	28.9	30.2	31.2
Activity index–Industry	1.0	2.0	3.0	4.0	4.9	5.8	6.7	7.5	8.3	9.1	9.8	10.5
Activity index-Services	1.5	2.7	3.8	5.0	6.1	7.2	8.2	9.2	10.2	11.1	11.9	12.7

Appendix H. Calibration of the Shock on the International Prices

To calibrate these shocks, this paper increase the estimated price of the corresponding commodity in 2030, and, with that reference, it increases the growth rate of the price to achieve the shocked final price. To calculate the measure of the shock on the 2030 price I use the Hodrik-Prescott filter with parameter 100 to detrend the series and identify the shocks. Finally, the average size of all positive shocks is measured. Figure 1.13 plots the regular IMF series of oil and agricultural commodities price and the detrended version.

Figure 1.11 – International price series of oil and agricultural commodities.



(a) Oil **(b)** Commodities

Note: International price series from the IMF. Trends were removed using the HP filter with a parameter of 100.

Appendix I. Supplementary data

Supplementary data to this article can be found online at: Link to supplementary data.

Chapter 2: Driving Change: Assessing the Impact of EV-promoting Policies in Argentina

Abstract

To assess the impact of policies promoting electric vehicles (EVs), I estimate a tractable dynamic model of the automobile market including both primary and secondary markets, a charging-service investment sector, and indirect network effects, using data from Argentina. I evaluate three counterfactual regimes: (i) subsidies to new EVs and charging infrastructure, (ii) the welfare-maximizing EV subsidy under alternative externalities and tax settings, (iii) a ban on new internal combustion engine (ICE) sales. Under purchase subsidies and the baseline EV prices, residential EV shares rise to 11.88% at a 30% subsidy. Network effects can cut penetration by up to 10.63 p.p. for a 30% subsidy. Emissions fall from 12.99 to 10.84 MTCO2eq while battery disposals jump to 27.09 thousand per year. The results show that the tax regime used to fund EV promotion is not distributionally neutral and plays a central role in shaping the policy's equity implications. Charging-infrastructure subsidies alone have negligible impact. The optimal EV subsidy is 29% under the status quo, 24% in the absence of environmental externalities, 20% without network effects, 17% when car taxes are not considered, and 25% when VAT is removed. A ban on new ICE-sales requires EV prices to drop by 37% to preserve welfare (44% to maintain carless-household shares), fully electrifying the fleet, cutting emissions to 2.72 MTCO2eq, but surging battery waste to 127 thousand units.

Keywords: Electric vehicles, Transportation, Welfare, Climate Change
JEL Codes: C63, D12, H23, L91

2.1 Introduction

Transportation activities account for nearly a quarter of global emissions and road transportation is the most polluting one in this group (IEA, 2023b). Therefore, decarbonizing the automotive fleet is essential for mitigating climate change. Electric vehicles (EVs) have been widely recognized as a promising alternative to replace conventional internal combustion engine (ICE) vehicles. This is particularly true considering the downward trend in the price of lithium-ion batteries and the ambitious targets set by governments and the international community to combat climate change (IEA, 2025b). However, despite being available for more than a decade, EVs still represent a small fraction of the automotive fleet in most countries[13]. Particularly, in developing countries, the proportion of electric vehicles remains very limited (Li et al., 2021).

Two main factors contribute to these results. First, EVs have a higher upfront cost compared to ICE vehicles (Sheldon et al., 2023). Second, there are infrastructure constraints in the battery charging system (Luo et al., 2023). Also, according to Li et al. (2017a), the market for EVs exhibits indirect network effects due to the interdependence between the adoption of this technology and the investments in charging stations. This leads to feedback loops that impact the diffusion process of EVs. Particularly, in many developing countries, the share of EVs in the automobile fleet and the amount of charging stations is particularly small. In this context, countries worldwide have implemented policies to encourage the adoption of EVs. Three main policies can be identified: (i) subsidies for new EVs (Sheldon and Dua, 2020), (ii) reductions in the purchase tax for EVs (Liu, 2023), and (iii) reductions in car and ownership taxes for EVs (ACEA, 2022). Additionally, some countries have set bans on the sales of new ICE vehicles between 2030 and 2050 (IEA, 2023c).

The objective of this article is to assess the impact of different policy scenarios on EV penetration, emissions, battery disposals, household welfare, and fiscal revenue. The research questions are: What is the impact of subsidizing new EVs and new charging infrastructure on adoption, emissions, battery disposals, welfare, and fiscal outcomes? What is the welfare-maximizing subsidy for new EVs, and how does it change when environmental externalities, network externalities, and tax policies change? If banning new ICE vehicle sales is considered, by how much should EV prices decrease to maintain pre-ban household welfare? The case of study is Argentina. Argentina constitutes an interesting case study, as it is a developing country in which car ownership plays a central role due to infrastructure limitations (World Bank, 2023). At the same time, Argentina exhibits a very low penetration of electric vehicles and severe infrastructure constraints in the charging services market (AFAC, 2024).

Modeling the automobile market is particularly challenging due to the exchange alternatives provided by the presence of primary and secondary markets. In these markets, consumers face a large number of manufacturers and models of new cars, but they also have a wide variety of options for used cars. This results in complex patterns of vehicle trade. Additionally, there are related markets whose conditions impact the performance of the automobile market, such as the battery charging market and the fuel market.

I develop and estimate a dynamic structural model that considers trading patterns

[13]Electric vehicles have been around for more than 10 years in the mass market. For example, the Smart Electric was launched in 2007, the Nissan Leaf has been on the market since 2010, and the Tesla Model S has been available since 2012.

in the primary and secondary automobile markets of the type described in Gillingham et al. (2022). There are two distinctive aspects of this model: First, the modelling of a battery charging service market characterized by an optimal investment problem. This market interacts with consumer decisions regarding EVs and the amount of kilometers each household drives. Second, the introduction of indirect network effects arising from the interdependence between EV adoption and investment decisions regarding charging infrastructure. These effects can limit EV adoption and erode the effectiveness of the EV-promoting policies. Only two types of vehicles are considered (EVs and ICE vehicles), the prices of new cars and fuel are given, and there is persistent income heterogeneity among households. The model is solved for the stationary equilibrium and provides ownership distributions and equilibrium prices for used cars and charging services. The model is calibrated for Argentina using a minimum distance estimator to reproduce different statistics from the automobile market and household driving behavior. The dynamic structure of the model captures interactions between new and used vehicle markets, which is crucial given that low-income households participate more actively in secondary markets, while high-income households primarily purchase new vehicles (Gillingham et al., 2022; Gavazza et al., 2014). Because the policies analyzed in this paper subsidize only new electric vehicles, their effects on low-income households operate mainly through indirect channels via the used-car market.

I use the calibrated parameters to simulate three blocks of counterfactual scenarios. In the first block, I quantify the effects of subsidies to new EVs ($s \in [0, 0.3]$) and charging infrastructure ($s_c \in [0, 0.3]$), both with and without network effects. To account for price dynamics, I consider three EV price scenarios: (i) baseline, (ii) a 7% reduction, and (iii) a 15% reduction following (IEA, 2025b). I find that subsidies to new EVs substantially encourage adoption: the residential EV share rises from 0.32% in the baseline to 11.88% at a 30% subsidy, while the share of households without a car falls from 60.41% to 58.09%. Network effects become more important as the subsidy increases. When network effects operate and households care about infrastructure availability, EV market penetration falls by up to 10.63 percentage points at a 30% subsidy with respect to the no network effects situation. Charging costs and the number of charging stations both increase significantly with the subsidy. Carbon emissions decline from 12.99 to 10.84 MTCO2eq, while battery disposals increase from 0.97 to 27.09 thousand per year. Fiscal revenues remain stable at around 1.24% of GDP, and average household welfare increases from 4.25 to 4.32 thousand USD. The results also show that the tax regime used to finance EV promotion is not distributionally neutral and plays a central role in shaping the policy's equity implications. Lower EV prices further amplify EV adoption and the magnitude of these effects. By contrast, subsidies to charging infrastructure alone have limited effects. These results indicate that the primary barrier to EV adoption is the high upfront cost of vehicles and that charging infrastructure responds mainly to increases in EV adoption rather than to direct subsidies.

In the second block, I estimate the welfare-maximizing subsidy to new EVs. The optimal subsidy equates marginal social benefits with marginal social costs. Benefits include (i) reduced noise and local air pollution and (ii) lower travel costs due to EVs' higher efficiency in cost per kilometer. Social costs arise from the tax burden required to fund the subsidy. Under the status quo, the optimal subsidy equals 29%, yielding an EV share of 9.36%, a no-car share of 58.62%, charging costs of 48.16 USD cents per kWh, emissions of 11.28 MTCO2eq, and battery disposals of 21.03 thousand per year. Fiscal revenue reaches 1.26% of GDP, and average welfare rises to 4.32 thousand USD. Excluding en-

vironmental externalities reduces the optimal subsidy to 24%, lowering the EV share to 4.05%, charging costs to 39.88 USD cents per kWh, emissions to 12.27 MTCO2eq, battery disposals to 8.88 thousand, and average welfare to 4.32 thousand USD. Excluding network externalities further reduces the subsidy to 20%. Estimating the optimal subsidy jointly with the elimination of car taxes or VAT yields optimal subsidies of 25% and 17%, respectively. Eliminating car taxes generates the highest EV penetration, with an EV share of 29.33%, a no-car share of 53.86%, charging costs of 63.24 USD cents per kWh, emissions of 8.13 MTCO2eq, battery disposals of 75.14 thousand, fiscal revenues declining to 1.10% of GDP, and average welfare rising to 5.17 thousand USD.

In the third block, I simulate a ban on new ICE vehicle sales by imposing prohibitively high transaction costs. To preserve pre-ban household welfare, EV prices must fall by 37%, which fully electrifies the fleet, raises the no-car share to 74.35%, increases charging costs to 72.71 USD cents per kWh, and substantially expands the number of charging stations. Emissions decline to 2.72 MTCO2eq, battery disposals reach 127.27 thousand per year, and fiscal revenues fall to 0.57% of GDP. Alternatively, to maintain the pre-ban share of carless households, EV prices must decline by 44%. In this case, charging costs rise to 79.21 USD cents per kWh, the number of charging stations increases further, emissions reach 3.81 MTCO2eq, battery disposals rise to 201.78 thousand, fiscal revenues equal 0.74% of GDP, and average welfare increases to 5.98 thousand USD.

The paper proceeds as follows. Section 2 reviews the related literature, Section 3 presents the institutional context, Section 4 describes the model, Section 5 discusses the calibration strategy, Section 6 presents the counterfactual exercises and results, and Section 7 concludes. Appendix A reviews the evolution of automobile market modeling. Appendix B reports Argentine market and driving statistics. Appendix C details exogenous parameters and data sources. Appendix D describes the estimation methodology. Appendix E provides proofs of the propositions. Appendix F presents an illustrative example of reallocating resources toward public transportation. Appendix G reports the calculation of car prices. Appendix H presents the sensitivity analysis for the productivity of the charging infrastructure sector.

2.2 Related Literature

This article contributes to several strands of the literature. First, to the literature on durable goods that has studied the role of secondary markets in the allocation of new and used goods (Manski, 1980; Rust, 1985; Stolyarov, 2002). Gavazza et al. (2014) provide a quantitative analysis of the allocative and welfare effects of secondary car markets. Gavazza and Lanteri (2021) study the equilibrium dynamics in car markets after aggregate credit shocks. Gillingham et al. (2022) introduce a dynamic equilibrium model of the car market with heterogeneous consumers to study policies related to the Danish automobile market. This article contributes to this literature by extending traditional models to include EVs and the modellization of the corresponding battery charging market accounting for indirect network effects. The computation of the equilibrium is possible using a fast and robust algorithm based on the Newton method developed by Gillingham et al. (2022), which can be nested with different estimation procedures.

Second, this article contributes to the literature studying the energy transition with a focus on the electrification of the automotive fleet. This article is linked to the work

of Holland et al. (2016), who combine a theoretical discrete choice model of vehicle purchase, an econometric analysis of electricity emissions, and the AP2 air pollution model to estimate the geographical variation in the environmental benefits of driving electric vehicles. It is also related to Sheldon et al. (2023), who evaluate the federal subsidy program for electric vehicles in the United States. Reynaert et al. (2025) develop and estimate a joint equilibrium model of the German electricity and automobile markets, highlighting the role of intraday variation in generation costs and pollution. They show that, under Germany's current pricing scheme, EVs impose a substantial pecuniary externality on electricity costs, while exposing charging to wholesale price variation eliminates this externality and fosters EV adoption. This article contributes to the literature by examining the effects of subsidizing EVs in a developing country context, using Argentina as a case study. It evaluates the impact of a subsidy to new EVs and a complementary subsidy for charging infrastructure. The framework is then used to estimate the optimal EV subsidy. In addition, it analyzes the implications of banning ICE vehicles, a policy that has received limited attention in the literature.

Finally, this article contributes to a novel literature that studies the role of infrastructure constraints and the role of charging infrastructure for the adoption of electric vehicles. In this regard, the work of Arlt and Astier (2023) studies whether various activities (parking lots, gas stations, shopping malls, restaurants, etc.) have incentives to install and operate EV charging stations. They also construct a simple model of imperfect competition in which these activities can invest in a charging station to attract additional customers from their competitors. Schwab et al. (2022) use a multilevel equilibrium model to study the cost of charging EVs for different levels of adoption and different charging strategies, considering their impact on the electricity sector. Li et al. (2017a) studies the impact of network effects in the adoption of EVs with data from 353 metro areas from 2011 to 2013. This article contributes to this literature by including the problem of charging infrastructure development in the context of standard automobile market models. Also, this article contributes by modelling the interdependence of EV adoption with the investment in charging infrastructure.

2.3 The Residential Automobile Market in Argentina

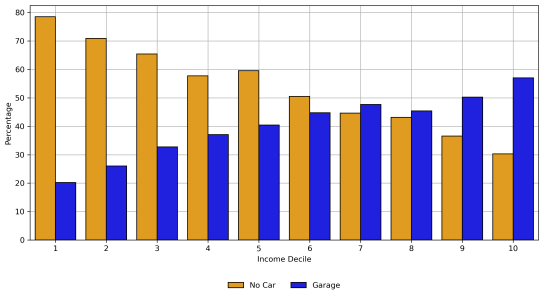
This section has two main objectives. First, it introduces the primary datasets used in this paper. Second, it presents descriptive information about the residential vehicle fleet and key characteristics of car-owning households.

I combine two main datasets. The first is the 2017/2018 National Household Survey (ENGHo), published by INDEC (Argentina's National Institute of Statistics and Census). The ENGHo provides detailed data on household income, expenditure, and other sociodemographic features. Within ENGHo, the Equipment Survey module reports ownership of durable goods, including vehicles. This dataset allows to identify car ownership profiles, fuel expenditure patterns, the amount of kilometers driven, and link these aspects to household characteristics such as income. The second source is the Annual Vehicle Fleet Report published by AFAC (the Argentine Association of Automotive Manufacturers). This report offers updated information (through 2024) on the size and composition of the national vehicle fleet.

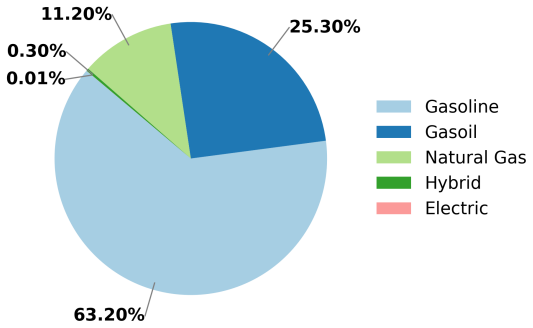
Using the ENGHo as a baseline, I update three key variables to 2024: vehicle ex-

penditure, fuel expenditure, and kilometers driven. To update these variables, I rely on observed price variations between the survey year and 2024 to estimate changes in household demand for fuel and vehicles. Appendix B explains the methodology in detail and provides additional context on Argentina's automobile market. Figure 2.1 presents five key variables that describes the Argentine automobile market and household characteristics, while Figure 2.2 shows regional data on vehicle counts and the vehicle-to-person ratio.

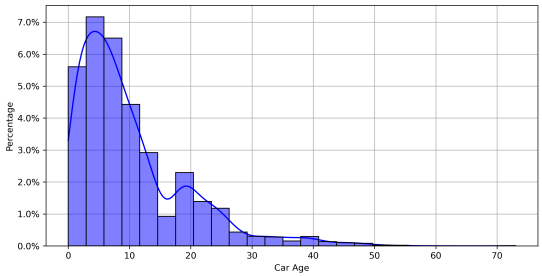
Figure 2.1 – Household and vehicle fleet characteristics.



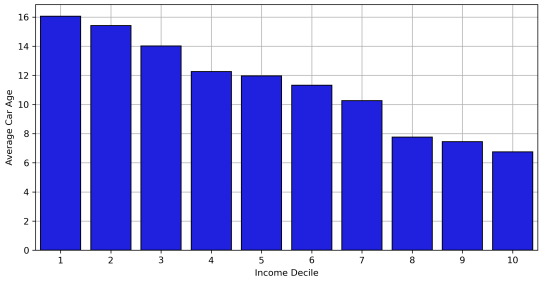
(a) Share of households without a car and with a private garage by income decile



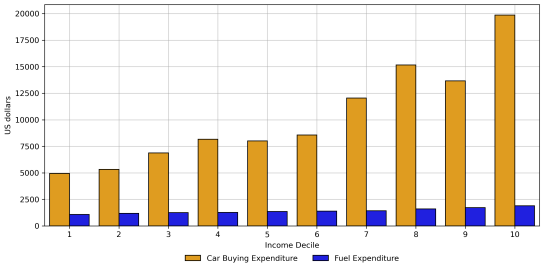
(b) Vehicle distribution by fuel type



(c) Histogram of car ages



(d) Average car age by income decile



(e) Fuel and car purchase expenditure by income decile

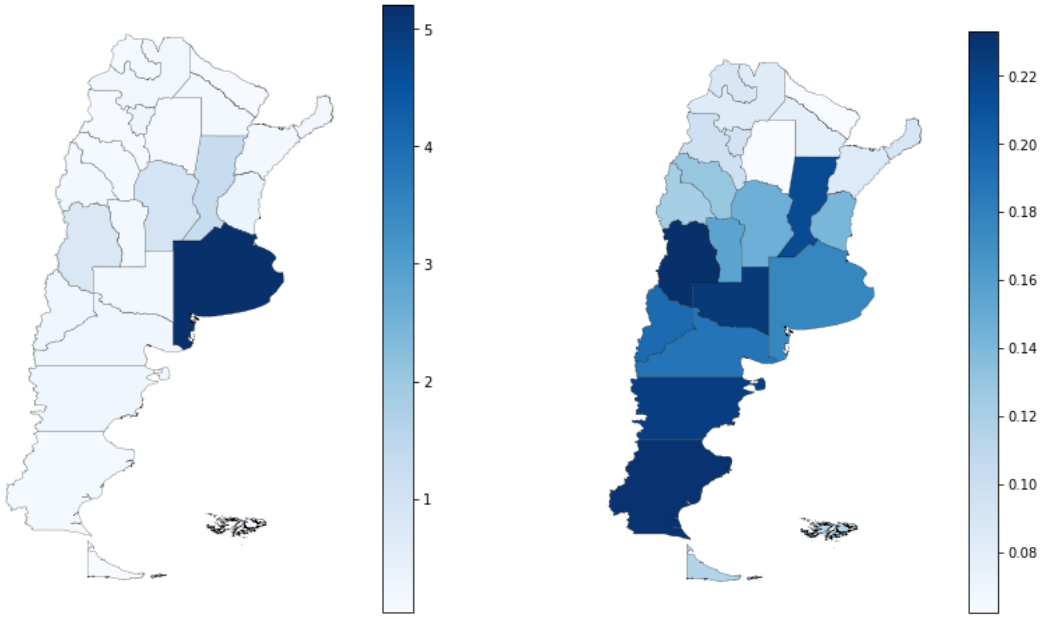
Note: Figure 2.1 presents five plots illustrating the characteristics of the Argentine automobile market and households. Each plot highlights an aspect of the vehicle fleet or a household characteristics: (a) the share of households without a car and the share of households with a private garage by income decile, (b) the automobile fleet distribution by fuel type, (c) the distribution of car ages, (d) the average car age by income decile, and (e) the average fuel and car purchase expenditure by income decile. Source: Elaborated from ENGHo data and the 2024 AFAC annual report. Note: The values corresponding to panel (e) are an update of those estimated from the ENGHo. Appendix B provides information on the methodology used to update those variables.

The 2024 Annual Vehicle Fleet Report by AFAC reports that Argentina's vehicle fleet totals 15.56 million units. Of this total, 81.2% are automobiles, 14.7% are light or utility vehicles, and the remaining share consists of heavy vehicles. Figure 2.1(a) shows that the share of households without a car (orange bars) decreases as income increases. In the low-

est income decile, 78.5% of households do not own a car, while in the highest decile, this share drops to 30.2%. On average, 53.3% of households do not own a car. In contrast, the share of households with a private garage increases with income. Only 20.2% of the poorest households have a private garage, compared to 56.9% of the wealthiest households. The average share of households with a private garage is 40.4%. Figure 2.1(b) indicates that most vehicles run on gasoline (63.2%), followed by gasoil (25.3%) and natural gas (11.2%). Electric vehicles account for only 0.01% of the fleet. Regarding vehicle age, the fleet's average age is 10.11 years. However, wealthier households own newer vehicles. In the highest income decile, the average vehicle age is 6.75 years, whereas in the lowest decile, it rises to 16.1 years. Fuel and car purchase expenditures also increase with income. Households in the highest income decile spend, on average, 1,891.4 US dollars per year on fuel, while those in the lowest decile spend 1,082.7 US dollars. Among households that purchased a car, the wealthiest decile spends an average of 19,867.85 US dollars, while the poorest spends 4,951.1 US dollars. These figures include both new and used vehicles.

Figure 2.2 presents the regional distribution of the vehicle fleet and the number of cars per person in each Argentine province.

Figure 2.2 – Information on the Argentine residential vehicle fleet by province.



(a) Number of vehicles **(b)** Vehicles per person

Note: Figure 2.2 presents two maps showing the territorial data of Argentina with provincial division. Each map is assigned one of two variables: (a) Number of vehicles (millions), (b) Vehicles per person. Darker colors are associated with higher variable values, while lighter colors correspond to lower values. Source: Elaborated from ENGHo data and the 2024 AFAC annual report. Note: These maps were constructed based on data from the Equipment Survey and the Household Expenditure Survey included in the 2017/2018 ENGHo. The first survey was necessary to identify households with cars and their ages, while the second was used as a weighting factor to extrapolate sample results. The values for the total fleet were taken from the 2024 AFAC annual report and distributed according to regional results obtained from the ENGHo.

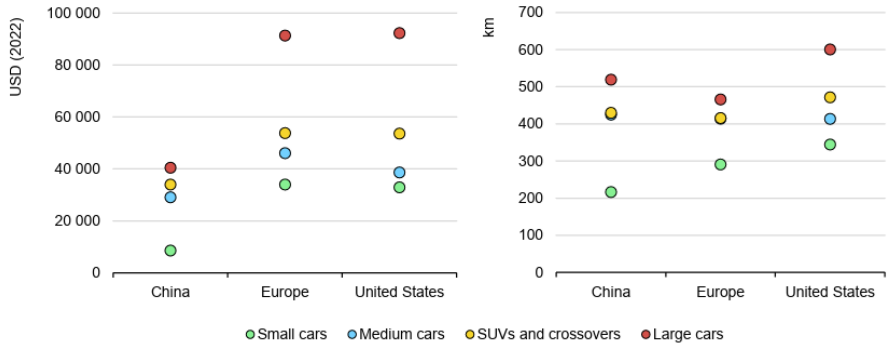
Figure 2.2 shows that the majority of the automotive fleet is concentrated in the area of the Province of Buenos Aires and the Autonomous City of Buenos Aires. This region is followed in importance by Córdoba, Santa Fe, and Mendoza. This result is intuitive since these regions are where the majority of the Argentine population is concentrated. However, in terms of density, the most relevant provinces are those located in the south

and center of the country, with the least relevant being those in the north. This is mainly due to the large distances between towns in the southern region of Argentina, which requires the use of personal vehicles.

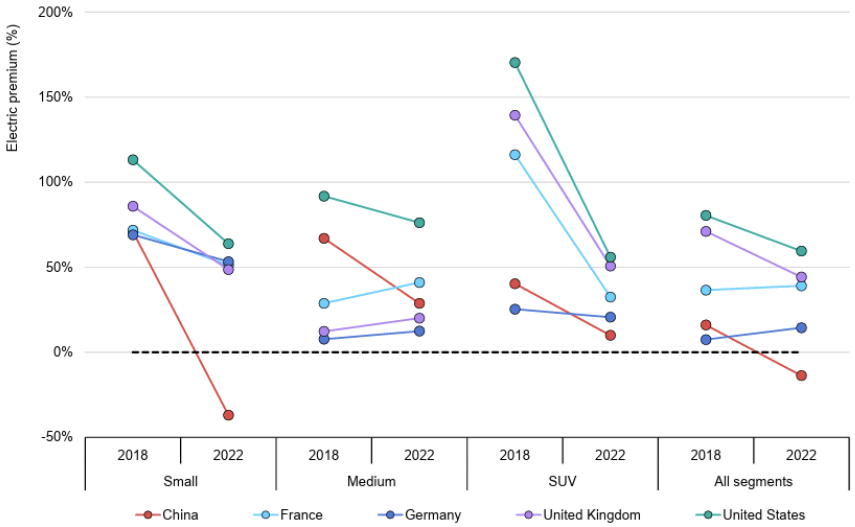
An important factor shaping EV adoption is the price gap between ICE vehicles and EVs. I calculate ICE prices in Argentina using two datasets: (i) the 2023 AFAC report, which provides the distribution of new vehicles across three price segments: Low, Medium, and High, and (ii) the dataset from the Argentine Automobile Trade Association, which reports final retail prices for all models sold in the country. For EV prices, I rely on the EVDatabase platform[14]. Appendix G details the full price construction. The average ICE price in Argentina in 2023 was USD 20,422. The low-price segment averaged USD 15,996, the medium segment USD 26,237, and the high segment USD 44,513. EVs remain more expensive: the average EV price reached USD 39,796, with segment averages of USD 35,055, USD 45,918, and USD 66,175, respectively. These results imply an average ICE–EV price gap of 48.6%. The gap varies across segments, reaching 54.3% in the low-price market, 42.8% in the medium segment, and 32.7% in the high segment. These values align with international evidence reported by IEA (2023c) and IEA (2024b). Figure 2.3 illustrates the IEA estimates for EV prices and the corresponding ICE–EV price gap.

[14]Consulted in December 2023.

Figure 2.3 – Information on the IEA estimated price of EVs and the corresponding price gap with ICEs.



(a) Sales-weighted average retail price (left) and driving range (right) of BEV passenger cars in selected countries, by size, in 2022.



(b) Price gap between the sales-weighted average price of conventional and electric cars in selected countries, before subsidy, by size, in 2018 and 2022.

Note: Panel (a) reports the sales-weighted average retail price and driving range of BEV passenger cars in selected countries in 2022, as estimated by IEA (2023c). Panel (b) reports the price gap between conventional ICE and electric vehicles in selected countries, before subsidies, in 2018 and 2022, as estimated by IEA (2024b).

Argentina's estimated price gap is in line with that of countries such as the United Kingdom and France. Prices, however, have decreased rapidly with the arrival of low- and medium-sized Chinese EVs, which in some cases are cheaper than ICE vehicles (IEA, 2025b). To account for this trend, I consider alternative EV price levels in the simulations.

2.4 The Model

Consider an economy populated by households differentiated by their income level, firms providing EV charging services, and a government. Households face a dynamic discrete choice problem regarding car ownership. Firms make decisions regarding capital accumulation and charging infrastructure operation. Finally, the government makes fiscal policy decisions concerning the automobile market.

A large body of research studies the automobile market using static discrete choice models, particularly to analyze the adoption of electric vehicles (Reynaert et al., 2025; Moraga-González et al., 2023; Springel, 2021; Petrin, 2002). For example, Reynaert et al.

(2025) develops a discrete choice model embedded in a joint equilibrium framework that links the German vehicle and electricity markets. The study quantifies how EV adoption feeds back into electricity prices and how different pricing regimes shape vehicle choices. Springel (2021) uses large-scale vehicle registry data from Norway and a two-sided market framework to evaluate EV subsidies and measure their effectiveness in the presence of network externalities.

In this paper, I model consumers' decisions through a dynamic discrete choice framework, motivated by the need to conduct a welfare analysis across income groups. Evidence shows that low-income households participate more actively in secondary vehicle markets, while high-income households tend to purchase new cars. A dynamic structure allows me to capture these interactions and the way policies propagate through both markets. As a result, policies targeting new EVs primarily affect low-income households indirectly, through the secondary market, especially because the simulated subsidies apply only to new vehicles. This mechanism aligns with findings in Gavazza et al. (2014) and Gillingham et al. (2022). Gavazza et al. (2014) shows that transaction costs substantially shape allocations in both new and used markets, with modest aggregate welfare effects but significant distributional consequences: low-income households experience large welfare losses when transaction costs rise. Gillingham et al. (2022) uses a dynamic discrete choice model to study Denmark's new-car registration tax and finds that lowering new-car taxes while increasing fuel taxes raises total welfare, boosts tax revenue, and reduces emissions. However, the policy does not constitute a Pareto improvement without compensating transfers, as households with long commutes lose while those with shorter commutes gain. Another reason to use a dynamic framework is that the subsidy policies assessed in this paper, as in Gillingham et al. (2022), apply only to new vehicles.

2.4.1 Households

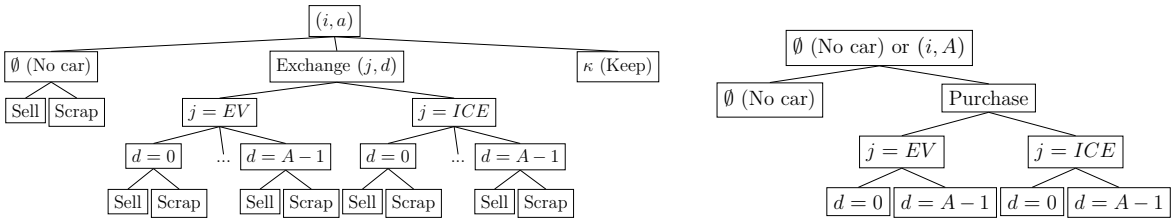
The structure of the household's dynamic problem. Households are differentiated by income level, which is permanent (households cannot change their income levels). There are τ households where $\tau \in \{\tau_1, \tau_2, \tau_3\}$[15] distributed according to a distribution f where f_τ is the proportion of households of type τ in the population. Vehicles differ in two dimensions: type i and age a. While this model could consider many types of vehicles, it focuses on $i \in \{\text{Electric } (EV), \text{ Internal Combustion Engine } (ICE)\}$. Age can take values $a \in \{1, ..., A\}$ where A represents the maximum age for a vehicle. It is assumed that from A onwards, the car cannot be used anymore and must be scrapped. Using data from the ENGHo 2017/18 as a reference, I set $A = 30$. See Apprendix B.

To properly specify the dynamic problem, it is necessary to define the household's state and decision space. At the beginning of the period, a household τ has three possible states: (i) owning a car (i, a), (ii) owning a car at the terminal age (i, A), or (iii) not owning a car $(\emptyset)$. Thus, the state of a household at the beginning of any period t is given by the vector (i, a) where $i \in \{\emptyset, EV, ICE\}$ denotes the model of car that the consumer owns at the start of the period, and $a \in \{\emptyset, 1, ..., A\}$ denotes its age. Now the decision space depends on the state of the household. For households that own a car (i, a), there are three decisions available: (i) exchange (i, a) for a different car (j, d), (ii) keep their car (κ) if $(a < A)$, or (iii) get rid of the car (i, a) and choose to stay without a car $(\emptyset)$. For those households without a car $(\emptyset)$ or in the state (i, A), the available

[15] τ_1 represents high-income households, τ_2 represents middle-income households, and τ_3 represents low-income households.

options are: (i) buy a car (i, a) or (ii) choose to stay without a car $(\emptyset)$. If the household's decision is to no longer continue with its car (either because it wants to exchange it for another or because it no longer wants to have a car), it can either sell it $(s = 0_s)$ or scrap it $(s = 1_s)$. Figure 2.4 presents decision trees for a household for each possible initial state.

Figure 2.4 – Decision tree according to household's initial state.



(a) Decision tree for households starting in the state (i, a)

(b) Decision tree for households starting in the state $(\emptyset)$ or in the state (i, A)

Note: Figure 2.4 illustrates the decision space. Note: EV: Electric vehicle; ICE: Inernal Combustion Engine; κ: Keep; $\emptyset$: No car.

Sequence of events. The sequence of events within a period describes the order in which households decide and how they transition from one period to another. There are three events happening between t to $t + 1$:

Event 1. Each consumer τ enters the period in one of three states: owning a car (i, a), owning a car at the terminal age (i, A), or having no car $(\emptyset)$.

Event 2. Household τ must decide, if it has a car, whether to exchange it for another, to keep it (κ), or to have no car $(\emptyset)$. If it has no vehicle or has a vehicle at terminal age, they must decide whether to remain without a car $(\emptyset)$ or buy one. If the household already has a car and chooses not to keep it, it must decide what to do with it: (i) sell the vehicle (1_s) or (ii) scrap it (0_s).

Event 3. Those who decided to have a car drive it throughout the period, and with probability α, the car ages normally from a to $a + 1$, and with probability $(1 - \alpha)$, it suffers a severe accident and becomes unusable (aging directly from a to A).

The state in which household τ ends the period will be the starting point for the next period.

The utility function. The state of each consumer at the beginning of each period t is defined by (i, a, ϵ) where $i \in \{\emptyset, EV, ICE\}$ and $a \in \{\emptyset, 1, \ldots, A\}$. Then, the utility function for household τ that enters the period in the state (i, a, ϵ) and decides to buy (j, d) is defined as follows:

$$U_\tau((i, a, \epsilon), (j, d)) = u_\tau(j, d, x_\tau) - \mu_\tau(\text{operating cost} + \text{transaction cost}) + \epsilon$$

Where μ_τ represents the marginal utility of money. Thus, multiplying total expenses (operating costs and transaction costs) by this parameter shows the disutility associated with these expenses. Likewise, the level of μ_τ is linked to the individual's wealth level: low values of μ_τ are associated with a higher income level, while higher values are associated with a lower income level. This is because a lower level of μ_τ weights less the total expenses in terms of utility.

$u_\tau(j, d, x_\tau)$ represents the utility derived by household τ from owning and driving the car (j, d) for x_τ kilometers. The utility function u_τ is decreasing in the age (d) and follows a functional form similar to the one used in Gillingham et al. (2022). Particularly, the functional form is: $u_\tau(j, d, x_\tau) = \psi^\tau - \rho^\tau d + (B^\tau - \lambda^\tau d)\log(x_\tau) - \mu_\tau P_j^f x_\tau$. It is possible to consider the sum of the first two terms on the right hand side of the previous equation to be the utility that the household gets from the pure ownership (and option value to drive) even if the household does not do any driving [16]. The remaining components are the net utility from driving, after deducting the cost of driving (translated into utility). I assume that for a household τ, both models i have the same parameters in the utility function. In other words, driving an EV or a ICE vehicle for x_τ kilometers gives the same utility u_τ (if they have the same age). In this setup, $x_\tau^* = \arg\max_{x_\tau}\{(B^\tau - \lambda^\tau a)\log(x_\tau) - \mu_\tau P_i x_\tau\}$ and the utility derived by the household from driving is $u_\tau(j, d, x_\tau^*)$. Note that the choice of x_τ^* depends on the prices per kilometer (p_j^f) of each car type j. I assume that the cost of refueling an ICE vehicle is given and, at that price, the household can demand as much fuel as desired. However, the charging cost of an EV is an endogenous variable.

For EVs, there is an additional term in the utility function. For this type of vehicles the utility function is $u_\tau(EV, d, x_\tau) = \psi^\tau - \rho^\tau d + (B^\tau - \lambda^\tau d)\log(x_\tau) - \mu_\tau P_{EV}^f x_\tau - ne_\tau(m)$ where:

$$ne(m) = \begin{cases} \eta(m - \bar{m})^2 & \text{if } m - \bar{m} \leq 0 \\ 0 & \text{if } m - \bar{m} > 0 \end{cases}$$

This last term, where $m \in [0, 1]$, accounts for indirect network effects that may arise from insufficient charging infrastructure. In this case, m is the amount of chargers in stationary equilibrium and $\bar{m}$ is the benchmark level of chargers for which network effects are zero. Note that the network cost disappears as m reaches $\bar{m}$. Later, in the section corresponding to describing the EV charging services firms problem, I will elaborate more on how m is determined.

The operating cost accounts for all the expenses related to car ownership and driving, such as fuel expenditure, insurance, and taxes. The transaction cost accounts for all the expenses that the household incurs when changing cars or moving to another state[17]. For example, consider the case of a consumer τ who owns a car (i, a) and wants to exchange it for a car (j, d). In that case, the cost associated with that transaction would be $P_{jd} - P_{ia} + T_b(j, d) + T_s(i, a)$ where $P_{jd} - P_{ia}$ represents the difference between the purchase and sale price, $T_b(j, d)$ represents the costs of buying (j, d) and $T_s(i, a)$ represents the costs of selling (i, a).

Note that if the household τ decides to keep its car (κ) then the utility u_τ will be the utility corresponding to own and drive the corresponding vehicle for x_τ^* km and it only pays for the operative costs. For those households that decide not to have a vehicle, the utility in the $\emptyset$ state is normalized to zero.

Finally, ϵ is a random shock that captures all those aspects that cannot be captured in the model and is distributed GEV (Generalized Extreme Value). The choice of the distribution of ϵ follows standard discrete choice literature.

[16] This utility function has decreasing marginal returns in the number of kilometers driven. This can be thought of as the individual getting tired as the kilometers driven increases.

[17] Remember that the household can choose to be without a car $\emptyset$

Note that this specification relies on two strong assumptions. First, both types of vehicles are assumed to share the same terminal age, denoted by $\bar{A}$. The rationale for this assumption is that, because EVs are a relatively new technology, there is insufficient empirical evidence to determine a reliable terminal age specific to EVs. Moreover, the terminal age is expected to depend on the technical characteristics of the vehicle, particularly the durability and degradation profile of the battery, which remain uncertain in the Argentine context. Second, the parameters of the utility function are assumed to be identical for both technologies (EVs and ICEs). This assumption is motivated by the limited availability of data on EV adoption in Argentina, which prevents the identification of technology-specific preference parameters. This assumption has important implications for the results. First, assuming identical vehicle lifecycles may distort the lifetime profitability of electric vehicles. If EVs have shorter lifespans than internal combustion engine vehicles and therefore require earlier replacement, the annualized upfront cost increases, reducing the relative profitability of EV adoption. Second, assuming identical utility function parameters for EVs and ICE vehicles rules out the possibility that households have intrinsic preferences in favor of EVs or ICEs (Jang and Choi, 2021), which could affect adoption responses under different policy shocks. Consequently, household decisions regarding car ownership in the model primarily hinge on vehicle prices and per-kilometer fuel costs.

Another important aspect to consider is that the model is computed for households differentiated by income level. However, a second relevant dimension for analyzing the electrification of the automobile fleet is the distinction between rural and non-rural households. Urban households typically benefit from more accessible public transportation systems and tend to drive fewer kilometers, whereas the opposite holds for rural households (McKinney et al., 2025). In addition, charging infrastructure is generally more limited in rural areas (Winikoff, 2024). Put differently, the value of owning a vehicle and the outside option ($\emptyset$) differ systematically across household types, with rural households facing a higher implicit cost of not having a vehicle. Consequently, the impacts of energy-transition policies targeting the automobile fleet are likely to be heterogeneous, potentially generating differentiated effects between rural and urban households. Due to the lack of data on the electrification of the automobile fleet in Argentina for rural and urban areas, this dimension is not explored further in the present analysis.

The dynamic problem of the household. The optimal strategy regarding vehicle ownership for the household is characterized by the solution to an expected utility maximization problem, which, in this case, constitutes a discrete choice dynamic optimization problem (Rust, 1987). Let $V(i, a, \epsilon)$ be the value function of a consumer in state (i, a, ϵ) where $i \in \{\emptyset, VE, VC\}$ and $a \in \{\emptyset, 1, \ldots, A\}$. Thus, the dynamic problem is defined by the following state-specific problems, which, all together, cover the entire state-choice space.

For a household τ who enters the period without a car ($\emptyset$), the dynamic problem is:

$$V(\emptyset, \epsilon) = \max \left\{ v(\emptyset, \emptyset) + \epsilon(\emptyset); \quad \max_{j,d} v(\emptyset, j, d) + \epsilon(j, d) \right\} \tag{1}$$

Where the first argument of the maximum represents the value derived from remaining without a car, and the second argument represents the value of buying the car (j, d)

that offers the maximum value among all available car alternatives. The specific value functions for each choice are:

$$v(\emptyset, \emptyset) = u(\emptyset) + \beta \mathbf{E}v(\emptyset)$$
$$v(\emptyset, j, d) = u(j, d, x_\tau^*) - \mu_\tau [P_{jd} + T_b(j, d)] + \beta[(1-\alpha)\mathbf{E}v(j, d+1) + \alpha \mathbf{E}v(j, A)]$$

Also, the expected values in each decision are defined by the following integrals.

$$\mathbf{E}v(\emptyset) = \int_\epsilon V(\emptyset, \epsilon) f(\epsilon|\emptyset) d\epsilon \quad ; \quad \mathbf{E}v(i, a) = \int_\epsilon V(i, a, \epsilon) f(\epsilon|i, a) d\epsilon \tag{2}$$

Where $f(\epsilon|.)$ is the corresponding probability function of a GEV distribution for ϵ. This specification assumes that ϵ is independent of its past realizations.

For the case of a household τ entering the period with a car on its terminal age (A), the dynamic problem is defined by:

$$V(i, A, \epsilon) = \max \left\{ v(i, A, \emptyset) + \epsilon(\emptyset); \quad \max_{j,d} v(i, A, j, d) + \epsilon(j, d) \right\} \tag{3}$$

The first argument of the maximum captures the value of the option to move to not having a car, while the second one captures the value of the option to choose a car (j, d) from all the available models and ages. The specific value functions for each choice are:

$$v(i, A, \emptyset) = u(\emptyset) + \mu_\tau \underline{\mathrm{p}}_i + \beta \mathbf{E}v(\emptyset)$$
$$v(i, A, j, d) = u(j, d, x_\tau^*) - \mu_\tau [P_{jd} - \underline{\mathrm{p}}_i + T_b(j, d)] + \beta[(1-\alpha)\mathbf{E}v(j, d+1) + \alpha \mathbf{E}v(j, A)]$$

Where $\underline{\mathrm{p}}_i$ represents the price that the household obtains for scrapping its vehicle.

Finally, for the household τ who enters the period with a car (i, a), the dynamic problem is defined by:

$$V(i, a, \epsilon) = \max \left\{ v(i, a, \kappa) + \epsilon(\kappa); \max_s v(i, a, \emptyset, s) + \epsilon(\emptyset, s); \max_{j,d,s} v(i, a, j, d, s) + \epsilon(j, d) \right\}$$

The household τ in this state has three options: to keep their car (first argument of the maximum), to move to not having a car (second argument of the maximum), and to switch to another car (j, d) among all available options (third argument of the maximum). Likewise, it can choose either to sell its car ($s = 1_s$) or to scrap it ($s = 0_s$). The specific value functions for each decision are:

$$
\begin{aligned}
v(i,a,\emptyset,1_s) &= u(\emptyset) + \mu_\tau \underline{\mathrm{p}}_i + \beta \mathbf{E}v(\emptyset) \\
v(i,a,\emptyset,0_s) &= u(\emptyset) + \mu_\tau [P_{ia} - T_s(i,a)] + \beta \mathbf{E}v(\emptyset) \\
v(i,a,\kappa) &= u(i,a,x_\tau^*) + \beta[(1-\alpha)\mathbf{E}v(j,d+1) + \alpha \mathbf{E}v(j,A)] \\
v(i,a,j,d,0_s) &= u(j,d,x_\tau^*) - \mu_\tau [P_{jd} - \underline{\mathrm{p}}_i + T_b(j,d)] + \beta[(1-\alpha)\mathbf{E}v(j,d+1) + \alpha \mathbf{E}v(j,A)] \\
v(i,a,j,d,1_s) &= u(j,d,x_\tau^*) - \mu_\tau [P_{jd} - P_{ia} + T_b(j,d) + T_s(i,a)] + \beta[(1-\alpha)\mathbf{E}v(j,d+1) + \alpha \mathbf{E}v(j,A)]
\end{aligned}
$$

The set of equations presented covers the entire state-decision space. The specific value functions and the formula determining the expected value of each state define the Bellman equation for the household's decision problem as a function that maps from the function space $V(i,a,\epsilon)$ to itself. Standard contraction arguments ensure the existence of a unique fixed point for the Bellman operator. However, solving the problem computationally could be much simpler in terms of the projection $\mathbf{E}v(i,a)$, which, independent of ϵ, is a lower-dimensional object. $\mathbf{E}v(i,a) \in \mathbb{R}^{2A+1}$, representing the expected value of starting the next period in state (i,a), where $i \in \{EV, ICE\}$, $a \in \{1,\ldots,A\}$, or without a car $\emptyset$. By applying the previously defined value functions, we derive a system of $2A+1$ nonlinear equations as:

$$
\mathbf{E}v = \Gamma(\mathbf{E}v)
$$

The solution of the bellman equations reconstructs v and characterizes the household's optimal strategy. $\Gamma(\cdot)$ is the Bellman operator, a contraction mapping from $\mathbb{R}^{2A+1}$ to itself. This allows to use a combination of Newton's method and successive approximation to solve the problem more efficiently. The advantage of combining these two methods is that it enables us to find a solution to the dynamic problem more quickly (Gillingham et al., 2022).

Given the assumption that ϵ follows a GEV distribution, the integrals in (2) that characterize $\mathbf{E}v$ have closed-form expressions. The analytical form of these integrals depends on the decision tree and how alternatives combine in different branches. The value functions that are specific to each choice $v(i,a)$ are combined to form the tree according to McFadden (1981) using a log-sum function (ω):

$$
\omega(\lambda, x_1, ..., x_n) = \lambda \log(\exp \frac{x_1}{\lambda} + ... + \exp \frac{x_n}{\lambda})
$$

Where λ is a scale parameter in each grouping alternative. For example, the expected value of stating next period with (i,a) follows:

$$
\mathbf{E}v(i,a) = \omega \left(\sigma, \underbrace{\omega(\sigma_s, v(i,a,\emptyset,1_s), v(i,a,\emptyset,0_s))}_{\text{No car}}, \underbrace{v(i,a,\kappa)}_{\text{Keep}}, \underbrace{\omega(\sigma_r, \omega_{EV}, \omega_{ICE})}_{\text{Replace}} \right)
$$

Another example, define ω_i as the expected value of the car i, also obtained by applying the log-sum function.

$$\omega_i = \omega\left(\sigma_i, \underbrace{\omega(\sigma_s, v(i,a,j,0,1_s), v(i,a,j,0,0_s))}_{\text{New car}}, ..., \omega(\sigma_s, v(i,a,j,A-1,1_s), v(i,a,j,A-1,0_s))\right)$$

Note that when all scale parameters are equal $\sigma = \sigma_i = \sigma_s$, the log-sum functions described above collapse, and the expected value reduces to a single log-sum function where the specific values of each choice correspond to all alternatives in the decision set. Note that the expected values in the no-car state $\mathbf{E}v(\emptyset)$ and in the terminal age state $\mathbf{E}v(i, A)$ follow similar expressions.

Choice Probabilities: In this model, the present and future utility obtained by the individual in each decision is affected by a random component ϵ. This component generates noise in the decision-making process. Then, the result is not a specific discrete choice but rather a probability distribution over the decision space. Let $\Pi^\tau(j, d, s|i, a)$ be the conditional probability of choosing option (j, d, s) from the decision set if the consumer τ is in the initial state (i, a). Under the assumption of GEV, these probabilities follow a NMNL (Nested Multi-Nomial Logit) form and depend on the structure of the decision tree (McFadden, 1981). For example, the probability of changing the car (i, a) for another car (j, d) is defined as:

$$\Pi^\tau(j,d,s|i,a) = \frac{\exp(v(j,d,i,a)/\sigma)}{\exp(\omega(\sigma_s,v(i,a,\emptyset,1_s),v(i,a,\emptyset,0_s))/\sigma)+\exp(v(i,a,\kappa)/\sigma)+\exp(\omega(\sigma_r,\omega_{EV},\omega_{ICE})/\sigma)}$$

Another example could be the probability of replacing the car (i, a) with any other car. This probability is defined as:

$$\Pi^\tau(\text{Replace}|i,a) = \frac{\exp(\omega(\sigma_r,\omega_1,...,\omega_J)/\sigma)}{\exp(\omega(\sigma_s,v(i,a,\emptyset,1_s),v(i,a,\emptyset,0_s))/\sigma)+\exp(v(i,a,\kappa)/\sigma)+\exp(\omega(\sigma_r,\omega_{EV},\omega_{ICE})/\sigma)}$$

Ownership Distribution: The ownership distribution captures how households of a certain type τ are distributed among the different states (car ownership or people without cars). Let $q^\tau_{ia} \in [0, 1]$ be the share of population of type τ with a car type (i, a) and $q^\tau_\emptyset$ be the share of population of τ without a car. Thus, the complete distribution of individuals τ over the states is defined as:

$$q^\tau = \left((q^\tau_{EV,1}, ..., q^\tau_{EV,A}), (q^\tau_{ICE,1}, ..., q^\tau_{ICE,A}), q^\tau_\emptyset\right) \in \mathbb{R}^{2A+1}$$

Towards the end of the period, households distribution over the states changes either because vehicle ownership changed due to car exchanges or because the vehicles aged. Two transition matrices describe this process: $\Omega^\tau(P)$ and Q. The first accounts for the probabilities of household τ conditional on state (i, a) moving to state (j, d) to describe the change in ownership distribution associated with car exchanges. The second matrix accounts for the accident probability α and describes the physical transition of car aging.

The exchange transition matrix $\Omega^\tau(P)$ is defined as follows:

$$\Omega^\tau(P) = \begin{bmatrix} \Delta^\tau_{EV,EV}(P) + \Lambda^\tau_{EV}(P) & \Delta^\tau_{EV,ICE}(P) & \Delta^\tau_{EV,\emptyset}(P) \\ \Delta^\tau_{ICE,EV}(P) & \Delta^\tau_{ICE,ICE}(P) + \Lambda^\tau_{ICE}(P) & \Delta^\tau_{ICE,\emptyset}(P) \\ \Delta^\tau_{\emptyset,EV}(P) & \Delta^\tau_{\emptyset,ICE}(P) & \Pi^\tau(\emptyset|\emptyset,P) \end{bmatrix}$$

Where $\Delta_{ij}(P) \in \mathbb{R}^{AxA}$ contains the exchange probabilities

$$\Delta_{ij}^{\tau}(P) = \begin{bmatrix} \Pi^{\tau}(j,1|i,1,P) & ... & \Pi^{\tau}(j,A-1|i,1,P) & \Pi^{\tau}(j,0|i,1,P) \\ \vdots & \ddots & \vdots & \vdots \\ \Pi^{\tau}(j,1|i,A-1,P) & ... & \Pi^{\tau}(j,A-1|i,A-1,P) & \Pi^{\tau}(j,0|i,A-1,P) \\ \Pi^{\tau}(j,1|i,A,P) & ... & \Pi^{\tau}(j,A-1|i,A,P) & \Pi^{\tau}(j,0|i,A,P) \end{bmatrix}$$

With

$$\Delta_{\emptyset j}^{\tau}(P) = \begin{bmatrix} \Pi^{\tau}(j,1|\emptyset,P) & ... & \Pi^{\tau}(j,A-1|\emptyset,P) & \Pi^{\tau}(j,0|\emptyset,P) \end{bmatrix}; \Delta_{i\emptyset}^{\tau}(P) = \begin{bmatrix} \Pi^{\tau}(\emptyset|i,1,P) \\ \vdots \\ \Pi^{\tau}(\emptyset|i,A,P) \end{bmatrix}$$

Notice that since there is no market for vehicles in their terminal age (A), the row and column corresponding to A are used for transactions associated with new cars ($a = 0$) (Gillingham et al., 2022). On the other hand, $\Lambda_i^{\tau}(P) \in \mathbb{R}^{AxA}$ contains the probabilities of keeping the vehicle.

$$\Lambda_i^{\tau}(P) = \begin{bmatrix} \Pi^{\tau}(\kappa|i,1,P) & ... & 0 & 0 \\ \vdots & \ddots & \vdots & \vdots \\ 0 & ... & \Pi^{\tau}(\kappa|i,A-1,P) & 0 \\ 0 & ... & 0 & 0 \end{bmatrix}$$

After the exchange, the vehicles are driven and, with probability α, they have accidents that render them unusable and, with probability $(1-\alpha)$, they age one year. This dynamic is captured by the physical transition matrix Q where:

$$\mathrm{Q} = \begin{bmatrix} Q_{EV} & 0 & 0 \\ 0 & Q_{ICE} & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \text{where} \quad \mathrm{Q}_i = \begin{bmatrix} 0 & 1-\alpha & ... & 0 & \alpha \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & ... & 1-\alpha & \alpha \\ 1-\alpha & 0 & ... & 0 & \alpha \end{bmatrix}$$

Thus, the multiplication of any ownership distribution q^{τ} by $\Omega^{\tau}(P)$ results in the post-exchange distribution. Similarly, the multiplication of the post-exchange distribution by the physical transition matrix Q results in the distribution for the next period $q^{\tau}\Omega^{\tau}(P)Q$.

2.4.2 Charging Infrastructure Firms

One of the key features of the EV charging service market is its size. In most developing countries, this industry is small or non-existent (Li et al., 2021). Therefore, this paper addresses the modeling of this industry using an optimal investment model. This model accounts for the decisions of firms that must choose how much to invest in this market and how to operate this new infrastructure. Since there is no evidence of increasing return to scale in this market, I model firms as price takers. I assume that uncertainty is not an issue in this market and firms know the evolution of the price. Therefore, firms must decide how much charging infrastructure to invest and how much charging services to

provide each period.

The following problem represents the optimization that a representative firm in this market confronts.

$$\begin{aligned}
\max_{\{X;y_t\}} \quad & \pi(X, y_t) = \sum_{t=0}^{\infty} \beta^t (p_t F(y_t) - c_y y_t - \delta c_e X) - c_e X \\
\text{s.t.} \quad & F(y_t) = z y_t^{\theta}, \\
& F(y_t) \leq \gamma X, \\
& X \geq 0, \\
& y_t \geq 0 \forall t
\end{aligned}$$

The representative firms maximizes the present value of its benefits ($\pi(X, y_t)$) that is a function of the electricity demanded to produce charging services (y_t) and the amount of chargers installed (X). Those benefits also depends on the following parameters: The discount factor (β), the cost of electricity (c_y), the depreciation rate or maintenance cost (δ), the cost of each individual charger (c_e). Therefore, given a sequence of prices (p_t) the firm receives $\pi(X, y_t)$.

There are four constraints in this problem. First, $F(y_t) = z y_t^{\theta}$ that accounts for the production function where z is the productivity level and θ account for the returns to scale ($\theta \in [0, 1)$). Second, $F(y_t) \leq \gamma X$ accounts for the fact thar the representative firms cannot produce more than the amount that installed infrastructure allows. In this sense, γ accounts for the maximum amount of KWh that a charger can provide in a period. Finally, the last two constraints are the non-negativity constraints for X and y.

The stationary solution for this model requires that $p_t = p_{t+1} = p$ and $y_t = y \forall t$. Therefore, the stationary version of the problem is the following:

$$\begin{aligned}
\max_{X;y} \quad & \pi(X, y_t) = \frac{1}{1-\beta}(p F(y) - c_y y - \delta c_e X) - c_e X \\
\text{s.t.} \quad & F(y) = z y^{\theta}, \\
& F(y) \leq \gamma X, \\
& X \geq 0, \\
& y \geq 0
\end{aligned}$$

Note that since $F(y)$ is increasing in y, this variable is always non-negative and the maximum production constraint always holds as equality ($F(y) = \gamma X$) meaning that the firm never leave idle infrastructure. In this sense, we can express the previous problem as:

$$\begin{aligned}
\max_{X;y} \quad & \pi(X, y_t) = \frac{1}{1-\beta}(p z y^{\theta} - c_y y - \delta c_e X) - c_e X \\
\text{s.t.} \quad & z y^{\theta} = \gamma X, \\
& X \geq 0
\end{aligned}$$

The Lagrangian for this problem is the following:

$$\mathcal{L}(X; y, \lambda) = \frac{1}{1-\beta}(p z y^{\theta} - c_y y - \delta c_e X) - c_e X + \lambda(\gamma X - z y^{\theta}) + \mu X$$

The Kuhn-Tucker-Karush conditions are:

$$\begin{aligned}
\frac{\partial \mathcal{L}}{\partial X} &: c_e + \frac{\delta c_e}{1-\beta} = \lambda\gamma + \mu, \\
\frac{\partial \mathcal{L}}{\partial y} &: \frac{p\theta z y^{\theta-1} - c_y}{1-\beta} = \lambda\theta z y^{\theta-1}, \\
\frac{\partial \mathcal{L}}{\partial \lambda} &: \gamma X - z y^{\theta} = 0 \\
KKT1 &: \mu \geq 0, \\
KKT2 &: X \geq 0, \\
KKT3 &: \mu X = 0
\end{aligned}$$

Note that there are two cases here, either $\mu > 0$ or $\mu = 0$. The first case implies that the non-negativity constraint is bidding. Hence, $X^* = 0$ and therefore both $y^* = 0$ and $F(y^*) = 0$. For the second case, since $\mu = 0$ then X can be strictly positive. This leads to proposition 1.

Proposition 1: *Manipulating the previous first order conditions under $\mu = 0$. Then, y^* and X^* are:*

$$\begin{aligned}
y^* &= \left(\frac{z\theta}{c_y}\left(p - \frac{c_e(1+\delta-\beta)}{\gamma}\right)\right)^{\frac{1}{1-\theta}} \\
X^* &= \frac{F(y^*)}{\gamma}
\end{aligned}$$

Proof Appendix E.

Now that I characterized the solution under both scenarios I will characterize under which parameter configuration the non-negativity constraint is bidding and when it is not.

Proposition 2: $\mu = \frac{1}{1-\beta}(c_e(1-\beta+\delta) - p\gamma)$

Proof Appendix E.

Note that the non-negativity constraint is bidding as long as $\frac{c_e(1-\beta+\delta)}{\gamma} > p$. This means that if the entry cost is high enough or the discount rate is big enough with respect to price it is not profitable to install any charger. However, as price increase μ´s positivity disappear. Finally, when $\frac{c_e(1-\beta+\delta)}{\gamma} \leq p$ the non-negativity constraint is not active an X is positive.

To conclude, the optimal behavior of the representative firm can be summarized as:

$$y^* = \begin{cases} \left(\frac{z\theta}{c_y}\left(p - \frac{c_e(1+\delta-\beta)}{\gamma}\right)\right)^{\frac{1}{1-\theta}} & \text{if } \dfrac{c_e(1-\beta+\delta)}{\gamma} \leq p \\ 0 & \text{if } \dfrac{c_e(1-\beta+\delta)}{\gamma} > p \end{cases}$$

$$X^* = \begin{cases} \dfrac{F(y^*)}{\gamma} & \text{if } \dfrac{c_e(1-\beta+\delta)}{\gamma} \leq p \\ 0 & \text{if } \dfrac{c_e(1-\beta+\delta)}{\gamma} > p \end{cases}$$

2.4.3 Market Equilibrium

To characterize the equilibrium, it is necessary to define the excess demand functions. In this case, there are $2(A-1)$ secondary markets. Therefore, the equilibrium price vector that equates supply with demand for each of these markets is $P_c = (P_{EV}, P_{ICE}) = ((P_{EV,1}, \ldots, P_{EV,A-1}), (P_{ICE,1}, \ldots, P_{ICE,A-1})) \in \mathbb{R}^{2(A-1)}$. Additionally, there is a market for EV charging services for which P^{sc} is the equilibrium price that equates supply and demand. Therefore, the complete price vector is defined as $P = (P_c, P^{sc}) \in \mathbb{R}^{2(A-1)+1}$.

Recall that q^τ represents the ownership distribution of households of type τ. The complete distribution of the economy is defined as $q = (q_1 f_1, \ldots, q_{N_\tau} f_{N_\tau}) \in \mathbb{R}^{N_\tau(2A+1)}$ where N_τ represents the amount of households being considered. Note that $N_\tau = 3$ since $\tau \in \{\tau_1, \tau_2, \tau_3\}$.

Let $D_{jd}(P, q)$ be the demand for used vehicles type (j, d) conditional on the ownership distribution q. $D_{jd}(P, q)$ is defined as:

$$D_{jd}(P,q) = \sum_{\tau=1}^{N_\tau} \left(\Pi^\tau(j,d|\emptyset,P) q^\tau_\emptyset + \sum_{i\in[VE,VC]} \sum_{a\in[1,A-1]} \Pi^\tau(j,d|i,a,P) q^\tau_{ia} \right) f_\tau$$

Likewise, the supply $S_{jd}(P, q)$ is defined as follows.

$$S_{jd}(P,q) = \sum_{\tau=1}^{N_\tau} \left((1-\Pi^\tau(\kappa|j,d,P))(1-\Pi^\tau(1_s|j,d,P)) q^\tau_{jd} \right) f_\tau$$

Thus, the excess demand is defined as $ED_{jd}(P, q) = D_{jd}(P, q) - S_{jd}(P, q)$. Let $ED_c \in \mathbb{R}^{2(A-1)}$ be the vector that groups all the excess demands.

For the charging service market, let $D_{is}(P, q)$ be the demand for those services conditional on the prices and the ownership distributions:

$$D_{is}(P,q) = \sum_{\tau=1}^{N_\tau} \left(\sum_{a\in[1,A]} x^\tau_{EV} \Gamma q^\tau_{EV,a} \right) f_\tau$$

Where x^τ_{EV} is the number of kilometers driven by households τ with EVs, Γ is the parameter representing how many KWh are required per kilometer. Now, let $S_{is}(P)$ be the supply of charging services defined as $S_{is}(P) = y(P)$. Therefore, the excess demand for charging services is $ED_{is}(P, q) = D_{is}(P, q) - S_{is}(P)$.

Thus, the complete excess demand vector is defined as $ED(P, q) = (ED_c(P, q), ED_{is}(P, q)) \in \mathbb{R}^{2(A-1)+1}$.

Definition of the Stationary Equilibrium: A stationary equilibrium in an economy with $\tau \in \{1, \ldots, N_\tau\}$ households, 2 vehicles models with a bounded by A is given by a price vector and ownership distributions $(P, q) \in \mathbb{R}^{2A-1}\text{x}\mathbb{R}^{N_\tau(2A+1)}$ such that:

1. Households follow their optimal exchange strategies that arise from the solution to their dynamic programming problem.

2. The firms providing EV charging services maximizes its profit and their distribution is time-invariant ($m_{t+1} = m_t = m$).

3. Market-clearing conditions hold. $ED(P^*, q^*) = 0$

4. The ownership distribution is time-invariant. This requires that $q^{\tau *}\mathbf{\Omega}^{\tau}(P^*)Q = q^{\tau *} \quad \forall \tau$.

5. New cars are acquired at a fixed price $\bar{P}_i$ and can be scrapped at $\underline{p}_i$.

Gillingham et al. (2022) provides proofs on the existence of equilibrium and shows that in a stationary equilibrium, the number of cars entering the fleet each year is equal to the number of cars leaving due to reaching the terminal age. Appendix D describes the procedure to compute the solution of the model.

2.5 Calibration of Unknown Parameters

In Section 2.4, a dynamic model of car exchange with an associated EV battery charging market was presented. Using this model, along with a calibration algorithm, it is possible to link the model to the data and present an empirical study. This section is divided into two parts. The first one presents the methodology used to calibrate the model with data from the Argentine market. The second one presents the results of the estimation.

2.5.1 Identification

This paper calibrates the vector $\hat{\chi} = \{z; \mu_\tau; \psi^\tau; \rho^\tau; B^\tau; \lambda^\tau, \eta\} \forall \tau$ using a minimum distance estimator. The idea behind this method is to match different indicators arising from the model with the equivalent indicator coming from the data by minimizing a loss function. More precisely, for a parameter vector χ, the algorithm solves the model presented in the previous section. Then, it calculates the moments of the model ($\dot{x}$) that should match with the moments of the data (x). The loss function is defined by the distance between $\dot{x}$ and x. Particularly, it is characterized by the following expression: $e(\dot{x}, x|\chi)We(\dot{x}, x|\chi)^T$. Where $\chi \in X$ is the vector of unknown parameters to be calibrated, W is a weighting matrix, and $e(\dot{x}, x|\chi)$ is the function that calculates the difference between the data simulated by the model x and the estimated data $\dot{x}$. Particularly, W is the identity matrix. Therefore, the loss function is the quadratic error function. Thus, the estimated parameter vector, $\hat{\chi}$, is defined as:

$$\hat{\chi}(W) = \arg\min_{\chi \in X} e(\dot{x}, x|\chi)We(\dot{x}, x|\chi)^T$$

The identification of the model is similar to that performed in other structural models, such as Galenianos and Gavazza (2017). Despite the highly non-linear nature of the model, such that all parameters affect all variables, the identification of parameters is associated with key moments of the data. The moments of the average age of vehicles corresponding to each type of household identify the parameter characterizing the disutility associated with an additional year of vehicle age (ρ^τ). The average kilometers driven according to the age range of the vehicle identifies parameter linked to the disutility of one more year of age in the driving utility (λ^τ). The average fuel expenditure per household type identifies the utility parameter linked to the number of kilometers traveled per household (B^τ). The average expenditure on the purchase of used and new vehicles per household serves to identify the utility function parameter ψ^τ. The share of households without vehicles identifies the marginal utility of money (μ_τ). Finally, the cost of charging an EV identifies

the parameter z of the production function and the share of EVs in the automotive fleet identifies η.

2.5.2 Calibration and fitting

Table 2.1 reports the results for the calibrated parameters $\hat{\chi}$ using the minimum distance estimator.

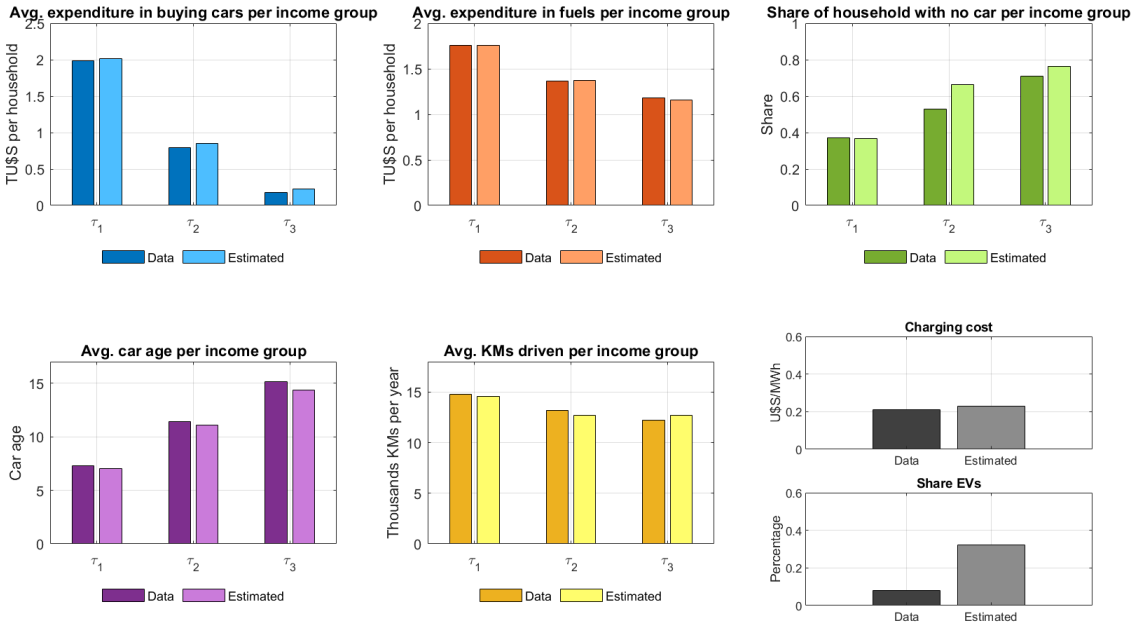
Table 2.1 – Results of the calibrated parameters for $\hat{\chi}$.

Parameter	Value	Parameter	Value
z	0.2576	B^{τ_2}	2.4272
η	2,781	B^{τ_3}	2.3961
μ^{τ_1}	0.1595	ρ^{τ_1}	-0.6408
μ^{τ_2}	0.1704	ρ^{τ_2}	-0.5206
μ^{τ_3}	0.1954	ρ^{τ_3}	-0.4471
ψ^{τ_1}	2.1508	λ^{τ_1}	-0.0011
ψ^{τ_2}	1.6392	λ^{τ_2}	-0.0025
ψ^{τ_3}	1.1747	λ^{τ_3}	-0.0035
B^{τ_1}	2.8257		

Note: Table 2.1 reports the calibrated values for $\hat{\chi}$ estimated using the minimum distance estimator.

Figure 2.5 presents a comparison between the empirical moments of the data for the car market and those resulting from simulating the model using the calibrated parameters $\hat{\chi}$. In general, the model correctly reproduces the data. Remarkably, the model not only successfully reproduces the data but also captures the variation according to the income level. This suggests that the identification strategy was successful.

Figure 2.5 – Model Fit.



Note: This table reports the values of empirical moments and those obtained from simulating the model using $\hat{\chi}$ (reported in Table 2.1). Note: TU$S: Thousand US Dollars; Avg.: Average; τ_1: High-income households; τ_2: Middle-income households; τ_3: Low-income households.

The main source of information to estimate these parameters is the 2018 National Household Expenditure Survey published by INDEC. This survey provides a characteri-

zation by household income, an equipment sub-survey where households are asked, among other things, about their car holdings, and within the expenditure survey, they are asked about their car purchase/sale patterns and fuel purchases. Additionally, AFAC presents the annual report of the vehicle fleet where it surveys its characteristics. On the other hand, the fuel price data published by the Argentine Ministry of Energy is used. Finally, the estimation regarding the charging cost is based on data from the Alternative Fuels Observatory. Appendix B presents statistics on the automobile market in Argentina and the fuel consumption patterns of Argentine households. Appendix C provides a summary table with the exogenous parameters used in the model and their sources.

2.6 Counterfactual Exercises and Results

This section analyzes the impact of EV-promoting policies on EV adoption, emissions, battery disposals, household welfare, and fiscal outcomes using the model. The analysis is structured into five scenario blocks:

1. **Subsidy for new electric vehicles:** This scenario evaluates the effects of subsidizing the price of new EVs at a rate s. I simulate values of $s \in [0, 0.3]$, a range consistent with policies implemented worldwide. For instance, the average EV subsidy in the European Union is approximately 12%, based on country-level data from ACEA[18]. To isolate the effect of charging infrastructure on EV adoption, I consider two cases: (i) with network effects ($\eta > 0$) and (ii) without network effects ($\eta = 0$). The model computes the stationary equilibrium of the economy. However, EV prices are non-stationary and exhibit a clear downward trend over time. To capture this dynamic, I focus on product entry and evaluate outcomes under three EV price levels: (i) the baseline price (see Section 3 and Appendix C), (ii) a 7% price reduction, consistent with the average decline observed between 2023 and 2024 driven by innovations in battery technology (IEA, 2025b), and (iii) a 15% price reduction reflecting further technological advances that continue to lower battery costs. The government finances the subsidy through a direct tax on households. To assess the distributional effects of this tax, I consider two funding schemes: (i) *standard funding*, which distributes the tax burden across the income groups according to the observed tax distribution using data from the 2017–2018 National Household Expenditure Survey (ENGHo), and (ii) *progressive funding*, which allocates the tax burden by income level, also based on the ENGHo 2017–2018.

2. **Subsidy for new charging infrastructure:** This scenario evaluates subsidies for new charging infrastructure at a rate s_c. I simulate values of $s_c \in [0, 0.3]$. As in the previous scenario, I evaluate outcomes under three EV price levels: (i) the baseline price, (ii) a 7% price reduction, and (iii) a 15% price reduction. The government funds these subsidies through the same direct tax mechanisms described above (standard and progresive). As with EV subsidies, I consider two cases: (i) with network effects ($\eta > 0$) and (ii) without network effects ($\eta = 0$).

3. **Optimal subsidy for new EVs:** Here, I estimate the EV subsidy that maximizes social welfare:

$$s^* = \arg\max_s \; SW(s) = SB(s) - SC(s)$$

[18]Electric cars: Tax benefits and purchase incentives 2023 Report

where $SW(s)$ represents social welfare, $SB(s)$ the social benefits, and $SC(s)$ the social costs. At s^*, marginal social benefits equal marginal social costs. The benefits include: (i) Reduced noise and local pollution, (ii) lower travel costs due to EVs' higher efficiency in price per kilometer. The social costs stem from the tax burden required to finance the subsidy. I first estimate s^* under the baseline scenario, then consider three variants:

- **No Environmental externalities:** Estimates s^* without accounting for pollution and noise externalities. It allows to isolate their effect on the optimal subsidy.
- **No Network externalities:** Estimates s^* without accounting for network externalities arising from the absence of charging infrastructure. It allows to isolate its effect on the optimal subsidy.
- **No car tax:** Estimates s^* assuming the government removes car taxes for EVs.
- **No VAT:** Estimates s^* assuming the government eliminates VAT on new EVs.

4. **Ban on new ICE vehicle sales:** This scenario simulates a ban on new ICEs sales. I implement this scenario by imposing a high transaction cost on ICEs. The cost is set high enough to shut down both primary and secondary ICE markets in the stationary equilibrium. I use this scenario to determine how much EV upfront costs should decrease to maintain household welfare at pre-ban levels. I also estimate how much should this cost decrease to keep the share of households with no car at pre-ban levels.

Allocating public resources to promote EVs may have significant opportunity costs. To illustrate this trade-off, I analyze an alternative scenario in which resources go toward improving public transportation:

5. **Improvements in public transportation:** This scenario aims to assess the role of the expansion and improvement of public transportation services. To do so, I increases the utility of households in the no-car state ($\emptyset$), representing public transport improvements. The utility increase is arbitrary and purely illustrative. Appendix F presents the results of this exercise.

The first subsection defines the main indicators. The second subsection reports the baseline results. The third and fourth subsection present the results for Blocks 1 and 2. The fifth subsection reports the results for Block 3, and the sixth subsection focuses on Block 4. Appendix F presents the results for Block 5. Appendix H reports a sentivity analysis for the for the productivity of the charging infrastructure sector (z).

2.6.1 Indicators

For each simulation, I report and discuss a set of variables and indicators. This subsection explains how I compute each one.

1. **EV Share**: Share of electric vehicles (SH_{EV}) in the total automobile fleet. I compute it as $SH_{EV} = \dfrac{EVs}{Total_Fleet} \times 100$, where EVs denotes the number of EVs and $Total_Fleet$ the total automobile fleet.

2. **Network penalty:** The network penalty measures the difference in EV share between simulations with network effects ($\eta > 0$) and without network effects ($\eta = 0$). It captures the share of EVs that does not enter the market due to limited charging infrastructure.

3. **No Car Ownership**: Share of households without a car as a percentage of total households. I compute it as $NCO = \frac{No_Car_Households}{Total_Households} \times 100$, where $No_Car_Households$ is the number of households without a car and $Total_Households$ the total number of households.

4. **Charging Cost**: Unit cost of one kWh at a public charging station.

5. **Charging Stations**: Number of public charging stations per household.

6. **Emissions**: Annual CO_2 emissions from ICE vehicle use and from electricity generation for EV charging, measured in MTCO2eq. I compute this indicator by multiplying the number of kilometers driven by each car type i (KM_i) by the corresponding emission coefficient (EC_i): $EM = \sum_i KM_i \times EC_i$.

7. **Discarded Batteries**: Number of EV batteries discarded per year. I compute this indicator as the number of EVs exiting the automobile fleet each year in stationary equilibrium.

8. **Fiscal Revenue**: Total tax revenue from vehicle use and vehicle sales. This indicator includes annual vehicle inspection fees (USD 20), fuel taxes (43%, including VAT, the liquid fuel tax, the CO_2 tax, and the gross income tax), VAT on new vehicles (21%), vehicle ownership taxes (3%), and transaction taxes on purchases (4.7%) and sales (0.75%).

9. **Welfare**: Welfare equals the utility, expressed in monetary terms, from owning and driving a vehicle minus (i) driving-related externalities and (ii) the cost of funding EV-support policies. I define household-specific welfare (W_τ) as

$$W_\tau = \frac{\sum_{i,a} V_\tau(i,a)\, q_\tau(i,a) + V_\tau(\emptyset)\, q_\tau(\emptyset)}{\mu_\tau}.$$

   Here, $V_\tau(i,a)$ denotes the value from owning and driving vehicle type i of age a, and $\emptyset$ represents the outside option. As before, $q_\tau(\cdot)$ denotes the distribution of household τ across states. Because $V_\tau(\cdot)$ is measured in utility units, I divide it by the marginal utility of money, μ_τ, to express welfare in monetary terms. This is the same procedure as applied in Gillingham et al. (2022).

   To compute household-level externalities, I first calculate total externalities and then allocate them across households using the weights f_τ. Following Gössling et al. (2019), total externalities include noise (0.007 EUR/km), local pollution (0.007 EUR/km), and climate change (0.011 EUR/km). I multiply each external cost by the number of kilometers driven. For EVs, I compute climate externalities by multiplying EV kilometers driven by the CO_2 intensity per kilometer and applying a carbon price of 10 USD/MTCO2eq, consistent with Argentine legislation (Mardones and Andaur, 2024). I calculate the CO_2 intensity per kilometer using the amount of kilometers that an EV can travel per kWh and the CO_2 emissions associated with generating one kWh under the current electricity system.

   I allocate the taxes required to fund EV policies under two alternative schemes:

- *Standard*: allocation based on the observed distribution of tax payments across households.
- *Progressive*: allocation by income level.

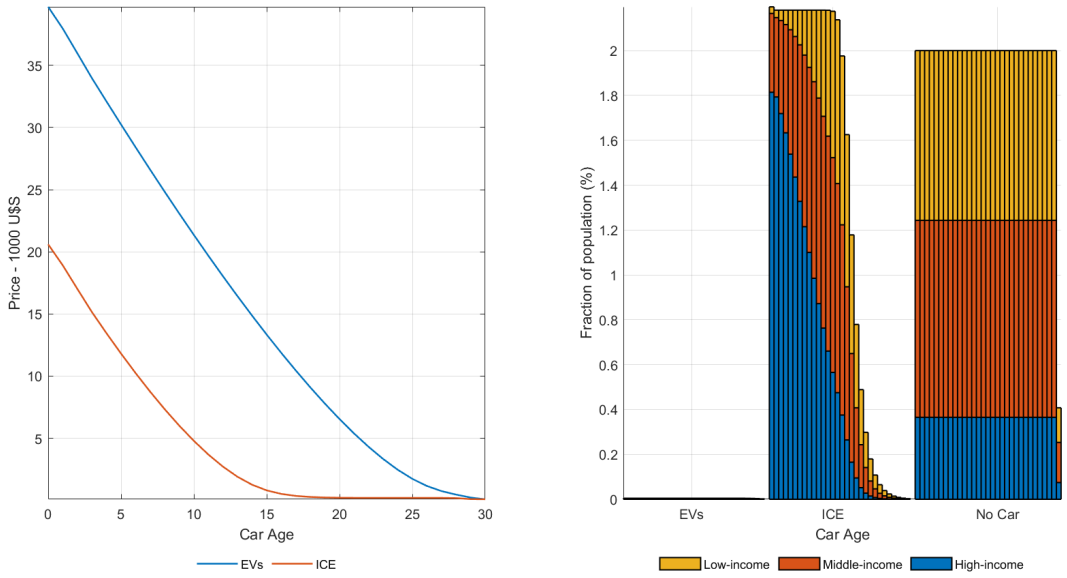
The average welfare equals the weighted average of household-specific welfare, using weights f_τ.

Appendix C reports the main exogenous parameters and the corresponding data sources in detail.

2.6.2 Baseline

This subsection presents the baseline results, which serve as a reference for assessing the impact of simulations. The model is solved under the *status quo* scenario. Figure 2.6 displays the estimated equilibrium ownership distributions and vehicle prices.

Figure 2.6 – Equilibrium prices for EVs and ICE vehicles by age and ownership distribution of vehicles by household type.



Note: The first plot (a) contains the equilibrium prices of each type of vehicle for different ages. The second plot (b) shows how vehicles are distributed among households and how the population of households without vehicles is composed by income level. The sum of all areas is equal to 1. Note: EVs: Electric Vehicles; ICEs: Internal Combustion Engine Vehicles.

Figure 2.6(a) shows the price trajectory of EVs and ICE vehicles. The price of a new car matches the calibration price and then declines as the vehicle ages, approaching zero at the terminal age (A). Figure 2.6(b) presents ownership distribution results. High and middle-income households primarily own new cars. As vehicles age, ownership shifts toward middle-income households, with the oldest cars predominantly owned by low-income households. This pattern aligns with findings in Gavazza et al. (2014) and Gillingham et al. (2022). Table 2.2 presents the results for the relevant indicators in the baseline.

Table 2.2 – Baseline Results.

Indicator	Unit of measure	Base
Fleet characteristics		
Share EVs	Percentage	0.32
No car ownership	Percentage	60.41
Charging variables		
Charging cost	USD cents/ KWh	22.96
Charging stations	Units per household	0.00
Environment		
Emissions	MTCO2eq	12.99
Discarded batteries	Thousands	0.97
Fiscal revenue and welfare		
Fiscal outcome	% of GDP	1.24
High-inc. household welfare	TUSD per household	10.96
Medium-inc. household welfare	TUSD per household	2.31
Low-inc. household welfare	TUSD per household	0.14
Average welfare	TUSD per household	4.25

Note: This table reports the baseline values for the main indicators to be studied in this article. Note: USD: US Dollars; KWh: Kilo-Watt hour; MTCO2eq: Million tons of CO2 equivalent; TUSD: Thousands of US Dollars.

In the baseline, EVs make up only 0.32% of the fleet, with the rest consisting of fossil fuel-powered vehicles. Additionally, 60.41% of households do not own a car. Residential fleet emissions amount to 12.99 MTCO2eq. The fiscal outcome is 1.24% of GDP, incorporating revenues from car purchases and sales, vehicle taxes, fuel taxes, and the Technical Vehicle Verification. As expected, high-income households experience greater welfare levels than low-income households [19]. Finally, average household welfare is 4.25 thousand USD.

2.6.3 Demand Side: Impact of Subsidies on New EVs

This subsection analyzes the impact of subsidy policies for new EVs and charging infrastructure. I simulate various levels of EV subsidies ($s \in [0, 0.3]$), a range that reflects common policy practices. To capture price dynamics, I focus on product entry and evaluate outcomes under three EV price levels: (i) the baseline price (see Section 3 and Appendix C), (ii) a 7% price reduction, consistent with the average decline observed between 2023 and 2024 driven by innovations in battery technology (IEA, 2025b), and (iii) a 15% price reduction reflecting further technological advances that continue to lower battery costs. Table 2.3 reports the results for the EV subsidy scenarios.

[19] Household welfare is calculated by dividing the utility level by the marginal utility of money, μ_τ. Since utility is ordinal rather than cardinal, these indicators measure intra-household welfare impacts but cannot be used for cross-household comparisons.

Table 2.3 – Counterfactual Simulations to Estimate the Impacts of Subsidies to New EVs.

Indicator	Unit of measure	Subsidy scenarios					
Setup							
Subsidy rate	Percentage	0	10	15	20	25	30
Price Scenario: BASE							
Fleet characteristics							
Share EVs	Percentage	0.32	0.85	1.41	2.45	4.66	11.88
Share EVs: Network Penalty	Percentage	-1.76	-4.01	-5.87	-8.35	-11.09	-10.63
No car ownership	Percentage	60.41	60.31	60.20	60.00	59.58	58.09
Charging variables							
Charging cost	USD cents/ KWh	22.96	28.31	31.63	35.69	41.15	50.87
Charging stations	Units per household	0.00	0.00	0.01	0.01	0.02	0.04
Environment							
Emissions	MTCO2eq	12.99	12.89	12.77	12.57	12.15	10.84
Discarded batteries	Thousands	0.97	2.06	3.22	5.42	10.23	27.09
Fiscal revenue and welfare							
Fiscal outcome	% of GDP	1.24	1.24	1.24	1.24	1.25	1.27
Average welfare	TUSD per household	4.25	4.27	4.29	4.30	4.32	4.32
Price Scenario: 7%							
Fleet characteristics							
Share EVs	Percentage	0.63	1.62	2.74	5.09	12.68	30.54
Share EVs: Network Penalty	Percentage	-3.15	-6.46	-8.87	-11.37	-10.22	-0.56
No car ownership	Percentage	60.35	60.16	59.95	59.49	57.91	53.50
Charging variables							
Charging cost	USD cents/ KWh	26.56	32.60	36.58	41.97	51.65	63.96
Charging stations	Units per household	0.00	0.01	0.01	0.02	0.04	0.09
Environment							
Emissions	MTCO2eq	12.93	12.73	12.52	12.07	10.70	7.95
Discarded batteries	Thousands	1.62	3.66	6.04	11.19	29.08	79.25
Fiscal revenue and welfare							
Fiscal outcome	% of GDP	1.24	1.24	1.24	1.24	1.25	1.27
Average welfare	TUSD per household	4.27	4.31	4.34	4.38	4.48	4.53
Price Scenario: 15%							
Fleet characteristics							
Share EVs	Percentage	1.41	3.78	7.28	20.19	33.79	43.16
Share EVs: Network Penalty	Percentage	-5.87	-10.31	-11.94	-5.59	-0.02	0.00
No car ownership	Percentage	60.20	59.75	59.05	56.18	52.58	49.67
Charging variables							
Charging cost	USD cents/ KWh	31.63	39.28	45.49	57.67	65.67	70.20
Charging stations	Units per household	0.01	0.01	0.02	0.06	0.10	0.13
Environment							
Emissions	MTCO2eq	12.77	12.32	11.66	9.46	7.53	6.45
Discarded batteries	Thousands	3.22	8.30	16.16	48.68	89.85	124.04
Fiscal revenue and welfare							
Fiscal outcome	% of GDP	1.24	1.25	1.26	1.30	1.33	1.34
Average welfare	TUSD per household	4.32	4.40	4.51	4.87	5.00	4.68

Note: Table 2.3 reports results for $s \in [0, 0.3]$. The network penalty, reported in the second line of Fleet Characteristics, measures the share of EVs that does not enter the market due to low availability of infrastructure. I evaluate outcomes under three EV price levels: the baseline price (see Section 3 and Appendix C), a 7% reduction reflecting recent battery-driven cost declines (IEA, 2025b), and a 15% reduction reflecting further technological progress. Subsection *Indicators* describes the welfare measure, and Appendix C reports the exogenous parameters.

Table 2.3 shows that EV penetration rises with the subsidy rate, reaching 11.88% of the fleet at $s = 0.3$ under the baseline price. At the same subsidy level, the share of households without a car declines to 58.09%. At low subsidy rates, EVs remain substantially more expensive than ICE vehicles, limiting adoption. As the subsidy narrows the price gap, EV adoption accelerates. Lower EV prices amplify adoption: at $s = 30\%$, a 7% price reduction raises the EV share to 30.54%, while a 15% reduction increases it to 43.16%. As EV prices fall, the share of households without a car correspondingly declines. I compute network penalty as the difference in EV adoption between the case without network effects in the utility function ($\eta = 0$), where households do not value charging availability, and the case with network effects ($\eta > 0$), where households value the avail-

ability of charging infrastructure. When network effects are absent, subsidies generate substantially higher EV adoption. When network effects operate, households suffer from limited charging infrastructure, reducing EV market penetration by up to 10.63 percentage points at $s = 30\%$ under baseline prices. The network penalty peak at intermediate EV price levels and vanish when prices become sufficiently low. At high prices, households do not adopt EVs. At sufficiently low prices, EVs become attractive even in the absence of infrastructure, which raises demand for charging services and induces the installation of new chargers. Full price parity is not required, as lower per-kilometer driving costs reduce total ownership and operating expenses.

For the scenario with the base EV price and $s = 0.3$, the expansion of the EV fleet increases demand for charging services, which raises charging costs from 22.96 to 50.87 USD cents/kWh at baseline prices. This level is consistent with observed prices in countries such as Belgium, Switzerland, and France[20]. The ratio of charging stations per household also increases with EV penetration. Because the sector's response closely depends on EV adoption, combining this policy with lower EV prices amplifies these effects. Under the lowest EV price scenario, charging costs rise to 70.20 USD cents/kWh (consistent with prices observed in countries such as Austria and Denmark). These results depend critically on the estimated productivity of the charging sector: Appendix H presents a sensitivity analysis.

From an environmental perspective, higher EV adoption reduces carbon emissions from 12.99 MTCO2eq in the baseline to 10.84 MTCO2eq at $s = 0.3$ under baseline prices. However, the number of discarded batteries rises from 0.97 to 27.09 thousand units per year. These results indicate that the environmental gains from promoting EVs depend critically on the availability of effective battery disposal and recycling technologies. These effects intensify when the same subsidy applies under lower EV prices. With a 15% price reduction and $s = 0.3$, emissions fall to 6.45 MTCO2eq, while discarded batteries increase to 124.04 thousand units per year. Note that higher EV adoption raises electricity demand, which may generate a rebound effect on emissions at high penetration levels if the electricity system is not sufficiently clean.

Fiscal outcomes remain stable across all subsidy levels. Although the government loses revenue from fuel taxes and VAT on new ICE vehicles, it gains revenue from VAT and vehicle taxes on new EVs. At lower EV prices, subsidies induce higher adoption, which increases public revenues as a share of GDP by reducing the share of households without cars and expanding the tax base. Average welfare increases with both the subsidy rate and lower EV prices, reaching 4.32 thousand USD per household at $s = 30\%$ under baseline prices and 4.68 thousand USD with the same subsidy and a 15% lower price. EV promotion reduces local pollution and enables a technology with lower driving costs. Although the policy directly targets the upfront cost of new EVs, it also affects secondary markets, leading to heterogeneous welfare effects across income groups. These differences reflect variation in EV use, exposure to externality reductions, and the distribution of the policy's fiscal cost. I next examine welfare effects by income level.

Table 2.4 reports the welfare effect of the previous scenarios by income level. To assess the distributional effects of the tax required to fund the subsidy, I consider two funding schemes: (i) *standard funding*, which distributes the tax burden across three

[20]Source: European Alternative Fuels Observatory. Consulted December 2024. https://alternative-fuels-observatory.ec.europa.eu/consumer-portal/electric-vehicle-recharging-prices

income groups according to the observed tax payment distribution, and (ii) *progressive funding*, which allocates the tax burden by income level.

Table 2.4 – Welfare Effects of Subsidies to new EVs by Income Level.

Indicator	Subsidy scenarios											
Setup												
Subsidy rate	0	10	15	20	25	30	0	10	15	20	25	30
Tax structure	Standard						Progressive					
Price Scenario: BASE												
High-inc. household welfare	10.96	11.00	11.04	11.08	11.14	11.23	10.96	10.99	11.01	11.01	10.97	10.67
Medium-inc. household welfare	2.31	2.32	2.33	2.34	2.34	2.33	2.31	2.33	2.34	2.37	2.42	2.58
Low-inc. household welfare	0.14	0.15	0.15	0.15	0.13	0.07	0.14	0.15	0.16	0.17	0.20	0.30
Average welfare	4.25	4.27	4.29	4.30	4.32	4.32	4.25	4.27	4.29	4.30	4.32	4.32
Price Scenario: 7%												
High-inc. household welfare	10.99	11.07	11.14	11.23	11.48	11.70	10.99	11.05	11.08	11.10	11.01	10.13
Medium-inc. household welfare	2.32	2.35	2.37	2.39	2.47	2.51	2.32	2.36	2.39	2.46	2.67	3.21
Low-inc. household welfare	0.15	0.16	0.16	0.17	0.16	0.05	0.15	0.17	0.19	0.22	0.35	0.69
Average welfare	4.27	4.31	4.34	4.38	4.48	4.53	4.27	4.31	4.34	4.38	4.48	4.53
Price Scenario: 15%												
High-inc. household welfare	11.08	11.26	11.46	12.15	12.44	11.94	11.08	11.21	11.32	11.57	11.07	9.60
Medium-inc. household welfare	2.36	2.42	2.50	2.80	2.93	2.70	2.36	2.44	2.56	3.05	3.54	3.74
Low-inc. household welfare	0.17	0.20	0.23	0.35	0.32	0.06	0.17	0.22	0.29	0.58	0.88	1.02
Average welfare	4.32	4.40	4.51	4.87	5.00	4.68	4.32	4.40	4.51	4.87	5.00	4.68

Note: Table 2.4 reports results for $s \in [0, 0.3]$. To assess the distributional effects of the tax used to fund the subsidy, I consider two funding schemes: (i) *standard funding*: distributes the tax burden across three income groups according to the observed tax distribution using data from the 2017–2018 ENGHo. (ii) *progressive funding*: allocates the tax burden by income level, also based on the ENGHo. Subsection *Indicators* describes the welfare measure, and Appendix C reports the exogenous parameters.

Table 2.4 shows that standard and progressive funding mechanisms generate different distributional outcomes. When the policy is funded through the standard tax scheme, EV promotion is regressive: high-income households benefit the most, as they are more likely to purchase new vehicles, while low- and middle-income households bear a larger share of the tax burden and experience welfare losses. Under a progressive funding scheme, the distributional effects reverse. High-income households experience welfare losses, whereas low-income households gain. These results show that the tax regime used to fund EV promotion is not distributionally neutral and plays a central role in shaping the policy's equity implications. Although the policy increases overall welfare, it generates different income distribution outcomes. The funding mechanism therefore plays a crucial role in ensuring equitable results. This is particularly important in developing countries.

2.6.4 Infrastructure Supply: Impact of Subsidies on Public Charging Stations

Table 2.5 reports the results for charging infrastructure subsidies for $s_c \in [0, 0.3]$ under the same setup as the previous simulations. I evaluate outcomes under three EV price levels: the base price (see Section 3 and Appendix C), a 7% reduction reflecting recent battery-driven cost declines (IEA, 2025b), and a 15% reduction reflecting further technological progress.

Table 2.5 – Counterfactual Simulations to Estimate the Impacts of Subsidies to Charging Infrastructure.

Indicator	Unit of measure	Subsidy scenarios					
		0	10	15	20	25	30
Price Scenario: BASE							
Fleet characteristics							
Share EVs	Percentage	0.32	0.33	0.33	0.33	0.33	0.34
Share EVs: Network Penalty	Percentage	-1.76	-1.77	-1.78	-1.79	-1.79	-1.80
No car ownership	Percentage	60.41	60.41	60.41	60.41	60.41	60.41
Charging variables							
Charging cost	USD cents/KWh	22.96	22.82	22.74	22.67	22.60	22.52
Charging stations	Units per household	0.00	0.00	0.00	0.00	0.00	0.00
Environment							
Emissions	$MTCO_2eq$	12.99	12.99	12.99	12.99	12.99	12.99
Discarded batteries	Thousands	0.97	0.98	0.99	1.00	1.00	1.01
Fiscal revenue and welfare							
Fiscal outcome	% of GDP	1.24	1.24	1.24	1.24	1.24	1.24
Average welfare	TUSD per household	4.25	4.17	4.12	4.08	4.03	3.99
Price Scenario: 7%							
Fleet characteristics							
Share EVs	Percentage	0.63	0.64	0.65	0.65	0.65	0.66
Share EVs: Network Penalty	Percentage	-3.15	-3.17	-3.18	-3.19	-3.20	-3.21
No car ownership	Percentage	60.35	60.35	60.35	60.35	60.34	60.34
Charging variables							
Charging cost	USD cents/KWh	26.56	26.42	26.35	26.28	26.21	26.15
Charging stations	Units per household	0.00	0.00	0.00	0.00	0.00	0.00
Environment							
Emissions	$MTCO_2eq$	12.93	12.93	12.93	12.93	12.92	12.92
Discarded batteries	Thousands	1.62	1.64	1.65	1.66	1.67	1.68
Fiscal revenue and welfare							
Fiscal outcome	% of GDP	1.24	1.24	1.24	1.24	1.24	1.24
Average welfare	TUSD per household	4.27	4.12	4.04	3.96	3.88	3.80
Price Scenario: 15%							
Fleet characteristics							
Share EVs	Percentage	1.41	1.43	1.44	1.45	1.46	1.47
Share EVs: Network Penalty	Percentage	-5.87	-5.90	-5.92	-5.93	-5.95	-5.96
No car ownership	Percentage	60.20	60.20	60.20	60.19	60.19	60.19
Charging variables							
Charging cost	USD cents/KWh	31.63	31.51	31.45	31.39	31.33	31.27
Charging stations	Units per household	0.01	0.01	0.01	0.01	0.01	0.01
Environment							
Emissions	$MTCO_2eq$	12.77	12.77	12.77	12.77	12.77	12.76
Discarded batteries	Thousands	3.22	3.27	3.29	3.31	3.33	3.35
Fiscal revenue and welfare							
Fiscal outcome	% of GDP	1.24	1.24	1.24	1.24	1.24	1.24
Average welfare	TUSD per household	4.32	4.02	3.87	3.71	3.55	3.39

Note: Table 2.5 reports the results for the relevant indicators when subsidies to charging infrastructure are applied for the range $[0, 0.3]$ ($s_c \in [0, 0.3]$). Those scenarios are simulated in two different setups: (i) considering network effects and (ii) without considering them ($\eta = 0$). The network penalty should be read as the share of EVs that is not entering the market due to network effects. To capture price dynamics, I evaluate outcomes under three EV price levels: the baseline price (see Section 3 and Appendix C), a 7% reduction reflecting recent battery-driven cost declines (IEA, 2025b), and a 15% reduction reflecting further technological progress. Subsection *Indicators* describes the welfare measure, and Appendix C reports the exogenous parameters.

Table 2.5 shows that subsidies to charging infrastructure have a limited impact on the reported indicators. EV adoption increases by only 4.31% at $s_c = 0.3$ under baseline EV prices and by 4.04% under a 15% price reduction. Although the policy reduces charging costs and increases the number of chargers, these effects remain modest. Overall welfare declines, as the fiscal cost of the policy exceeds the gains from lower driving and ownership costs and reduced environmental externalities. These results indicate that the primary barrier to EV adoption is its the high upfront cost. Consistent with this mechanism, charging infrastructure responds mainly to increases in EV adoption rather than to direct

subsidies. Therefore, the optimal strategy to promote electromobility is to directly reduce the upfront cost of EVs.

To explain why subsidies to charging infrastructure have limited effects, I illustrate the underlying mechanism with a simple calculation. Using the exogenous parameters in Appendix C, the total cost of a standard 50 kW DC public charger, including installation, is USD 48,000. Assuming a 10-year lifespan (Alliance, 2024), the annualized capital cost equals USD 4,800. Each kWh sold generates net revenue of USD 0.0946, after accounting for electricity costs and taxes (Appendix C)[21]. Operating 18 hours per day, a 50 kW charger can supply 328,500 kWh per year, yielding annual revenues of USD 31,076. Even under much more conservative assumptions on utilization or lifespan, operating revenues clearly exceed capital costs. These calculations imply that the low level of charging infrastructure in the model does not reflect high investment costs but rather low demand levels. As a result, charging infrastructure responds primarily to EV adoption rather than to reductions in the upfront cost of chargers. These results depend on the calibrated productivity of the charging sector and other exogenous parameters (Appendix C). Appendix H presents a sensitivity analysis with respect to productivity. Finally, this discussion focuses on 50 kW DC chargers while higher-capacity and ultra-fast chargers involve substantially higher capital and construction costs.

This analysis raises the question: What is the optimal subsidy level, and how does it change under different setups? The next subsection addresses that question.

2.6.5 Optimal subsidy to EVs

In this subsection, I estimate the optimal subsidy for new EVs. The optimal subsidy maximizes social welfare by equating the marginal social benefit with the marginal social cost. Table 2.6 reports the optimal subsidy under the status quo and four variants: (i) excluding environmental externalities from social welfare, (ii) excluding network externalities, (iii) eliminating car taxes for EVs, and (iv) eliminating VAT for EVs.

[21]For each kWh sold, the station earns USD 0.22 in gross revenue, minus USD 0.09 in electricity costs and 16% in taxes.

Table 2.6 – Optimal Subsidy to New EVs Analysis for Argentine Automobile Market.

Indicator	Unit of measure	Policy scenarios				
Setup						
Environmental externalities		Yes	No	Yes	Yes	Yes
Network externalities		Yes	Yes	No	Yes	Yes
VAT		Yes	Yes	Yes	No	Yes
Car tax		Yes	Yes	Yes	Yes	No
Optimal policy						
Subsidy	Percentage	29	24	20	25	17
Fleet characteristics						
Share EVs	Percentage	9.36	4.05	2.45	22.52	29.23
No car ownership	Percentage	58.62	59.70	60.00	55.61	53.86
Charging variables						
Charging cost	USD cents/KWh	48.16	39.88	35.69	59.24	63.24
Charging stations	Units per household	0.03	0.02	0.01	0.07	0.09
Environment						
Emissions	$MTCO_2eq$	11.28	12.27	12.57	9.10	8.13
Discarded batteries	Thousands	21.03	8.88	5.42	55.29	75.14
Fiscal revenue and welfare						
Fiscal outcome	% of GDP	1.26	1.25	1.24	1.25	1.10
Average welfare	TUSD per household	4.32	4.32	4.30	4.68	5.17

Note: Table 2.6 reports, in column 1, the optimal subsidy (s^*) under the status quo. The following columns reports four variants: (i) considering no environmental externalities affecting social welfare (column 2), (i) considering no network externalities affecting social welfare (column 3), (ii) eliminating VAT for EVs (column 4), and (iii) eliminating car taxes for EVs (column 5). Subsection *Indicators* describes the welfare measure, and Appendix C reports the exogenous parameters.

Under the status quo, the optimal subsidy is 29%. At this level, the share of EVs rises to 9.36% of the fleet, and the proportion of households without a car drops from 60.41% to 58.62%. Increased EV adoption drives higher demand for charging services, raising the charging cost to 48.16 USD cents per kWh and increasing the number of charging stations. As expected, emissions decrease from 12.99 MTCO2eq (baseline) to 11.28 MTCO2eq, while the number of discarded batteries increases from 0.97 thousand to 21.03 thousand per year. The fiscal outcome remains similar to the baseline, and average household welfare reaches 4.32 thousand USD.

When environmental externalities are excluded, the optimal subsidy falls to 24%, reflecting the lower marginal social benefit of EV adoption. Under this scenario, EV penetration and the associated effects on charging and environmental outcomes are smaller, and overall welfare declines relative to the baseline optimal subsidy. Nonetheless, welfare still increases for all households. When network externalities are excluded, the optimal subsidy decreases to 20%. Estimating the optimal subsidy jointly with tax reductions lowers the required subsidy, as less direct promotion is needed to incentivize EV adoption. Eliminating VAT on EVs yields an optimal subsidy of 25%, while eliminating car taxes implies an optimal subsidy of 17%. These instruments operate through different channels: VAT reductions lower the upfront purchase price, whereas car tax reductions lower the lifetime cost of vehicle ownership. Eliminating car taxes for EVs generates the highest EV penetration, with EVs accounting for 29.23% of the fleet and the share of households without a car falling to 53.86%. In this case, charging costs increase to 63.24 USD cents per kWh, and the number of charging stations rises. Fiscal revenues decline by 0.16% of GDP due to lower car and fuel tax revenues. Despite this fiscal cost, this scenario delivers the highest welfare outcome, with average household welfare reaching USD 5.17

thousand.

2.6.6 Ban on new ICE vehicles sales scenario

The scenario of banning ICE vehicles is implemented by increasing transaction costs for these vehicles until the ICE market closes in stationary equilibrium. I simulate this scenario for different price gaps levels to determine how much EV upfront costs should decrease to maintain household welfare at pre-ban levels. I also estimate how much should this cost decrease to keep the share of households with no car at pre-ban levels. Table 2.7 presents the results.

Table 2.7 – Price Convergence with Banning Analysis for Argentine Automobile Market.

Indicator	Unit of measure	Scenario	
		Constant welfare	Constant share no car
Setup			
Price reduction	Percentage	37	44
Fleet characteristics			
Share EVs	Percentage	100.00	100.00
No car ownership	Percentage	74.35	61.36
Charging variables			
Charging cost	U$S/KWh	72.71	79.21
Charging stations	Units per household	0.14	0.19
Environment			
Emissions	$MTCO_2eq$	2.72	3.81
Discarded batteries	Thousands	127.27	201.78
Fiscal revenue and welfare			
Fiscal outcome	% of GDP	0.57	0.74
High-inc. household welfare	TUSD per household	9.72	12.97
Medium-inc. household welfare	TUSD per household	2.57	3.93
Low-inc. household welfare	TUSD per household	1.10	1.72
Average welfare	TUSD per household	4.27	5.98

Note: Table 2.7 reports the price reduction that must be applied to EVs so, in a context of banning new ICEs sale, the average welfare of households remain the same (column 1). It also reports (column 2), the price reduction that must be applied to EVs so, in a context of banning new ICEs sale, the average share of households with no car remains the same.

Table 2.7 shows that maintaining constant household welfare requires a 37% reduction in EV prices. Under this scenario, all vehicles become EVs, and the share of households without a car increases to 74.35%. Charging costs rise to 72.71 USD cents/kWh, and the number of charging stations expands. Emissions fall sharply to 2.72 MTCO2eq, while discarded batteries increase to 127.27 thousand units per year. Fiscal revenues from the automobile fleet decline due to the loss of fuel tax revenues and the higher share of carless households relative to the baseline. If the objective is instead to maintain the baseline share of carless households, EV prices must fall by 44%. In this case, most variables behave similarly to the previous scenario, but higher EV adoption increases emissions from electricity generation and raises the number of discarded batteries. Fiscal outcomes improve with respect to the constant-welfare scenario as the government collects more revenue from car taxes and VAT, and lower vehicle ownership costs increase household welfare.

2.7 Conclusions

To assess the impact of policies promoting electric vehicles, I estimate a tractable dynamic model of the automobile market that includes both primary and secondary markets, following the framework described in Gillingham et al. (2022). The model incorporates a

market that is closely linked to EV adoption: the battery charging market. Given that these activities are still in their infancy in developing countries such as Argentina, the model includes an optimal investment framework for firms in the charging service sector. Furthermore, the model segments households by income level and accounts for network effects in EV adoption. I compute the stationary equilibrium by finding a price vector that clears all used-car markets and the battery charging service market, as well as the stationary ownership distributions.

Using data from Argentina, the paper simulates three counterfactual scenarios to assess how different policy measures affect EV adoption and related market outcomes. First, I evaluate the effects of subsidies on new EVs and charging infrastructure. To account for price dynamics, I perform the simulations under three EV price scenarios: the baseline price, a 7% reduction, and a 15% reduction. I find that subsidizing new EVs at baseline prices substantially boosts market penetration, increasing the EV share from less than 1% to over 11% at the highest subsidy considered ($s = 30\%$). When network effects operate, households suffer from limited charging infrastructure, reducing EV market penetration by up to 10.63 percentage points at $s = 30\%$ under baseline prices. EV adoption expands demand for charging services, reduces carbon emissions, and increases overall welfare, despite raising the number of discarded batteries. In contrast, subsidies to charging infrastructure have a minimal impact on market composition, although they slightly reduce charging costs. The results also show that the tax regime used to fund EV promotion is not distributionally neutral and plays a central role in shaping the policy's equity implications. Although the policy increases overall welfare, it generates heterogeneous income distribution outcomes, making the funding mechanism crucial for achieving equitable results, particularly in developing countries. These results are robust across the lower EV price scenarios considered.

I also identify optimal subsidy levels under alternative settings. Under current policies, a 29% subsidy maximizes social welfare. Excluding environmental externalities reduces the optimal subsidy to 24%, while excluding network externalities lowers it to 20%. Adjusting tax instruments further alters the optimal policy: eliminating VAT on EVs implies an optimal subsidy of 25%, whereas eliminating car taxes requires a 17% subsidy. Removing car taxes in combination with the optimal subsidy generates the highest EV market penetration.

Finally, a ban on new ICE vehicles requires a 37% reduction in EV prices to maintain household welfare, resulting in full fleet electrification and substantial emissions reductions, despite fiscal revenue losses. If the objective is instead to maintain the baseline share of carless households, EV prices must fall by 44%. In this case, a rebound effect on emissions emerges due to increased electricity demand for charging.

These findings highlight how tax policies, externalities, and market dynamics jointly shape effective strategies for the transition to electromobility in developing countries.

Appendices

Appendix A: A Brief Literature Review on the Evolution of the Modelling of the Automobile Market.

The methodological starting point of this article is the literature that studies durable goods. Durability allows a good to be exchanged in secondary markets and being used multiple times by different agents (Chen et al., 2013). Additionally, the durability of the good also leads to the formation of stocks, resulting in dynamic accumulation decisions (Gillingham et al., 2022). All of this generates complex patterns of buying and selling for these goods. An emblematic case of such markets is the automobile market.

This literature emerged in the 1980s with the works of Manski (1980), Manski and Sherman (1980), and Manski (1983) that introduced theoretical equilibrium models with secondary markets for the case of the automobile market and were the first approach to studying this phenomenon. The next significant contribution in this field was Berkovec (1985), who numerically estimated a large-scale equilibrium model with a new car market using a nested logit model. The author defined excess demand functions for each model and age by summing the estimated probabilities net of the number of cars scrapped. Berkovec (1985) computed the equilibrium using the Newton method to solve a system of equations derived from the excess demands. While these contributions were very advanced for the time (considering the low computing power of that time), they were not without limitations. All these works develop static equilibrium models. This is a significant limitation because, in durable goods markets, the decisions made by agents are dynamic and based on the formation of a stock or accumulation of an asset. Rust (1985) developed the first dynamic model of car exchange. He assumed that the state of the vehicle at a given time is captured by its odometer, which evolves according to a Markov process representing the random usage and deterioration of the car.

A relevant assumption of Rust (1985) is that there are no transaction costs. This assumption is quite unrealistic considering the general functioning of the automobile market. The main limitation was that equilibrium existence could not be demonstrated with transaction costs. This remained the case until the seminal paper of Konishi and Sandfort (2002), where the existence of the stationary equilibrium in the presence of transaction costs was established using advanced functional analysis methods (Fan and Glicksburg fixed-point theorem). Additionally, Stolyarov (2002) contributed to this literature by suggesting that a vehicle's state could be summarized by its age and computed a dynamic equilibrium for a model with transaction costs using a fixed-point formulation of the problem.

From the advances made by the literature in the early 2000s, many variants of these models emerged focusing on different aspects of the automobile market. For instance, Esteban and Shum (2007) studied the effect of product durability and the existence of secondary markets on firm equilibrium behavior. They constructed a dynamic oligopoly model with product differentiation to incorporate the dynamics arising from durability and secondary markets. Chen et al. (2013) constructed and calibrated a dynamic equilibrium

model with durable goods to understand the role of secondary markets in oligopolistic industries with product depreciation and heterogeneous population. This model is the first to study an oligopoly with durable goods under a framework of Markov Perfect Equilibrium (MPE). Within this group of modern research in the automonile market, other articles such as Gavazza et al. (2014), Gavazza and Lanteri (2021), and Gillingham et al. (2022) can be found.

Appendix B: Car Market Data and Driving Patterns in Argentina

This section describes the residential vehicle fleet and household characteristics. It also outlines the methodology used to update variables related to fuel and car purchase expenditures. I estimate car ownership profiles using data from the 2017/2018 National Household Survey. Based on the same source, I also derive expenditure patterns for fuel and car purchases and update them to 2024. The update relies on price changes between 2018 and 2024 to infer variations in quantities and prices. Adjusting fuel demand also allows for an updated estimate of kilometers driven. To carry out this process, I use data from:

- The 2017/2018 National Household Survey (ENGHo) and the Consumer Price Index published by INDEC.
- The Annual Vehicle Fleet Report published by AFAC[22].
- The national database of fuel prices published by the Argentine Secretariat of Energy.
- The automobile price index published by the National Association of Automobile Commerce (CCA, by its Spanish acronym).
- The exchange rates published by the Central Bank of the Argentine Republic.

Geographical Distribution of Vehicles

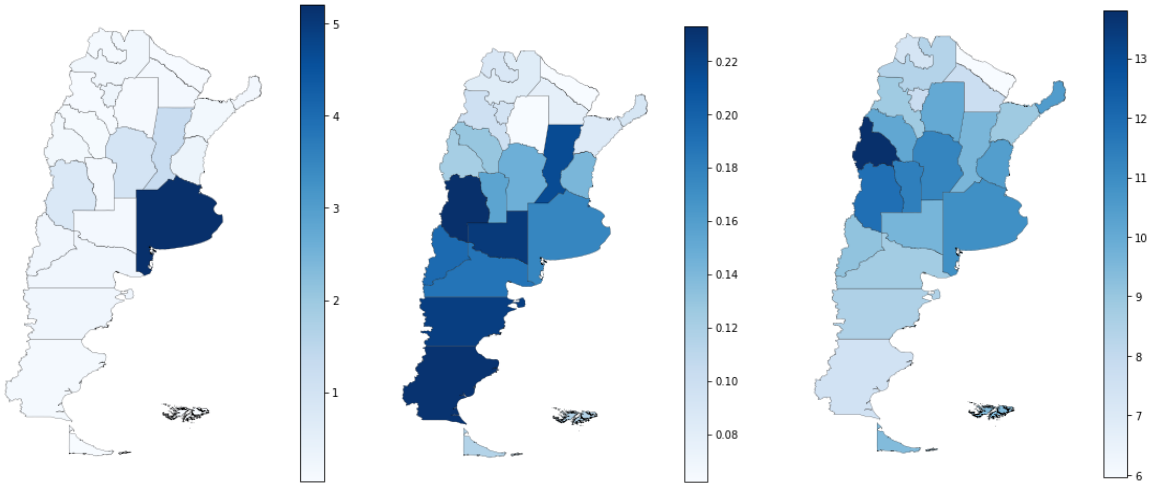
The 2024 Annual Vehicle Fleet Report by AFAC reports that Argentina's vehicle fleet totals 15.56 million units. Of this total, 81.2% are automobiles, 14.7% are light or utility vehicles, and the remaining share consists of heavy vehicles. Figure 2.7 show the regional distribution of the automotive fleet, the number of cars per person for each province in Argentina, and the average age distribution of the fleet by province. These maps were constructed based on data from the Equipment Survey and the Household Expenditure Survey included in the 2017/2018 ENGHo. The first survey was necessary to identify households with cars and their ages, while the second was used as a weighting factor to extrapolate sample results. The values for the total fleet were taken from the 2024 AFAC annual report and distributed according to regional results obtained from the ENGHo.

Figure 2.7 shows that the majority of the automotive fleet is concentrated in the area of the Province of Buenos Aires and the Autonomous City of Buenos Aires. This region is followed in importance by Córdoba, Santa Fe, and Mendoza. This result is intuitive since these regions are where the majority of the Argentine population is concentrated. However, in terms of density, the most relevant provinces are those located in the south and center of the country, with the least relevant being those in the north. This is

[22] Argentine Association of Automotive Factories

mainly due to the large distances between towns in the southern region of Argentina, which requires the use of personal vehicles. Finally, it is observed that older cars are concentrated in the central and central-western regions of the country.

Figure 2.7 – Information on the Argentine residential vehicle fleet by province.



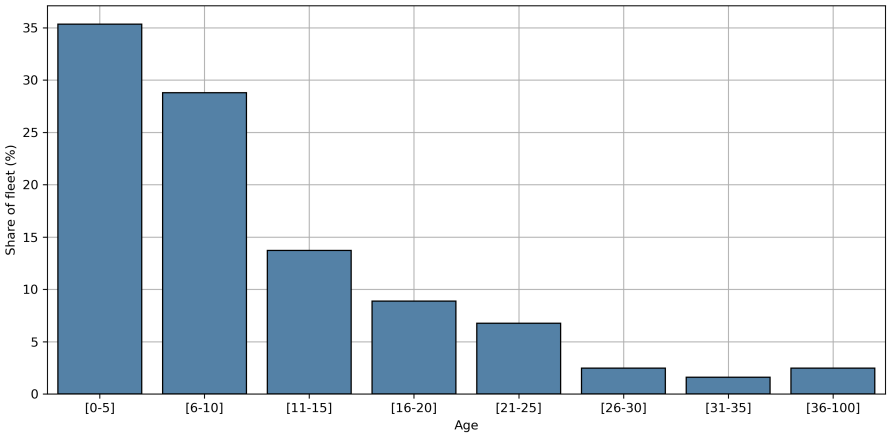
(a) Number of vehicles **(b)** Vehicles per person **(c)** Average age

Note: Figure 2.7 presents three maps showing the territorial intensity of Argentina with provincial division. Each map is assigned one of three variables: (i) Number of vehicles, (ii) Vehicles per person, and (iii) Average age of the residential fleet. Darker colors are associated with higher variable values, while lighter colors correspond to lower values. Note: Figure elaborated from ENGHo data and the 2024 AFAC annual report.

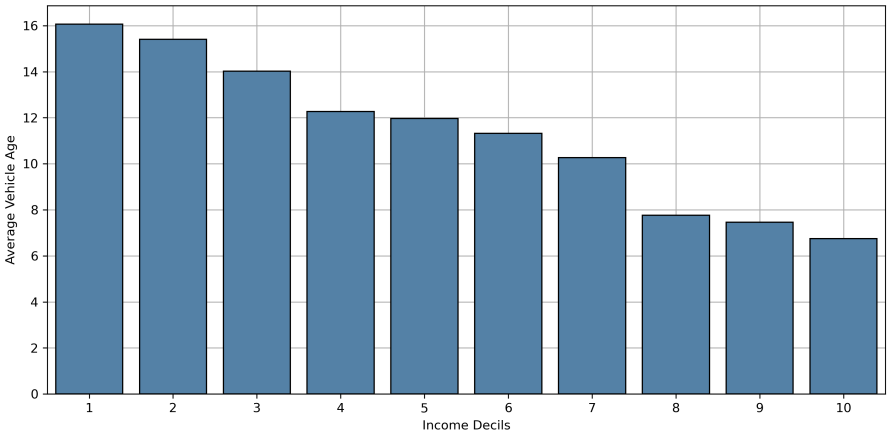
Age of the Residential Vehicle Fleet

Figure 2.8 presents a histogram showing the distribution of the residential vehicle fleet by age in five-year blocks and the average age of the fleet by income deciles. Like the previous figure, this one was elaborated based on the Equipment Survey and the Household Expenditure Survey of the ENGHo.

Figure 2.8 – Infographic on the age of the vehicle fleet.



(a) Distribution of fleet by age



(b) Average age by income quintile

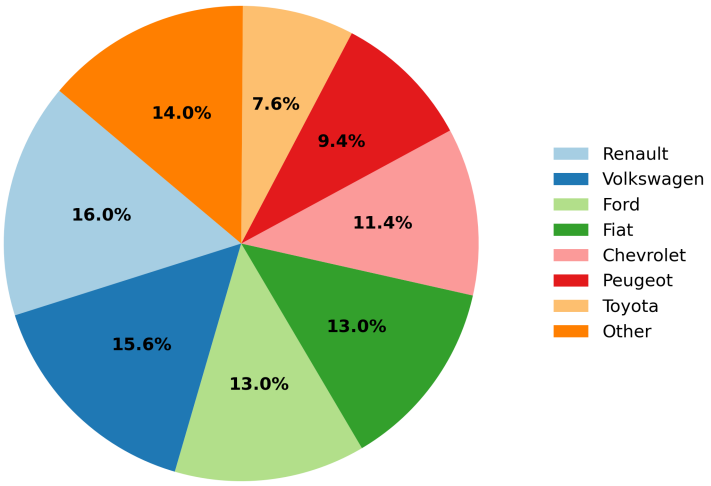
Note: Figure 2.8 reports the distribution of vehicles in the residential vehicle fleet by fleet age in five-year blocks and the average age of the vehicle per income quintile. Note: Figure elaborated from ENGHo data.

Figure 2.8 shows that more than half of the residential vehicle fleet is less than 9 years old, and only 4% of the fleet is over 30 years old. Likewise, it can be seen that the average age of the vehicle owned by each quintile decreases as income increases. Thus, vehicles owned by the poorest quintile have an average age of approximately 16 years, while for the wealthiest quintile, this value is approximately 7 years.

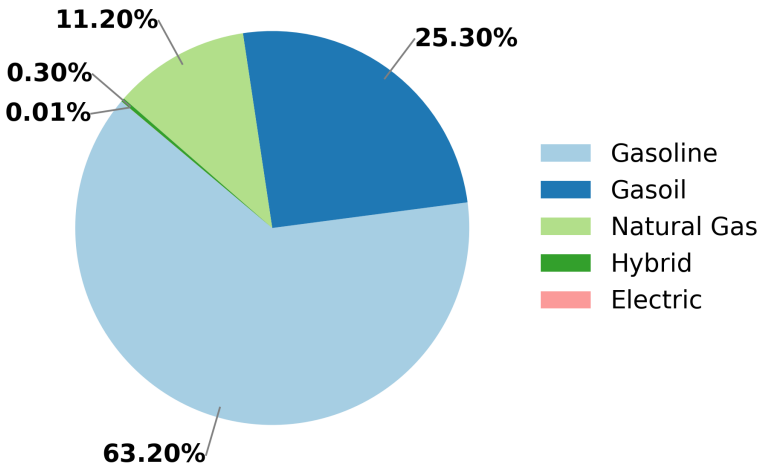
Characteristics of the Vehicle Fleet

Figure 2.9 presents the characteristics of the residential vehicle fleet, showing its composition by brand and type of engine.

Figure 2.9 – Infographic on the composition of the vehicle fleet.



(a) Brand



(b) Type of engine

Note: Figure 2.9 presents the composition of the vehicle fleet according to two variables: (a) vehicle brand and (b) type of engine. Note: GNC: Natural Gas. Note: This information is available at th 2024 Annual Report on the Automobile fleet published by AFAC.

As of 2024, the vehicle fleet shows a fairly equitable distribution among brands, with Renault, Volkswagen, and Ford (followed closely by Fiat) having the largest market share. Likewise, 63.2% of vehicles are powered by gasoline. It is important to note that by 2024, the participation of electric cars in the Argentine fleet is very low, accounting for only 0.01% of the total.

Structure of Fuel Consumption, Vehicle Purchases, and Household Sales Income

Figure 2.10 shows the structure of fuel consumption by income deciles in 2024, measured in US dollars. It reports average fuel expenditure by income level, estimated using data from the 2017/2018 ENGHo. I updated the original estimates to 2024 by combining official fuel price time series (including taxes) from the Argentine Secretariat of Energy with

the price-elasticities estimated in Khanna et al. (2023). The estimation includes the three main fuel types used in Argentina: (i) gasoline, (ii) diesel, and (iii) natural gas.

To account for differences in household behavior, I assigned fuel price elasticities by income group, following Khanna et al. (2023):

- Low-income households: -0.8
- Middle-income households: -0.66
- High-income households: -0.4

This approach captures how fuel consumption reacts to price changes across the income distribution. I define low-income households as the first three deciles of the distribution, middle-income households as the following four deciles, and high-income households as the three richest deciles in the distribution.

To update fuel expenditures, I applied the following method. Let p_i represent the price index of fuel i in Argentine pesos, and let e represent the exchange rate index. Both indices use 2018 as the base year. I define the dollar-denominated price index of fuel i as:

$$P_i = \frac{p_i}{e}$$

Next, let UP be the US Consumer Price Index, also with 2018 as the base year. Then, the real price index of fuel i in constant US dollars is:

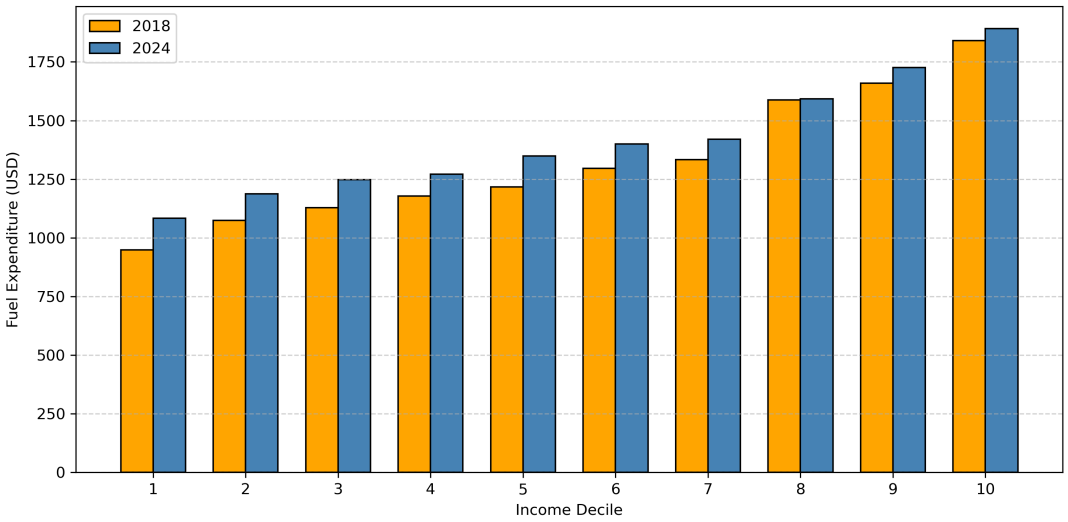
$$\hat{P}_i = \frac{P_i}{UP}$$

I use this real price change to estimate the shift in fuel demand. For each household h, with price elasticity σ_h, the percentage change in demand for fuel i is given by:

$$\Delta q_{ih} = \sigma_h \cdot \hat{P}_i$$

With this, I calculate how much fuel consumption and expenditures change between the survey year and 2024. Starting from the observed 2018 consumption, measured in US dollars, I apply the elasticity-based quantity adjustment and multiply it by the updated dollar price P_i. This method provides an estimate of 2024 expenditures across income levels. The last subsection of this appendix reports the price variations for each fuel.

Figure 2.10 – Argentina. Fuel consumption structure by income deciles. Comparisson 2018 versus 2024.



Note: Figure 2.10 shows the average annual expenditure on fuels (Gasoline, Diesel, and CNG) by households according to income deciles measured in current US dollars. The data were estimated from the 2017/2018 ENGHo and updated to 2024 using fuel price data published by the Ministry of Energy and using the price elasticity estimated in Khanna et al. (2023).

Note that Δq_{ih}, together with the fuel efficiency of the average vehicle using fuel i, can be used to update the amount of kilometers each household drives.

The method for updating vehicle purchase expenditures follows a similar approach to that used for fuels. I assign income-specific price elasticities based on Leard and Wu (2023):

- Low-income households: -0.8
- Middle-income households: -0.4
- High-income households: -0.2

To update vehicle expenditure, I define p^v as the price index of automobiles in Argentine pesos. Let e denote the exchange rate index. Then, the dollar-denominated price index of vehicles is:

$$P^v = \frac{p^v}{e}$$

Let UP be the US Consumer Price Index, with 2018 as the base year. The real vehicle price index in constant US dollars is:

$$\hat{P}^v = \frac{P^v}{UP}$$

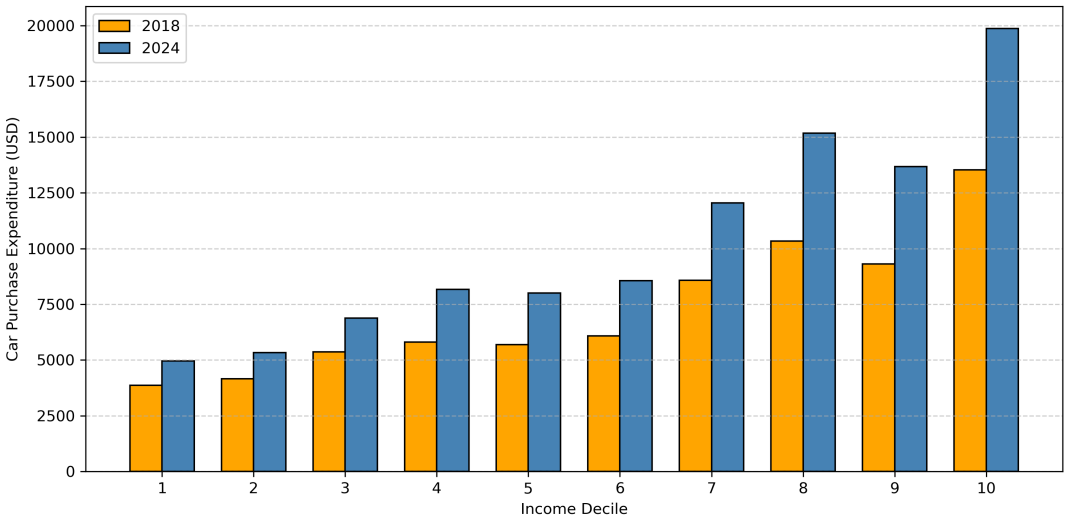
For each household h, with vehicle price elasticity σ_h^v, the percentage change in vehicle demand is:

$$\Delta q_h^v = \sigma_h^v \cdot \hat{P}^v$$

As with fuel expenditures, I use this change in quantities together with the updated price P^v to estimate vehicle expenditure in 2024. The last subsection of this appendix reports the price variations for automobiles.

Figure 2.11 compares vehicle expenditures in 2018 with the updated estimates for 2024, across income deciles.

Figure 2.11 – Comparison of vehicle expenditures in 2018 and estimated values for 2024, by income decile



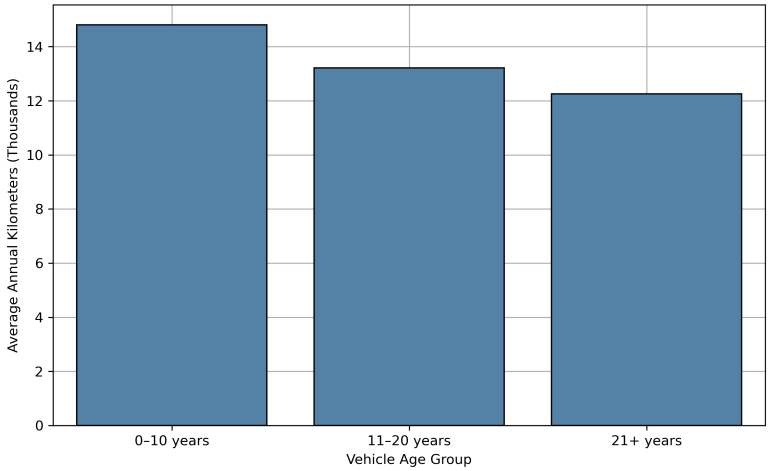
Note: The figure shows the average expenditure on vehicles for households that purchased a car in 2018, along with the estimated value for 2024 based on price changes and income-specific elasticities.

Kilometers

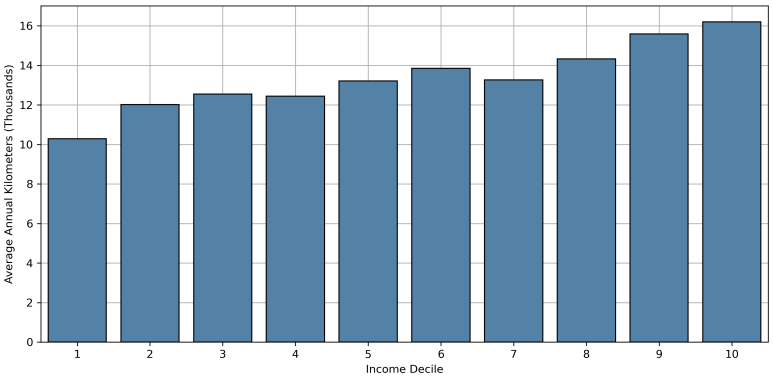
This subsection presents the estimated kilometers driven by households in 2024. As explained in the previous subsection, I used Δq_{ih}, along with the average fuel efficiency of vehicles using fuel i, to estimate the number of kilometers each household drives. Appendix C reports fuel efficiencies.

Figure 2.12 displays these estimates. Panel (a) shows the average annual kilometers driven by vehicles, grouped into three age categories. Panel (b) shows average kilometers driven by households with cars, across income deciles.

Figure 2.12 – Estimated kilometers driven by households, by vehicle age and income decile



(a) Kilometers driven by vehicle age



(b) Kilometers driven by income decile

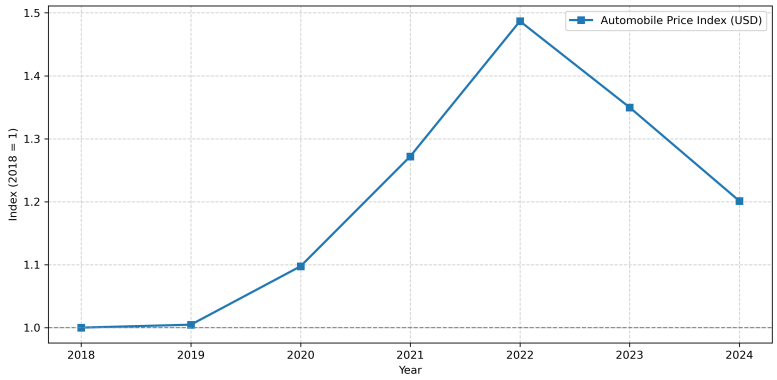
Note: Figure 2.12 presents the estimated kilometers driven in 2024 by income decile and by vehicle age. Panel (a) groups vehicles into three age categories: [0–10], [11–20], and over 20 years.

Figure 2.12 shows that wealthier households drive more kilometers on average, while kilometers decreases steadily as income falls. It also confirms that newer vehicles tend to be driven more, which aligns with the fact that newer cars are typically owned by higher-income households.

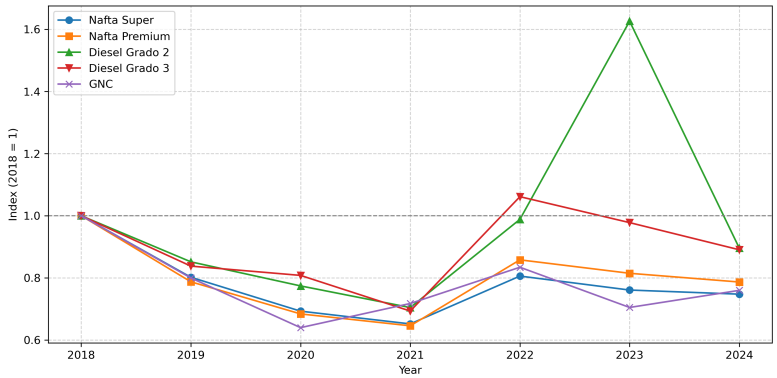
Prices

This subsection presents the price indices used to estimate fuel and vehicle expenditures. Figure 2.13 displays the relevant indices.

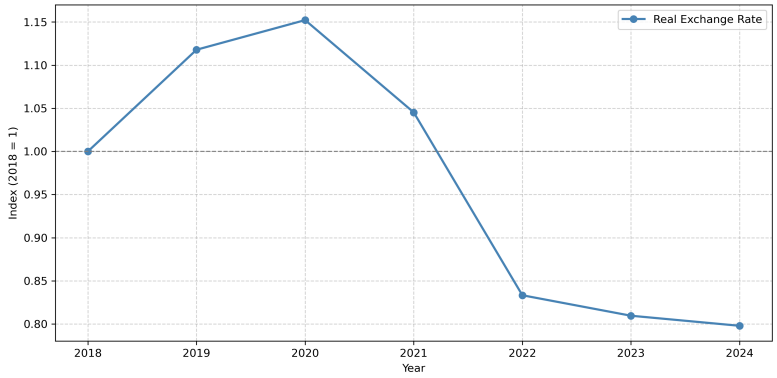
Figure 2.13 – Real exchange rate, average automobile prices, and fuel price indices



(a) Real Automobile Price Index



(b) Fuel Price Indices



(c) Real Exchange Rate Index

Note: Figure 2.13 shows the price indices from 2018 to 2024, with 2018 as the base year. Real exchange rate data were obtained from the Central Bank of the Argentine Republic. Fuel prices come from the Argentine Secretariat of Energy, and the automobile price index was provided by the National Association of Automobile Commerce (CCA, by its Spanish acronym).

Appendix C: Exogenous Parameters

Table 2.8 – List of exogenous parameters and their data sources.

Parameter	Value	Unit	Source
Cost of transfer - purchase	4.7	% of car value	DNRPA
Cost of transfer - sale	0.75	% of car value	DNRPA
Annual car tax expense	3%	% of car value	Average provincial laws
Annual insurance expense	5%	% of car value	Average Web quotation
VTV	20	Annual dollars	VTV
New EV price	39.796	Dollars	Own price estimations: See the corresponding appendix
New ICE vehicle price	20.422	Dollars	Own price estimations: See the corresponding appendix
Fuel cost at buyer's price	1.01	Dollars per unit	SENER
Maximum age per car	30	Years	ENGHo
ICE vehicle performance	10.1	km per fuel unit	2022 FCG - Canada
EV performance	4.76	km per KWh	2022 FCG - Canada
ICE vehicle emissions coefficient	242.02	Gr CO2eq / km	2022 FCG - Canada
Electric sector emissions coefficient	285.41	Gr CO2eq / kwh	CAMMESA
EV emissions coefficient	60.22	Gr CO2eq / km	Own calculation
Size of residential fleet	12.4	Million of cars	AFAC
Public charger cost	48	Thousands of U$S / charger	(1)
Probability of serious accident	1	%	Gillingham et al. (2022)
Scrap price	1	Thousands of U$S Dollars	Gillingham et al. (2022)
Beta	0.93	[0,1)	Garcia-Cicco et al. (2010)
Chargers depreciation rate	8	%	Assumption
Electricity cost	0.09	U$S/KWh	CAMMESA
γ	328,5	Thousands of KWh	(2)
Curvature Prod. Function (θ)	0.78	[0,1)	(3)
Charging sector tax rate	16	Percentage	COU-INDEC
$\bar{m}$	100	households per charger	(4)
Noise Externality	0.007	2017 EUR/KM	Gössling et al. (2019) (5)
Local Air Pollution Externality	0.007	2017 EUR/KM	Gössling et al. (2019) (5)
Climate Change Externality	0.011	2017 EUR/KM	Gössling et al. (2019) (5)
Share Home-Charging	50	%	ENGHo-INDEC
$f_{\tau 1}$	0.3	[0,1]	(6)
$f_{\tau 2}$	0.4	[0,1]	(6)
$f_{\tau 3}$	0.3	[0,1]	(6)

Note: FCG: Fuel Consumption Guide; DNRPA: Dirección Nacional de Registro de la Propiedad Automotor (National Directorate of Automotive Ownership Registry); VTV: Verificación Técnica Vehicular (Vehicle Technical Verification); SENER: Secretaría de Energía (Secretary of Energy); ENGHo: National Households Expenditure Survey; AFAC: Asociación de Fábricas Argentinas de Componentes (Association of Argentine Component Factories); COU-INDEC: National Supply and Use Table for Argentina provided by the National Institute of Statistics (INDEC).

This part of the appendix is dedicated to complement information providaded in the previous table for the entries where a number was given:

1. For the cost of public chargers, I use a value of 48,000 USD per unit, which is consistent with traditional 50 kW DC fast (Type 3) chargers. According to the U.S. Department of Energy,[23] charging equipment costs vary widely depending on the application, location, charging level, and technology. Smith and Castellano (2015) documents that Level 1 public chargers cost between 300 and 1,500 USD, while Level 2 chargers range from 400 to 6,500 USD per connector. DC fast chargers typically fall between 10,000 and 40,000 USD per connector, with higher costs for greater power output. Installation costs also differ significantly, from roughly 3,000 USD for Level 2 chargers to about 20,000 USD for DC fast chargers. Following Nicholas (2019), I adopt the cost of a standard 50 kW DC fast charging station—28,000 USD for the equipment plus 20,000 USD for installation, resulting in a total cost of 48,000 USD per charger.

2. To estimate the maximum annual energy supply of a public charger, I multiply its power rating (50 kW) by 18 hours of operation per day and by 365 days per year.

[23] https://afdc.energy.gov/fuels/electricity-infrastructure-development

3. I assume a parameter $\theta = 0.78$, which governs the curvature of the production function for public charging services.

4. If there are 100 households per charger, approximately 60% of them own a vehicle (implying 60 vehicle-owning households per charger), and approximately 41% of vehicle owners charge at home (which I approximate using the share of households without a garage). This leaves about 36.6 EV owners per charger.

5. Because the values are reported in 2017 euros, I adjust them to 2023 using the European Union price index provided by FRED[24]. Over the 2017–2023 period, this index implies cumulative inflation of 18%. I then convert the resulting values into 2023 U.S. dollars using the average euro–dollar exchange rate for 2023 reported by the IRS,[25] equal to 1.08 USD/EUR.

6. The participation of high, middle, and low-income households in the total population is a construction of the author. In this article, households are defined as high-income if they belong to the top 30% of the income distribution, as low-income if they belong to the lowest 30% of the income distribution, and as middle-income if they belong to the 40% between these two.

Appendix D: The Methodology to Compute the Model

This subsection describes the procedure to compute the solution of the model. The algorithm associated with solving the model has the following logical structure:

1. Take an initial price vector P and solve the household dynamic problem $\mathbf{E}V = \mathbf{\Gamma}(\mathbf{E}V)$ for the fixed point $\mathbf{E}V(P)$ using Newton-Kantorovich iterations for each τ.

2. From $\mathbf{E}V(P)$, calculate the exchange matrix $\mathbf{\Omega}^{\tau}(P)$ and the physical transition matrix Q.

3. Compute the ownership distribution $q(P)$ and $q^{\tau}(P)$ as invariant distributions.

4. Calculate the excess demands and update the price vector P via the Newton method. $P' = P - [\nabla_P ED(P, q(P))]^{-1} ED(P, q(P))$.

5. End the process if $ED(P', q(P')) = 0$ and use P' as the solution. Otherwise, replace P with P' and start the algorithm from scratch.

This algorithm has two instances: first, the instance of solving the household´s dynamic problem, and, second, there is the instance of calculating the equilibrium. Finally, there is a third instance that consists on estimating the unknown parameters through a minimum distance estimator that seeks to minimize the difference between the model results and the data.

[24] https://fred.stlouisfed.org/series/CP0000EZ19M086NEST

[25] https://www.irs.gov/individuals/international-taxpayers/yearly-average-currency-exchange-rates

Appendix E: Proofs for Propositions

Proposition 1: *Manipulating the previous first order conditions under $\mu = 0$. Then, y^* and X^* are:*

$$y^* = \left(\frac{z\theta}{c_y}\left(p - \frac{c_e(1+\delta-\beta)}{\gamma}\right)\right)^{\frac{1}{1-\theta}}$$
$$X^* = \frac{F(y^*)}{\gamma}$$

Recall that the KKT conditions established for the stationary problem of the representative firm are these ones:

$$\frac{\partial \mathcal{L}}{\partial X} : c_e + \frac{\delta c_e}{1-\beta} = \lambda\gamma + \mu,$$
$$\frac{\partial \mathcal{L}}{\partial y} : \frac{p\theta z y^{\theta-1} - c_y}{1-\beta} = \lambda\theta z y^{\theta-1},$$
$$\frac{\partial \mathcal{L}}{\partial \lambda} : \gamma X - z y^{\theta} = 0$$
$$KKT1 : \mu \geq 0,$$
$$KKT2 : X \geq 0,$$
$$KKT3 : \mu X = 0$$

If the non-negativity constraint is not bidding ($\mu = 0$) meaning that $X > 0$ we can obtain the optimal λ from $\frac{\partial \mathcal{L}}{\partial X}$. Particularly, it is possible to find that:

$$\lambda = \frac{1}{\gamma}\left(c_e + \frac{\delta c_e}{1-\beta}\right) = \frac{c_e(1-\beta+\delta)}{\gamma(1-\beta)}$$

To conclude, we replace λ in $\frac{\partial \mathcal{L}}{\partial y}$. Finding that:

$$\frac{p\theta z y^{\theta-1} - c_y}{1-\beta} = \lambda\theta z y^{\theta-1}$$
$$p - \frac{c_y}{\theta z y^{\theta-1}} = \lambda(1-\beta)$$
$$p - \lambda(1-\beta) = \frac{c_y}{\theta z y^{\theta-1}}$$
$$pz\theta - z\theta\lambda(1-\beta) = c_y y^{1-\theta}$$
$$\left(\frac{pz\theta}{c_y} - \frac{z\theta\lambda(1-\beta)}{c_y}\right)^{\frac{1}{1-\theta}} = y$$
$$pz\theta - z\theta\lambda(1-\beta) = c_y y^{1-\theta}$$
$$\left(\frac{pz\theta}{c_y} - \frac{z\theta c_e(1-\beta+\delta)}{c_y\gamma}\right)^{\frac{1}{1-\theta}} = y$$
$$\left(\frac{z\theta}{c_y}\left(p - \frac{c_e(1+\delta-\beta)}{\gamma}\right)\right)^{\frac{1}{1-\theta}} = y^*$$

Now that y^* was obtained, to get X^* it is required to replace y^* in $\frac{\partial \mathcal{L}}{\partial \lambda}$ getting:

$$X^* = \frac{F(y^*)}{\gamma}$$

Proposition 2: $\mu = \frac{1}{1-\beta}(c_e(1-\beta+\delta) - p\gamma)$

To star with this demonstration let´s recall the KKT conditions of the stationary problem for the representative firm:

$$\begin{aligned}
\frac{\partial \mathcal{L}}{\partial X} &: c_e + \frac{\delta c_e}{1-\beta} = \lambda\gamma + \mu, \\
\frac{\partial \mathcal{L}}{\partial y} &: \frac{p\theta z y^{\theta-1} - c_y}{1-\beta} = \lambda\theta z y^{\theta-1}, \\
\frac{\partial \mathcal{L}}{\partial \lambda} &: \gamma X - z y^{\theta} = 0 \\
KKT1 &: \mu \geq 0, \\
KKT2 &: X \geq 0, \\
KKT3 &: \mu X = 0
\end{aligned}$$

From $\frac{\partial \mathcal{L}}{\partial y}$ it is possible to get:

$$\frac{p}{1-\beta} - \frac{c_y}{(1-\beta)\theta z y^{\theta-1}} = \lambda$$

Now, it is possible to replace in $\frac{\partial \mathcal{L}}{\partial X}$:

$$\begin{aligned}
c_e + \frac{\delta c_e}{1-\beta} - \lambda\gamma &= \mu \\
c_e + \frac{\delta c_e}{1-\beta} - \frac{p\gamma}{1-\beta} + \frac{c_y\gamma}{(1-\beta)\theta z y^{\theta-1}} &= \mu \\
\frac{1}{1-\beta}\left(c_e(1-\beta+\delta) - p\gamma + \frac{c_y\gamma}{\theta z y^{\theta-1}}\right) &= \mu
\end{aligned}$$

From $\frac{\partial \mathcal{L}}{\partial \lambda}$ it is possible to get that $y = \left(\frac{\gamma X}{z}\right)^{\frac{1}{\theta}}$ and it can be used together with the previous equation:

$$\begin{aligned}
\frac{1}{1-\beta}\left(c_e(1-\beta+\delta) - p\gamma + \frac{c_y\gamma}{\theta z\left(\frac{\gamma X}{z}\right)^{\frac{\theta-1}{\theta}}}\right) &= \mu \\
\frac{1}{1-\beta}\left(c_e(1-\beta+\delta) - p\gamma + \frac{c_y\gamma}{\theta z}\left(\frac{\gamma X}{z}\right)^{\frac{1-\theta}{\theta}}\right) &= \mu
\end{aligned}$$

Note that if $\mu > 0 \Rightarrow X = 0$. Therefore, a positive μ implies that:

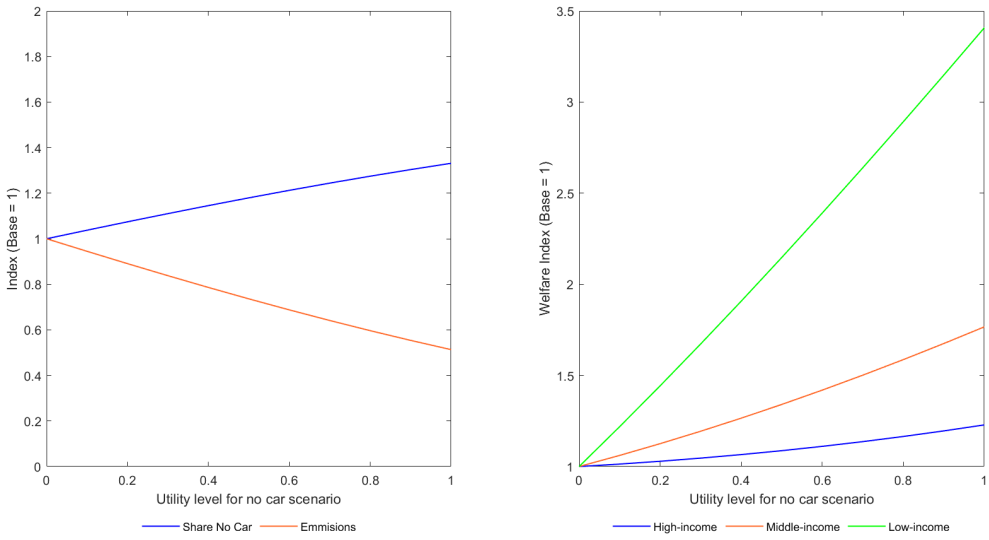
$$\frac{1}{1-\beta}\left(c_e(1-\beta+\delta) - p\gamma\right) = \mu$$

Appendix F: Public Transportation Enhancement Scenario

This scenario aims to assess the role of the expansion and improvement of public transportation services. In the context of this model, improvements in public transportation can be simulated as increases in the utility of the situation where the consumer does not

own a car ($\emptyset$). This would improve household welfare and, simultaneously, draw people away from using cars (Gillingham et al., 2022). For calibration, the utility derived from the situation without a car is normalized to zero. Thus, to illustrate the impact of improvements in public transportation, this parameter is increased. Variations of utility are simulated such that $\Delta u(\emptyset) \in (0, 1]$. Figure 2.14 presents the results for this set of simulations.

Figure 2.14 – Enhancement of public transportation.



Note: The first graph (a) contains the evolution of the proportion of households without cars and emissions for the simulated interval. The second graph (b) contains the evolution of welfare by income for the simulated interval.

Developing and improving public transportation results in a reduction in emissions motivated by a transition from using private vehicles as a means of transportation to using public transportation. Likewise, the benefits of these improvements are concentrated on low-income households as they are the ones that demand these services the most. Therefore, it is observed that improvements in public transportation yield a double dividend: simultaneous benefits in environmental and welfare terms.

Appendix G: Vehicle Prices

This section describes the data sources and procedures used to estimate vehicle prices. First, I compiled a list of ICE vehicles and EVs, along with their corresponding prices. EV prices come from the EVdatabase website, while ICE prices were obtained from the Automobile Trade Association dataset. Because each model can have multiple versions, I consistently selected the base version. To build the list, I included the models sold as new during the reference year for the main brands in the country. Second, I recorded each vehicle's segment. Finally, I assigned vehicles to one of three price categories: Low, Medium, or High following the 2022 and 2023 AFAC reports on the automobile market. It is important to note that the price scale differs substantially between EVs and ICEs. For EVs, I determined the price category by observing that Low typically corresponds to segment A, Medium to segments B and C, and High to segment D. Some segment C models may also fall into the High category, which represents a limitation of this classification

approach. Luxury vehicles have not been considered.

Table 2.9 and Table 2.10 report the data on ICE and EV prices.

Table 2.9 – ICE vehicle models and prices (2023)

Model	2023 USD Price	Segment	Type
Peugeot 208	14235	B	Low
Peugeot 308	20946	C	Low
Peugeot 2008	21351	B	Low
Peugeot 3008	48073	C	High
VW Polo	17905	B	Low
VW Taos	29354	C	Medium
Ford Ecosport	19326	B	Low
Ford Mondeo	35135	D	High
Peugeot Partner	15541	B	Low
Toyota Corolla	20946	C	Low
Toyota Etios	17009	B	Low
Toyota Yaris	15227	B	Low
Toyota Camry	50000	D	High
Fiat Cronos	12838	B	Low
Fiat 500	25568	A	Medium
Fiat Argo	13697	B	Low
Fiat Pulse	16622	B	Low
Chevrolet Joy	11486	B	Low
Chevrolet Onix	16646	B	Low
Citroën C3	16024	B	Low
Citroën Berlingo	14330	B	Low
Nissan Leaf	48149	C	High
Nissan Kicks	24189	C	Medium
Nissan Sentra	21758	C	Medium
Renault Kwid	10811	A	Low
Renault Sandero	14386	B	Low
Renault Logan	12291	B	Low
Renault Kangoo	18304	B	Low
Honda Civic	27728	C	Medium
Honda Fit	29105	B	Medium
Honda Accord	41211	D	High
Honda HR-V	25959	C	Medium

Table 2.10 – EV vehicle models and prices (2023)

Model	2023 USD Price	Segment	Type
Nissan Leaf	39578	C	Medium
Nissan Ariya	60940	C	Medium
Renault Zoe	40943	B	Medium
Renault Twingo	34360	A	Low
Renault Megane E	50498	C	Medium
Dacia Spring (Sandero)	33251	A	Low
Fiat 500e	42581	A	Low
Fiat 600e	45045	B	Medium
Peugeot 208e	42998	B	Medium
Citroën e-C3	28665	B	Medium
Citroën ë-C4	43673	C	Medium
Berlingo Electric	45475	B	Medium
Ford Mustang Mach-E	81668	D	High
VW ID Series	57330	C	Medium
Opel Astra Electric	51590	C	Medium
Opel Corsa Electric	44287	B	Medium
Tesla Model 3	58681	D	High
Tesla Model Y	61411	D	High
Toyota Yaharis	30030	A	Low
Toyota BZ4X	62940	D	High

Since there is no information on the distribution of sales across brands and models, I computed the simple average price for ICEs and EVs within each type. Finally, the

average price of each vehicle was obtained by weighting the corresponding average price by the share of each category in the circulating fleet, as reported in the 2023 AFAC report.

Appendix H: Sensitivity Analysis for the Productivity of Public Charging Infrastructure

This subsection reports the results of the sensitivity analysis for the productivity of the charging infrastructure sector. I rerun the simulations for subsidies to new EVs ($s \in [0, 0.3]$) and to new public charging infrastructure ($s_c \in [0, 0.3]$), increasing the productivity of the charging sector by 10%. Table 2.11 reports the former, and Table 2.12 reports the latter. These simulations show that the results for subsidies to new EVs are sensitive to the productivity of the charging service sector, particularly at intermediate EV price levels. A more productive charging sector lowers charging costs and, in turn, reduces vehicle ownership costs. In contrast, the effects of subsidies to new public charging infrastructure remain small. This reinforces the conclusion that the main barrier to EV adoption is the upfront purchase cost of vehicles and that low levels of charging infrastructure reflect weak demand rather than high investment costs.

Table 2.11 – Sensitivity Analysis: Counterfactual Simulations to Estimate the Impacts of Subsidies to new EVs.

Indicator	Unit of measure	Subsidy scenarios					
Setup							
Subsidy rate	Percentage	0	10	15	20	25	30
Price Scenario: BASE							
Fleet characteristics							
Share EVs	Percentage	0.37	1.00	1.71	3.11	6.74	22.64
Share EVs: Network Penalty	Percentage	-2.01	-4.56	-6.63	-9.22	-11.17	-2.78
No car ownership	Percentage	60.40	60.28	60.15	59.88	59.17	55.59
Charging variables							
Charging cost	USD cents/KWh	21.57	26.73	30.02	34.24	40.66	53.94
Charging stations	Unit per household	0.00	0.01	0.01	0.01	0.03	0.07
Environment							
Emissions	$MTCO_2eq$	12.98	12.86	12.72	12.44	11.76	9.11
Discarded batteries	Thousands	1.11	2.42	3.89	6.88	14.95	55.44
Fiscal revenue and welfare							
Fiscal outcome	% of GDP	0.61	0.62	0.62	0.62	0.63	0.65
Average welfare	TUSD per household	4.26	4.28	4.30	4.32	4.36	4.45
Price Scenario: 7%							
Fleet characteristics							
Share EVs	Percentage	0.74	1.98	3.54	7.60	23.53	34.77
Share EVs: Network Penalty	Percentage	-3.59	-7.26	-9.72	-11.10	-2.32	0.00
No car ownership	Percentage	60.33	60.09	59.80	58.99	55.36	52.33
Charging variables							
Charging cost	USD cents/KWh	25.02	31.00	35.21	41.78	54.45	60.17
Charging stations	Unit per household	0.00	0.01	0.01	0.03	0.08	0.11
Environment							
Emissions	$MTCO_2eq$	12.91	12.66	12.36	11.60	8.97	7.46
Discarded batteries	Thousands	1.88	4.46	7.80	16.93	57.96	92.66
Fiscal revenue and welfare							
Fiscal outcome	% of GDP	0.62	0.62	0.62	0.63	0.65	0.67
Average welfare	TUSD per household	4.28	4.32	4.37	4.45	4.75	4.58
Price Scenario: 15%							
Fleet characteristics							
Share EVs	Percentage	1.71	5.17	13.07	28.61	37.66	47.48
Share EVs: Network Penalty	Percentage	-6.63	-10.88	-8.72	-0.39	0.00	0.00
No car ownership	Percentage	60.15	59.48	57.83	54.04	51.46	48.22
Charging variables							
Charging cost	USD cents/KWh	30.02	38.31	47.31	57.20	61.48	65.59
Charging stations	Unit per household	0.01	0.02	0.04	0.09	0.12	0.15
Environment							
Emissions	$MTCO_2eq$	12.72	12.05	10.64	8.25	7.12	6.15
Discarded batteries	Thousands	3.89	11.40	30.06	72.95	102.68	140.97
Fiscal revenue and welfare							
Fiscal outcome	% of GDP	0.62	0.62	0.64	0.66	0.67	0.67
Average welfare	TUSD per household	4.34	4.47	4.75	5.19	5.11	4.75

Note: Table 2.11 reports results for $s \in [0, 0.3]$ under two setups: (i) with network effects and (ii) without network effects ($\eta = 0$). The network penalty, reported in the second line of Fleet Characteristics, measures the share of EVs that does not enter the market due to low abailability of infrastructure. I evaluate outcomes under three EV price levels: the baseline price (see Section 3 and Appendix C), a 7% reduction reflecting recent battery-driven cost declines (IEA, 2025b), and a 15% reduction reflecting further technological progress. In this scenario, I increase the productivity of the charging infrastructure sector (z) by 10%.

Table 2.12 – Sensitivity Analysis: Counterfactual Simulations to Estimate the Impacts of Subsidies to Charging Infrastructure.

Indicator	Unit of measure	Subsidy scenarios					
Setup							
Subsidy rate	Percentage	0	10	15	20	25	30
Price scenario: BASE							
Fleet characteristics							
Share EVs	Percentage	0.37	0.37	0.38	0.38	0.38	0.39
Share EVs: Network Penalty	Percentage	-2.01	-2.03	-2.04	-2.04	-2.05	-2.06
No car ownership	Percentage	60.40	60.40	60.40	60.40	60.40	60.40
Charging variables							
Charging cost	USD cents/KWh	21.57	21.42	21.35	21.27	21.20	21.13
Charging stations	Unit per household	0.00	0.00	0.00	0.00	0.00	0.00
Environment							
Emissions	$MTCO_2eq$	12.98	12.98	12.98	12.98	12.98	12.98
Discarded batteries	Thousands	1.11	1.12	1.13	1.14	1.15	1.16
Fiscal revenue and welfare							
Fiscal outcome	% of GDP	0.61	0.61	0.61	0.61	0.61	0.61
Average welfare	TUSD per household	4.26	4.15	4.10	4.05	3.99	3.94
Price scenario: 7%							
Fleet characteristics							
Share EVs	Percentage	0.74	0.75	0.75	0.76	0.77	0.77
Share EVs: Network Penalty	Percentage	-3.59	-3.62	-3.63	-3.64	-3.66	-3.67
No car ownership	Percentage	60.33	60.33	60.33	60.33	60.32	60.32
Charging variables							
Charging cost	USD cents/KWh	25.02	24.88	24.81	24.75	24.68	24.61
Charging stations	Unit per household	0.00	0.00	0.00	0.00	0.00	0.00
Environment							
Emissions	$MTCO_2eq$	12.91	12.91	12.90	12.90	12.90	12.90
Discarded batteries	Thousands	1.88	1.90	1.92	1.93	1.94	1.96
Fiscal revenue and welfare							
Fiscal outcome	% of GDP	0.62	0.62	0.62	0.62	0.62	0.62
Average welfare	TUSD per household	4.28	4.09	4.00	3.90	3.80	3.70
Price scenario: 15%							
Fleet characteristics							
Share EVs	Percentage	1.71	1.74	1.75	1.76	1.78	1.79
Share EVs: Network Penalty	Percentage	-6.63	-6.66	-6.68	-6.69	-6.71	-6.73
No car ownership	Percentage	60.15	60.14	60.14	60.14	60.13	60.13
Charging variables							
Charging cost	USD cents/KWh	30.02	29.91	29.85	29.79	29.74	29.68
Charging stations	Unit per household	0.01	0.01	0.01	0.01	0.01	0.01
Environment							
Emissions	$MTCO_2eq$	12.72	12.71	12.71	12.71	12.70	12.70
Discarded batteries	Thousands	3.89	3.95	3.98	4.01	4.04	4.07
Fiscal revenue and welfare							
Fiscal outcome	% of GDP	0.62	0.62	0.62	0.62	0.62	0.62
Average welfare	TUSD per household	4.34	3.96	3.77	3.57	3.37	3.16

Note: Table 2.12 reports results for $s \in [0, 0.3]$ under two setups: (i) with network effects and (ii) without network effects ($\eta = 0$). The network penalty, reported in the second line of Fleet Characteristics, measures the share of EVs that does not enter the market due to low abailability of infrastructure. I evaluate outcomes under three EV price levels: the baseline price (see Section 3 and Appendix C), a 7% reduction reflecting recent battery-driven cost declines (IEA, 2025b), and a 15% reduction reflecting further technological progress. In this scenario, I increase the productivity of the charging infrastructure sector (z) by 10%.

Chapter 3: Wide Economic Impacts of Energy Storage: The Case of Argentina

Joint work with Exequiel Romero-Gomez

Abstract

Renewable energy technologies offer a pathway to decarbonize power systems, yet their intermittent nature introduces important challenges for system operation. Energy storage can mitigate this issue by shifting supply across time, thereby stabilizing markets and enhancing system flexibility. This paper studies the economic and environmental impacts of deploying energy storage in Argentina using a two-step approach: an optimal electricity dispatch model to estimate electricity cost changes, and a recursive general equilibrium model to evaluate macroeconomic, sectoral, and distributional effects. I simulate storage capacities equal to 5% and 7% of total generation capacity under current conditions (2021) and under a projected 2030 system with higher demand and major expansions in renewable generation. Across scenarios, average electricity costs fall by 1.9–3.36%, with the largest gains in the 2030 system, where storage becomes more valuable as renewable penetration rises. These cost reductions generate broad economic benefits. GDP increases by 0.47–1.11 percentage points over a decade, unemployment falls by 0.07–0.19 p.p., and fiscal revenues rise by 0.43–1.13 p.p. Welfare improves for all households, especially among lower-income groups, reducing inequality. Emissions fall by 1.9–3.02 p.p. and the emissions intensity of the economy declines. Sectoral results show that electricity-intensive industries such as Construction, Non-Metallic Minerals, and Extraction are the main winners, while Fuels and Primary activities are the lossers. A comparison between annualized GDP gains and investment costs shows that the social benefits of storage exceed its capital expenditures in all scenarios. These findings highlight the strong case for public support to foster investment in energy storage and capture its full economic, environmental, and distributional benefits for Argentina.

Keywords: Electricity, Storage, Welfare, Climate Change
JEL Code: C68, D50, D61, L94, 013.

3.1 Introduction

The electricity sector is one of the largest contributors to global greenhouse gas (GHG) emissions (Crippa et al., 2023). Decarbonizing this sector is therefore crucial to the energy transition. Renewable technologies has become a profitable alternative to produce low-cost energy and reduce GHG emissions from power generation. However, this alternatives are intermittent, that is, they are not available on demand but depends on favorable weather conditions (Soini, 2021; Ambec and Crampes, 2021; Petersen et al., 2024). As a result, despite their advantages, they can introduce significant volatility into electricity markets.

One way to address intermittency is to increase regional integration, particularly by investing in transmission lines between different regions (Prol et al., 2023; Gonzales et al., 2023). The benefits of market integration can be understood through the traditional concept of gains from trade: it enables lower-cost power plants to export electricity and replace production from higher-cost plants, thereby improving allocative efficiency across regions. Another way to address this challenge is through energy storage (Andrés-Cerezo and Fabra, 2023; Domínguez et al., 2024). By storing electricity when renewable generation is high and releasing it when availability is low, storage eases the integration of renewables into electricity markets smoothing out production over time and flattening the price curve. Both energy storage and market integration are alternatives to address the problem of intermittency. The former works by linking electricity markets across time while the latter does it across regions. A third option involves demand management tools, such as real-time pricing, which encourage consumers to shift electricity use toward periods of high availability (Fabra, 2021; Joskow and Wolfram, 2012). These tools create incentives to consume more when supply is plentiful and less when it is limited, further contributing to system stability. In this article, I focus on energy storage, particularly lithium-ion battery energy storage systems. Note that although these systems can provide substantial benefits to the power system, their profitability remains uncertain given current capital costs and energy loss rates (Rohrer et al., 2025).

The objective of this study is to examine the economy-wide and sectoral impacts of deploying energy storage capacity in Argentina, a country with substantial potential for renewable energy generation (Ruggeri and Garrido, 2021). Argentina has also committed to expanding renewable capacity by 2030 through Law No. 27,191. In this context, energy storage systems constitute a key opportunity to facilitate the integration of renewable technologies. I address the following research questions: (i) How does the cost of electricity change under different levels of energy storage capacity? (ii) Given these new electricity costs, relative profitability between sectors changes: who are the winners and losers? (iii) What are the effects on aggregate variables and household welfare? (iv) Are the social benefits of installing this infrastructure greater than its capital costs?

To answer these questions, I develop a stylized dynamic model of the power market in Argentina. This model accounts for the optimal dispatch of electricity to satisfy hourly demand. There are two ways to smooth the price curve: either by managing a given charging infrastructure or by operating water reservoirs for hydroelectric production. I use hourly data on local supply and demand for Argentina in 2021 provided by CAMMESA to estimate the model. The main objective is to quantify how different levels of storage infrastructure affect the average cost of electricity. In addition, I develop a recursive General Equilibrium model to assess how these cost changes translate into aggregate and sectoral activity, fiscal outcomes, welfare, income distribution, and emissions.

To estimate this model, I rely on a self-developed Social Accounting Matrix (SAM) for Argentina for 2021, with a specific focus on energy-related activities.

I use the dispatch model to simulate four alternative storage scenarios: storage representing 5% and 7% of total generation capacity under current system conditions (year 2021), and the same storage shares in a projected 2030 system based on the National Secretariat of Energy's report, which incorporates a 22% increase in electricity demand and substantial expansions in renewable, hydro, nuclear, and combined-cycle capacity, consistent with Law 27,191. I assume full pass-through from changes in average generation costs of electricity to final prices, and assess the macroeconomic and microeconomic effects of these price changes using the general equilibrium model. Due to data limitations, I assume no electrification: sectors cannot substitute fuels with electricity. In this context, the estimated effects should be interpreted as lower-bound results: if electrification were taking place, the economic impact of changes in electricity costs would be amplified, strengthening the findings reported below.

This methodological approach provides a detailed representation of the electricity market, allowing me to assess how the deployment of energy storage translates into changes in electricity costs. The general equilibrium model, in turn, captures interactions among sectors and households and traces how these cost changes propagate throughout the economy, generating both direct and indirect effects. In this sense, the general equilibrium framework enables the evaluation not only of activity variables and emissions but also of welfare and distributional outcomes, thereby enriching the analysis (Chisari et al., 2012; Burfisher, 2021). A limitation of this approach is the absence of feedback between the detailed electricity model and the general equilibrium model.

The analysis shows that expanding storage capacity reduces the average cost of electricity. Across all scenarios, electricity costs fall between 1.9% and 3.36% relative to the baseline. The smallest reduction corresponds to the 5% storage scenario under the 2021 system configuration, while the largest reduction occurs in the 7% storage scenario within the projected 2030 generation structure. These reductions reflect improved use of existing generation and reduced reliance on expensive marginal technologies which are replaced by renewable generation. These cost reductions become stronger in a system with higher renewable penetration: by 2030, the same storage shares yield the largest cost reductions, confirming that storage becomes more valuable as variability in supply grows.

Reductions in the cost of electricity translate into improved macroeconomic performance. GDP increases in every scenario, with gains ranging from 0.47 to 1.11 percentage points over the ten-year horizon. Unemployment rate declines consistently as well, with reductions between 0.07 and 0.19 percentage points. The trade balance strengthens proportionally to overall economic activity, reflecting greater competitiveness from lower energy costs. Fiscal revenues also grow, rising between 0.43 and 1.13 percentage points, driven by higher production and household income. Altogether, these results point to a clear macroeconomic dividend from reducing electricity costs through energy storage. Welfare and distributional indicators reinforce the positive outlook. Every income group benefits, and gains are systematically larger for low-income households: welfare rises between 0.52 and 1.23 percentage points for the lower-income quintile, compared with 0.44 to 0.89 percentage points for the top quintile. Because electricity represents a higher share of the consumption basket of poorer households, these cost changes translate into a reduction in inequality, with the Gini Index falling modestly across all scenarios. Environ-

mental outcomes improve as well. Total emissions decline between 1.9% and 3.02%, while the emissions intensity of the economy also falls, indicating a cleaner and more efficient production structure.

The sectoral results show a clear pattern aligned with electricity intensity and input–output linkages. Besides the electricity sector, Construction, Non-Metallic Minerals, and Extraction are the main winners. These sectors are highly electricity-intensive and closely linked through input-output relationships. Gains in one sector create positive spillovers in others. By contrast, the Fuels sector and Primary activities are the main lossers. Storage reduces the need for fossil-based generation, directly affecting Fuels, while the low electricity intensity of Primary activities limits their competitiveness relative to more electricity-intensive sectors. These shifts suggest a reallocation of resources toward industries with improved performance.

Lastly, comparing the annualized macroeconomic gains with the annualized capital expenditure required to deploy energy storage shows that the social benefits exceed the investment costs in every scenario. For example, annualized GDP gains range from roughly USD 256 million to USD 598 million, while annualized capital expenditures range from USD 170 million to USD 391 million. This means that, even when private profitability remains uncertain due to financial conditions or technology costs, the net social return is positive. These results underscore a role for public policy in fostering the adoption of storage technologies, ensuring that their broad economic and environmental benefits can be captured.

The remainder of the article is organized as follows. Section 2 highlights our contribution to the literature. Section 3 provides the international and domestic context for energy storage. Section 4 presents the two models used in this study, along with the data. Section 5 describes the counterfactual exercises, outlines the mechanisms at play, and reports the results. Section 6 concludes. Additional details are provided in the Appendices.

3.2 Related Literature

This paper relates to three strands of the literature.

First, a growing body of research explores the sectoral effects of electricity policies, focusing on how regulatory changes influence pricing dynamics, market competitiveness, and deregulation processes (Choi et al., 2017; Li et al., 2017b; Lin and Wu, 2021; Zhang et al., 2021). These studies also explore sector-specific electricity demand elasticities and rebound effects. For example, Nepal et al. (2021) analyze the New Zealand case and find partial rebound effects of 54% in the industrial sector and 23% in the commercial sector, indicating that energy efficiency improvements may lead to increased electricity consumption in these sectors. I contribute to this literature by identifying potential winners and losers arising from the adoption of energy storage technologies at the sectoral level.

Second, the literature on the welfare and distributional impacts of electricity access and pricing (Ito et al., 2023; Rodrigues and Linares, 2015). Beyond economic dimensions, these works also assess the broader microeconomic consequences of electricity access, including improvements in education, income generation, and health outcomes (Gashaye et al., 2025). This literature provides insights into how energy policy can influence equity and social outcomes through indirect economic channels. We contribute to this literature

by estimating the welfare and distributional effect that is associated to the price changes that arise from energy storage.

A third line of research centers on the economics and optimization of energy storage, especially given the growing penetration of renewable energy. This literature has investigated the market structures and investment incentives required to support energy storage deployment (Andrés-Cerezo and Fabra, 2023). In addition, stochastic and simulation models are used to evaluate storage and transmission expansion strategies (Domínguez et al., 2024; Keck et al., 2019; Merrick et al., 2024). Empirical research documents the stabilizing effects of grid-scale battery storage on electricity markets, showing that large-scale deployments enhance grid reliability by balancing intermittent renewable generation, providing reserve capacity, and reducing the need for costly grid upgrades (Rangarajan et al., 2023). We contribute to this literature by developing a stylized model of electricity dispatch for Argentina that allows to assess the cost changes arising from energy storage.

A clear divide persists between two analytical approaches: multisectoral economic models (Li et al., 2019; He et al., 2010; Jiang et al., 2023), typically employed to evaluate broader macroeconomic and distributional impacts, and energy system simulations (Zhang et al., 2024; Abrell et al., 2019), which primarily examine technical feasibility, market efficiency, and system operation. The literature on energy storage systems largely relies on simulation-based frameworks to assess the role of storage within the electricity generation mix and its implications for system costs. For example, Keck et al. (2019), examining the Australian context, show that battery deployment becomes profitable only under high levels of renewable penetration, as fossil fuel technologies remain cost-competitive at lower renewable shares. Similarly, Chen et al. (2020) highlight the technical benefits of integrating lithium-ion batteries into the power system, including load smoothing and the mitigation of renewable intermittency. This study contributes to the literature by connecting these two strands of analysis, offering an integrated perspective on the multisectoral, socioeconomic, and environmental consequences of adopting electricity storage technologies.

3.3 Local and International Background

In this section, I discuss the role of energy storage as a key mechanism for addressing the intermittency inherent to renewable power generation, along with alternative strategies that can complement or substitute storage in managing variability. I then present a set of stylized facts on the global development of energy storage technologies, highlighting recent trends and the evolving international landscape. Finally, I examine how energy storage fits within the Argentine context, emphasizing the specific challenges and opportunities that shape its potential contribution to the national energy transition.

3.3.1 Key Concepts Related to Managing Renewable Intermittency

The literature on the energy transition, particularly in the context of electricity markets, highlights renewable technologies as a fundamental pathway for decarbonizing the power system (IEA, 2025a). However, their integration is not without challenges. Although renewables can provide clean electricity at increasingly competitive costs and the investment costs of large-scale renewable facilities have fallen significantly, these energy sources remain inherently intermittent (Chung et al., 2026; Petersen et al., 2024). This means

that electricity cannot be produced on demand but depends on favorable weather conditions. For example, wind power requires sufficiently strong and stable wind, while solar generation depends on adequate sunlight.

The large-scale deployment of renewables while maintaining a reliable electricity supply raises the critical issue of how to manage the variability they introduce into the system. In this regard, the literature identifies three main strategies for handling renewable-induced intermittency:

1. **Energy Storage**: Energy storage consists of withdrawing electricity from the grid when demand is low and renewable generation is abundant, and releasing it when demand is high. In doing so, storage shifts electricity from periods of low value to periods of high value, mitigating renewable volatility and smoothing price fluctuations (Andrés-Cerezo and Fabra, 2023; Feng and Lazkano, 2025). Several technologies with different characteristics and cost structures exist to store energy. The following subsection provides further details on these options.

2. **Regional Integration**: Regional integration involves expanding electricity transmission capacity across regions so that surplus renewable generation in one area can be exported to another, replacing more expensive generation (Gonzales et al., 2023). Similarly, when renewables are scarce in one region, they may be available in another, allowing trade to reduce variability and system costs. Importantly, the benefits of regional integration grow with the degree of complementarity between regions (Prol et al., 2023).

   Conceptually, the benefits of regional integration are the same as the gains from trade. There is a large body of literature that identifies these benefits. Gonzales et al. (2023) find that market integration in Chile increased solar generation by around 180%, reduced generation costs by 8%, and lowered carbon emissions by 5%. The authors also identify investment effects: a substantial amount of renewable entry would not have occurred in the absence of market integration. Wolak (2015) use data from the Alberta wholesale electricity market and identify cost reductions due to increased competition resulting from higher transmission capacity. Abrell and Rausch (2016) find that enhanced transmission infrastructure yields sizeable gains from trade that depend positively on renewable energy penetration. The authors also find that transmission infrastructure can either improve or worsen environmental outcomes, depending on renewable penetration: it complements emission abatement by mitigating dispatch problems associated with volatile and spatially dispersed renewables, but it can also increase average generation from low-cost coal if renewable production is too low.

3. **Demand Management**: Demand management uses pricing mechanisms to discourage electricity consumption during peak periods or when renewable generation is limited. By exposing consumers to higher prices at these times, demand management encourages them to shift consumption to periods with greater renewable availability. There is a substantial body of literature showing how Time-Varying Pricing (TP) improves efficiency by encouraging conservation and load shifting during expensive hours (Wolak, 2011; Allcott, 2011). There is also literature that identifies the impacts of TP on market power (Poletti and Wright, 2020), environmental outcomes (Holland and Mansur, 2008), and income distribution (Fabra et al., 2022).

It is important to note that these three approaches are not mutually exclusive. Rather, they are complementary and can be jointly integrated into an electricity system to enhance flexibility, reliability, and efficiency.

3.3.2 Energy Storage

Energy storage involves installing technologies that allow electricity to be stored when it is abundant and released when it is scarce, thereby reducing volatility and smoothing the price curve (Feng and Lazkano, 2025). However, several technologies are available to perform this function. The most common way to think about energy storage is through batteries (chemical storage). Nevertheless, there are other technologies that implicitly store energy. Besides chemical storage, this section covers the two main technologies that implicitly store energy: pumped hydro and hydrogen (IEA, 2025a).

First, one of the most established and widely deployed storage technologies is pumped hydro storage (PHS). This system operates by releasing water from an elevated reservoir to generate electricity during periods of high demand, and pumping the water back to the upper reservoir when demand is low. Studies such as Schöniger and Morawetz (2022) and Karhinen and Huuki (2019) examine the balancing role of PHS and highlight its contribution to facilitating the integration of renewable energy sources by reducing electricity costs and mitigating price volatility. Other works, including Simshauser and Gohdes (2025) and Chyong and Newbery (2022), focus on the challenges associated with deploying these capital-intensive, long-lived infrastructures, emphasizing the financial and regulatory hurdles that can facilitate new installations.

Second, chemical storage (most notably batteries) plays an increasingly important role in modern power systems. Batteries can store electricity during periods of high renewable generation and discharge it when renewable availability declines (IEA, 2025a). Storage can be deployed across different segments of the electricity system: at the generation level through grid-scale installations (Antweiler and Muesgens, 2025; Rangarajan et al., 2023), or at the consumption level through behind-the-meter systems, where households and firms rely on private battery units (Bravo-Melgarejo and Haritchabalet, 2025).

According to IEA (2023a), multiple battery chemistries coexist, with lithium-ion technologies currently dominating global deployment. However, alternatives such as sodium-based batteries are rapidly emerging. Despite their prominence, neither lithium-ion nor sodium-ion chemistries are expected to provide substantial shares of long-duration storage (multi-day), primarily due to high costs and technical limitations associated with maintaining prolonged states of charge (IEA, 2023a). Other chemistries may be better suited for longer-duration applications. For instance, redox flow batteries (whose architecture differs fundamentally from lithium) and sodium-ion systems offer a promising pathway for multi-day storage. Yet, significant challenges remain, particularly concerning the scalability and commercial deployment of these emerging technologies (IEA, 2023a).

It is important to note that the deployment of battery technologies relies on the extraction of critical minerals such as lithium, sodium, copper, nickel, and others (Islam et al., 2022). The specific chemistry of each battery type determines its technical properties and performance, making the availability of raw materials a central determinant of the evolution of chemical storage markets. Beyond mineral supply, large-scale deployment also depends on the industrial capacity to manufacture battery cells: an area currently dominated by a limited number of countries (Fitzner et al., 2023). Therefore, the rapid

expansion of energy storage systems requires not only substantial quantities of critical minerals but also robust industrial capabilities to scale cell production.

Finally, another important form of (clean) energy storage is the production of (green) hydrogen. When renewable generation is abundant, electricity can be used to produce hydrogen through electrolysis (a process that splits water molecules into hydrogen and oxygen) (Palmer et al., 2025). The resulting hydrogen can be stored and later converted back into electricity during periods of high demand. Beyond electricity generation, hydrogen has a wide range of potential applications, including transportation and the provision of heat in hard-to-electrify sectors such as steelmaking (Martinez-Rodriguez et al., 2026; Aguilar et al., 2025; Caiafa et al., 2025; Zubi et al., 2025). Despite its significant potential, the development of green hydrogen remains well below expectations. A key barrier is the high perceived financial risk associated with individual projects, driven by substantial uncertainties related to future hydrogen demand, fluctuating renewable energy availability, and volatile energy prices (Palmer et al., 2025; Scholvin et al., 2025). These uncertainties slow investment and hinder the scale-up of a sector that could otherwise play a central role in supporting deep decarbonization.

According to IEA (2023a), across all these technologies, a portion of the stored electricity is lost in the storage cycle. These energy losses represent a cost and can significantly affect the efficiency and profitability of storage systems. Another important characteristic is the charging and discharging speed: that is, the time required to fully charge the storage capacity and the rate at which it can be converted back into electricity (IEA, 2023a).

The concept of storage has also been examined extensively in other strands of the economic literature. In particular, two major bodies of work (the business cycle literature and the international trade literature) have analyzed the role of storage in the form of inventories. Within the business cycle literature, Auernheimer and Trupkin (2014) show that temporary demand shocks highlight the function of inventories as shock absorbers, whereas highly persistent demand shocks and technology shocks of any persistence emphasize the complementary role of inventories in supporting consumption. Earlier foundational work by Holt et al. (1960) introduced the production-smoothing motive for holding inventories within a simple model of optimal inventory behavior. Assuming convex production costs and uncertain demand for storable goods, this framework suggests that profit-maximizing firms have incentives to hold inventories to smooth production over time and thereby reduce average costs. Inventories also play a key role in international trade. Because trade involves time lags and relatively high transaction costs, firms engaged in global markets tend to hold substantially larger inventory stocks. This mechanism has been documented empirically by Alessandria et al. (2010b,a), who show that inventory management decisions are central to firms' ability to manage trade frictions and supply chain uncertainties.

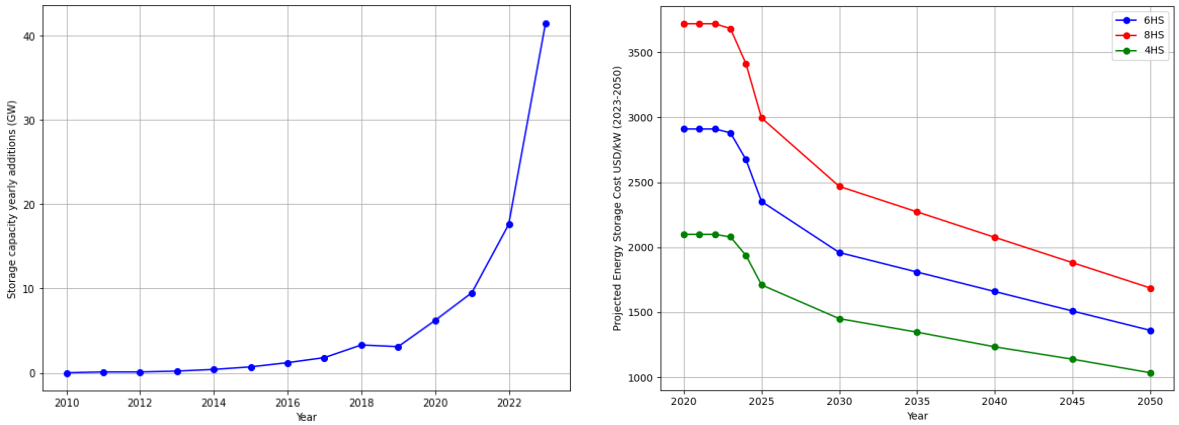
3.3.3 The International Context

At COP28 in December 2023, nearly 200 countries adopted the UAE Consensus, committing to an ambitious global energy agenda. This agreement outlines a clear path toward net-zero emissions in the energy sector by 2050, with key efforts focused on phasing out fossil fuels, tripling renewable energy capacity, and doubling energy efficiency improvements by 2030. These targets have the potential to reshape the global energy landscape, accelerating the transition to a more affordable, secure, and sustainable energy system. According to the IEA (2024a), the goal of tripling global renewable energy capacity by

2030 is within reach. However, unlocking its full potential requires modernizing electricity grids and scaling up energy storage infrastructure. In particular, the IEA (2024a) estimates that 1,500 gigawatts (GW) of energy storage capacity will be needed by 2030, with 1,200 GW coming from battery storage: a 15-fold increase from today's levels.

Figure 3.1 reports the annual battery storage capacity additions per year and the projected cost of capital for 4-hours, 6-hours and 8-hours grid-scales batteries.

Figure 3.1 – Annual Global Battery Storage Capacity Additions (2010–2023) and Projected Capital Cost Evolution of 4-hour, 6-hour and 8-hour Grid-Scale Batteries to 2050.



(a) Annual Global Battery Storage Capacity Additions (2010–2023)

(b) Projected Capital Costs of 4-hour, 6-hour and 8-hour Grid-Scale Batteries (2025–2050)

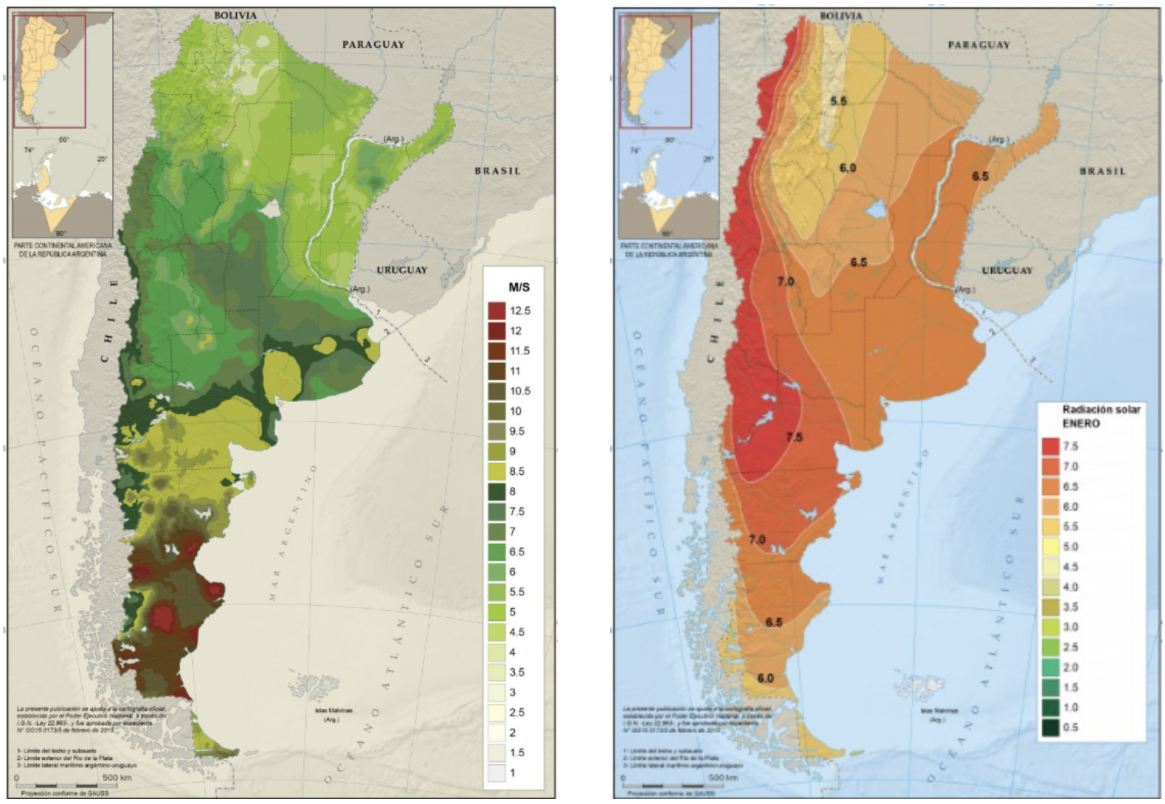
Note: Panel (a) presents annual global additions in battery storage capacity from 2010 to 2023. Source: IEA. Accessed: 01/04/2025. [Link: IEA Data and Statistics]. Panel (b) shows the projected capital costs of 4-hour, 6-hour and 8-hour utility-scale battery storage systems from 2025 to 2050. Source: National Renewable Energy Laboratory (NREL). Accessed: 01/04/2025. [Link: NREL Annual Technology Baseline].

In 2023, China and the United States dominated global energy storage installed capacity, with 27.1 GW and 15.8 GW, respectively. Together, they accounted for over 79% of total installed capacity (Energy-Institute, 2024). The United Kingdom (3.6 GW), Australia (1.8 GW), and Germany (1.7 GW) also played significant roles in this market (Energy-Institute, 2024). This installed capacity is projected to increase as the capital costs of batteries decrease and the performance improves. As shown in Figure 3.1, the projected cost of batteries is expected to decline over the coming decades, suggesting continued innovation in the sector. According to Feng and Lazkano (2022), innovation in energy storage has followed an upward trend and is largely driven by leading countries (Japan, the U.S., and Germany). The authors also find that most technological advances in energy storage are directed toward improving battery technologies. Finally, they show that an important driver sustaining the positive trend in innovation in the sector is the cost of electricity: specifically, they find a positive effect of electricity prices on the share of storage patents. In contrast, they also find that a one-unit increase in electricity prices leads to a 15.54% reduction in the share of storage patents relative to electricity generation patents. This suggests that higher electricity prices induce more innovation aimed at improving generation technologies rather than addressing the intermittency of renewable energy. This relationship between energy prices and innovation in energy transition technologies has also been documented in other studies, such as Popp (2002), Kim (2014), or Popp (2019).

3.3.4 The Case of Argentina

Argentina constitues a case where renewable production has greater potential. Argentina is a vast large country where the north and west holds significant advanteges to produce solar energy while the south has adventeges to produce eolic energy. Figure 3.2 reports geografic data on solar and wind intensity for the case of Argentina.

Figure 3.2 – Solar and Wind Intensity for Argentina.



(a) Average Year Wind Intensity **(b)** Solar Intensity January

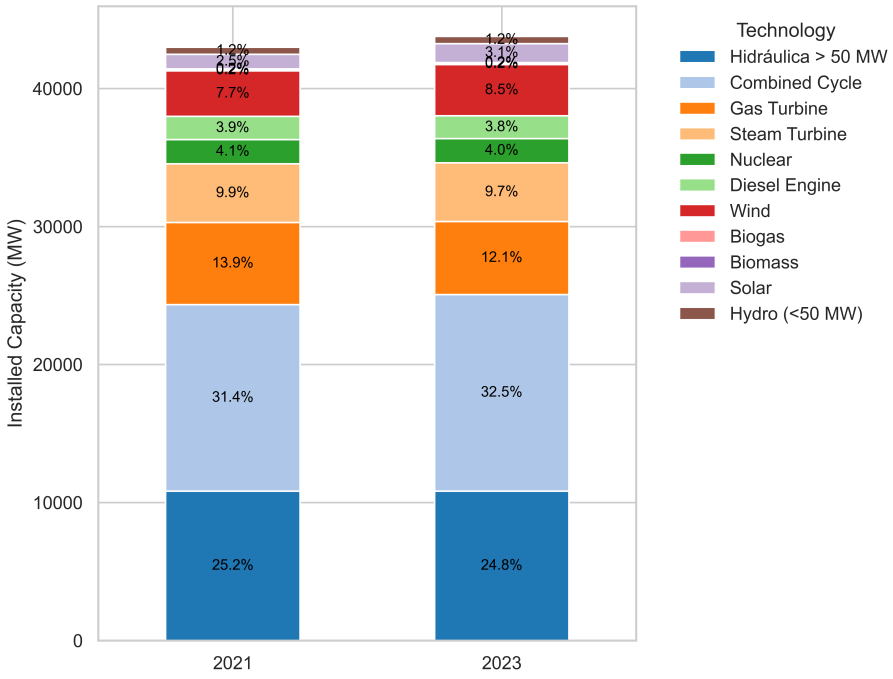
Note: Panel (a) presents argentine solar intensity. Source: YPF Fundation. Accessed: 01/04/2025. [Link: Wind Intensity Map]. Panel (b) shows solar intensity for Argentina. Source: YPF Fundation. Accessed: 01/04/2025. [Link: Solar Intensity Map].

In Argentina, the installation and operation of renewable energy capacity are regulated under Law No. 27,191 and managed by CAMMESA. Law No. 27,191 establishes a renewable energy promotion framework to meet capacity targets, while CAMMESA, an entity composed of 80% electricity market agents and 20% government representatives, oversees grid operations and capacity management. According to CAMMESA's monthly database[26], Argentina's renewable energy capacity expanded by approximately 77% between 2020 and 2024. As renewable installations continue to grow, developing energy storage infrastructure will be crucial to reduce market volatility and facilitating the integration of these technologies into the power system. Particularly, in the context of 25% of renewable capacity by 2030 set by Law No. 27,191.

Figure 3.3 presents the evolution of installed electricity generation capacity in Argentina between 2021 and 2023. The data include all generation technologies as classified by CAMMESA in its official database.

[26]Link: CAMMESA dataset

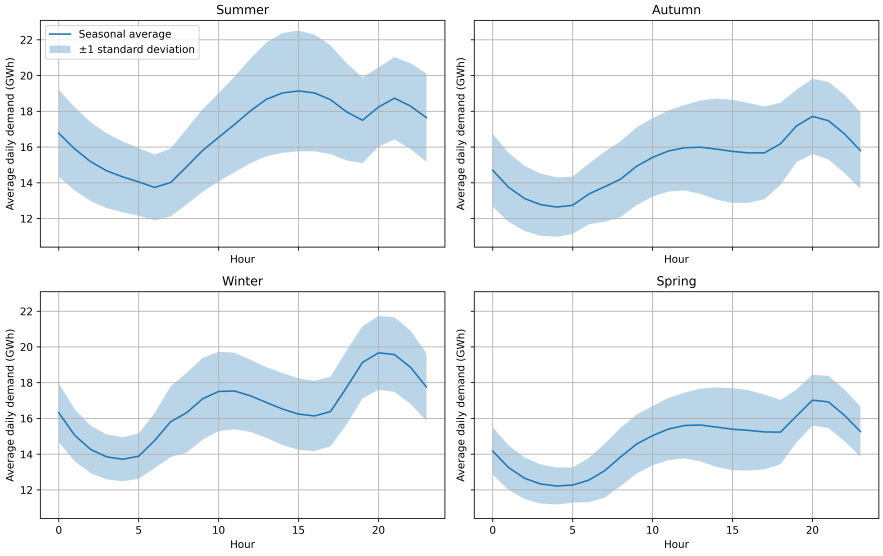
Figure 3.3 – Argentina 2021 and 2023. Installed Capacity Composition by Technology.



Source: CAMMESA.

Figure 3.4 illustrates the average hourly electricity demand for a representative day in each season. Daily consumption patterns naturally generate periods of lower load suitable for charging storage devices, and periods of higher load that call for discharging. In particular, electricity demand is lowest during the early hours of the day and peaks toward the end of the day.

Figure 3.4 – Argentina 2021. Average Hourly Demand for a Representative Day by Season.

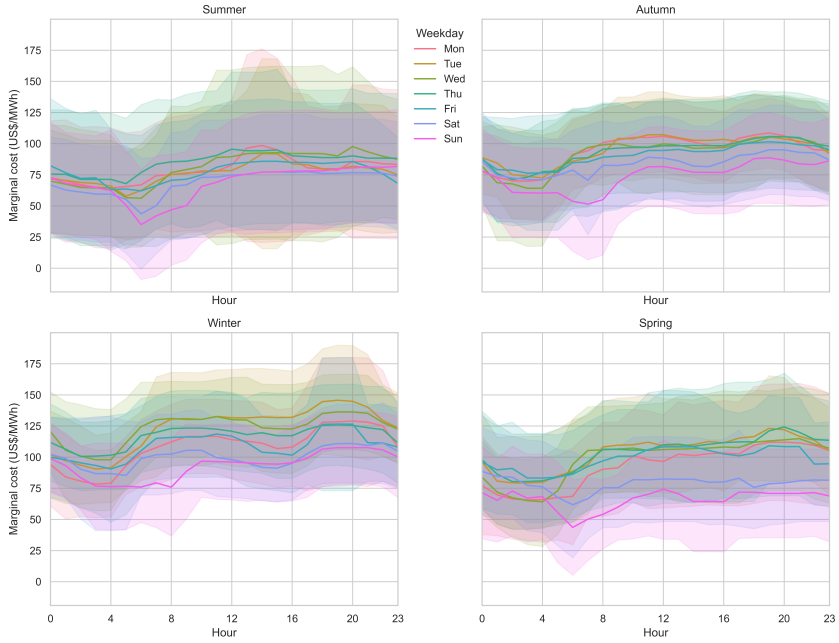


Source: CAMMESA.

Figure 3.5 reports the average marginal cost for each hour of each day of the week over an entire season. As shown, marginal costs exhibit substantial volatility. Storage

technologies can help mitigate this volatility, especially as renewable generation becomes more abundant.

Figure 3.5 – Argentina 2021. Average Hourly Marginal Cost for Each Representative Day of the Week by Season.



Source: CAMMESA.

Regarding the determination of electricity prices, the National Electricity Regulatory Authority (ENRE, for its acronym in Spanish) oversees the price-setting process. For households, residential electricity prices are not set on an hourly basis. Instead, they are differentiated by income level, with three main income brackets. Prices typically consist of a fixed charge plus a variable cost per kWh. For general users with low consumption, electricity prices follow the same structure (a fixed charge plus a variable charge), but with different values. For productive sectors with high electricity demand, the Argentine electricity system also does not feature hourly pricing. Instead, prices follow a peak/off-peak scheme with three time blocks: peak, off-peak, and "rest-of-day" hours. In all three cases, users pay a fixed charge, capacity charges, and a variable cost that depends on the time block. For all the users, the main component of electricity prices is the cost of electricity generation. In addition, prices incorporate transmission and distribution costs, capacity charges (depending on the type of user), as well as taxes and subsidies. The official ENRE electricity price website provides detailed information on the specific structure of electricity prices (ENRE Electricity Prices).

Argentina currently lacks both operational energy storage capacity and specific legislation to promote this technology. However, in February 2025, the government launched national and international tenders to install battery storage systems in the metropolitan area[27]. Additionally, authorities have urged other provinces to implement similar projects in critical grid nodes, aiming to enhance grid stability and modernization. Taking these considerations into account, Argentina constitutes a compelling case for studying the deployment of energy storage. The country has substantial renewable energy potential, and its government has committed to expanding clean generation capacity. Moreover, the

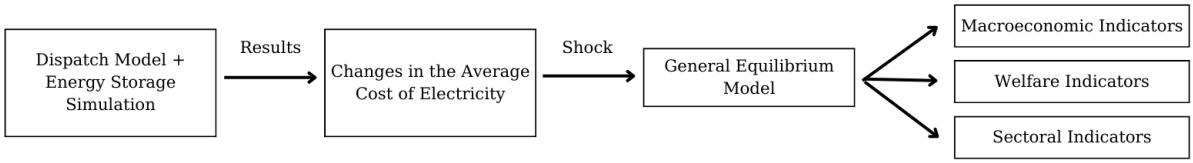
[27]Link: News About Energy Storage

variability in both electricity generation and demand creates meaningful space to examine the potential role of storage in enhancing system flexibility and reliability.

3.4 Methodology and Data

This section presents the models and data used in this study. I develop two models: first, a dynamic dispatch model of the Argentine power market that captures hourly power generation and electricity costs. Second, a general equilibrium model to assess both economy-wide and sectoral impacts of energy storage. The dispatch model estimates changes in the average cost of electricity derived from installing and operating energy storage facilities, while the general equilibrium model evaluates the broader economic effects of these changes. Figure 3.6 illustrates the relationship between these models.

Figure 3.6 – Link between the dispatch model and the general equilibrium model



Note: Figure 3.6 presents a flowchart illustrating the connection between the dispatch model of the Argentine power system and the general equilibrium model. Cost changes from energy storage serve as the linking mechanism between these models.

The following subsections presents the optimal dispatch model and its estimation results. The second subsection presents the general equilibrium model. Appendix A complements this presentation with data of the Social Accounting Matrix for Argentina.

3.4.1 The dispatch Model

There is a social planner that determines power dispatch, storage decisions, and the management of water reservoirs for hydroelectric production. I consider nine power generation technologies: Solar (SO), Wind (W), Bioenergy (B), Hydropower (H), Nuclear (N), Combined Cycles (CC), Diesel (D), Gas Turbine (GT), and Turbo Steam (TS). These technologies are indexed by $t \in \{SO, W, B, H, N, CC, D, GT, TS\}$.

Each time unit corresponds to one hour, indexed by $h \in H = \{1, \ldots, \bar{H}\}$. In this model, I consider all hours of the year. Therefore, $\bar{H} = 8769$. In this setting, the optimization process begins at the start of the year and concludes at its end. To calibrate the dispatch model, I take the year 2021 as the benchmark, ensuring temporal consistency with the Social Accounting Matrix, whose base year is also 2021.

Hourly demand, denoted by d_h, is exogenous and inelastic for each hour. Total generation is represented by x_{ht}, while $\mathbb{I}_{ht}$ is a binary variable that indicates whether a technology is operating. Generation costs are technology-specific and denoted by c_t, while startup costs are also technology-specific and denoted by sc_t. Each technology has an installed capacity K_t. However, availability may vary due to network constraints, maintenance, or repairs. Availability is captured by $a_{ht} \in [0, 1]$, which also accounts for the variability of renewable energy sources. All technologies are subject to ramping constraints, limiting adjustments in generation and charge/discharge between consecutive hours.

Hydroelectric production requires water reservoirs, denoted by R_h. The reservoir follows the law of motion:

$$R_h = R_{h-1} + \gamma - x_{H,h}, \tag{4}$$

where γ represents the average hourly replenishment of the reservoir, and $x_{H,h}$ denotes hydroelectric production in period h. Reservoirs are subject to capacity constraints, bounded by minimum ($\underline{R}$) and maximum ($\bar{R}$) levels.

Energy can also be stored in batteries. The stock of stored energy at time h is S_h, which evolves according to:

$$S_h = S_{h-1} + C_h(1-\epsilon) - DC_h, \tag{5}$$

where C_h represents the amount of energy charged, while DC_h denotes the amount discharged. Note that not all the energy charged into the battery is retained: ϵ captures the share of energy lost during the charging process due to chemical processes. Energy storage capacity is limited by ST. This model does not incorporate a nodal analysis of the electrical system and presents and stylized view of the dispatch system focusing on overall system costs and its dynamics.

Note that both energy storage and reservoir optimization introduce dynamic behaviour into the model. In particular, energy storage allows electricity to be shifted from periods in which it has low value to periods in which it becomes more valuable.

The social planner's problem is represented by the following optimization model:

- **Objective:** Minimize total costs, including both generation and startup costs.

$$\min_{\{x_{ht}, C_h, \mathbb{I}_{ht}\}} TC = \sum_h \sum_t c_{ht} x_{ht} + \sum_h \sum_t sc_{ht} \mathbb{I}_{ht}$$

- **Energy Balance Constraint:** Supply must match demand.

$$\sum_t x_{ht} = d_h + C_h - DC_h, \quad \forall h$$

- **Generation Capacity Constraints:** Generation is limited by available capacity.

$$x_{ht} \leq K_t a_{ht} \mathbb{I}_{ht}, \quad \forall t, h$$

$$x_{ht} \geq \alpha \mathbb{I}_{ht}, \quad \forall t, h$$

The parameter $a_{ht} \in [0, 1]$ accounts for the fact that generation capacity is not always fully available due to factors such as transmission congestion, weather conditions in the case of renewables, maintenance, among others. The second equation ensures that a power plant cannot be switched on without producing electricity. Particularly, α is a small positive constant introduced to avoid zero output when the plant is operating. Note that all elements of this problem are deterministic; therefore, dispatch in this model is not stochastic. In other words, the planner knows, for every hour, the availability of each technology.

- **Hydroelectric Generation Constraints:** Accounts for reservoir dynamics, and sets initial and terminal conditions, and capacity bounds.

$$\begin{gathered} R_h = R_{h-1} + \gamma - x_{H,h}, \quad \forall h > 1 \\ R_0 = R_{init} - x_{H,0} \\ R_{\bar{H}} = R_{fin} \\ R_h \in [\underline{R}, \bar{R}], \quad \forall h \end{gathered}$$

- **Storage Constraints:** Accounts for energy storage dynamics, and sets initial conditions, and storage limits.

$$\begin{gathered} S_h = S_{h-1} + C_h(1-\epsilon) - DC_h, \quad \forall h > 1 \\ S_0 = 0 \\ S_h \in [0, ST], \quad \forall h \end{gathered}$$

- **Ramping Constraints:** Limits generation adjustments (RL_t is the ramping limit of technology t, and RLS is the charging/discharging speed).

$$\begin{gathered} x_{t,h-1} - x_{t,h} \in [-RL_t, RL_t], \quad \forall h > 1, t \\ C_{h-1} - C_h \in [-RLS, RLS], \quad \forall h > 1 \end{gathered}$$

- **Positivity and Binary Constraints:** Ensures non-negativity and binary status of decision variables.

$$\begin{gathered} x_{ht} \geq 0, \quad \forall h, t \\ \mathbb{I}_{ht} \in \{0, 1\}, \quad \forall h, t \end{gathered}$$

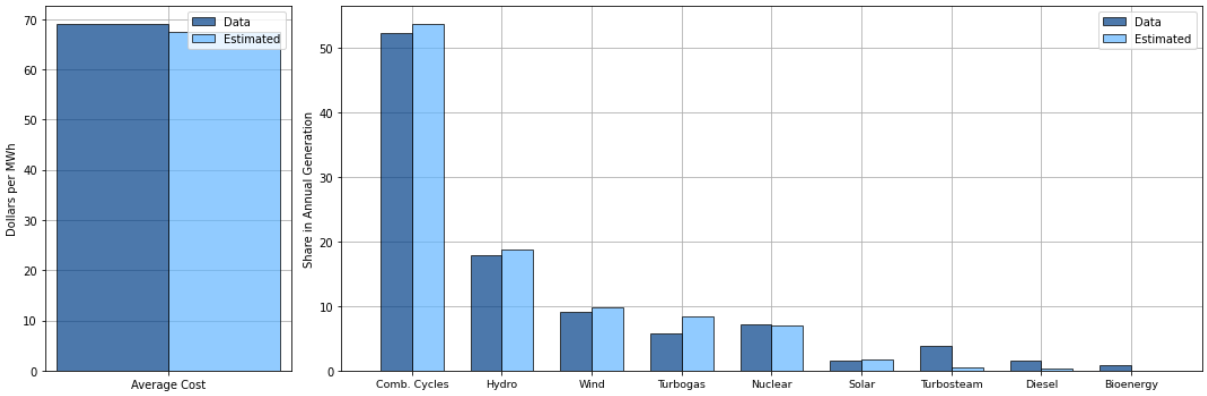
I estimate the model using hourly data on generation and demand, as well as cost data from CAMMESA. The model is estimated using a minimum distance estimator, selecting a vector of estimated parameters ($\hat{\theta}$) to minimize the distance between the observed data and the corresponding model-generated results. The minimum-distance estimator is defined as:

$$\hat{\theta}(W) \in \Theta : \hat{\theta}(W) = \arg\min_{\theta \in \Theta} e(\tilde{x}, x|\theta) W e(\tilde{x}, x|\theta)^T$$

The benchmarks used to estimate the model include the share of each technology in total annual generation and the average cost of electricity. The parameters calibrated in this process are $\{\gamma,\ a_t\ \forall t\}$. Note that the estimation relies on average availability over the entire year, implying that a_t is not indexed by h. For renewable technologies, I estimate their average availability while preserving the volatility observed in the data. Availability is calculated as the ratio of renewable generation to installed capacity. The implicit assumption is that, whenever renewable capacity is available, it is fully dispatched. Consequently, the variability in availability is attributed solely to weather conditions.

Figure 3.7 presents the model fit for the estimated parameters $\hat{\theta}$.

Figure 3.7 – Model Fitting: comparison between the estimated moments of the model and the data.



Note: Figure 3.7 reports the results of the model using the estimated $\hat{\theta}$ compared to the data to evaluate the fitting of the estimated model. There are two types of values that I use to estimate the model: The yearly average cost of electricity and the share of each technology in annual power generation.

As it can be observed in Figure 3.7, the estimated model reproduces both the average costs of electricity and the share of each technology in total annual generation.

An important outcome of this model is the average cost of electricity (ACE) in the benchmark year. We define the average cost as the ratio of total generation costs to total electricity generation:

$$ACE = \frac{\sum_h \sum_t c_{ht} x_{ht} \; + \; \sum_h \sum_t sc_{ht} \mathbb{I}_{ht}}{\sum_h \sum_t x_{ht}}.$$

The ACE differs from the marginal cost of electricity. While the marginal cost reflects, in each hour, the cost of the most expensive technology dispatched, the average cost captures the overall cost per unit of electricity generated across all technologies and all hours.

3.4.2 The General Equilibrium Model

The General Equilibrium model employed in this study follows a standard multi-sector structure (Chisari et al., 2012; Burfisher, 2021). The model is composed of four types of agents: (i) households, (ii) firms, (iii) the government, and (iv) the rest of the world. Each agent is represented through an optimization problem.

Households maximize utility derived from the consumption of goods and services, subject to a budget constraint. They are the owners of the production factors (labor, capital, and mixed income). Households are differentiated by income level and modeled with nested CES utility functions, where the top-level utility aggregates composite consumption bundles (energy and non-energy goods). The model features five representative household types, differentiated by income quintiles. Their demand system is derived from utility maximization, ensuring a consistent treatment of substitution patterns between domestic and imported goods.

Firms maximize profits. Each firm represents a sector/activity that produces a single good using a combination of value-added inputs and intermediate consumption. Value-added consists of labor, gross mixed income (GMI), and capital, aggregated via a Cobb-Douglas production function. Intermediate consumption (categorized into energy and

non-energy goods) is combined with value-added through a Leontief structure, reflecting strict complementarity. The model includes fifty productive sectors.

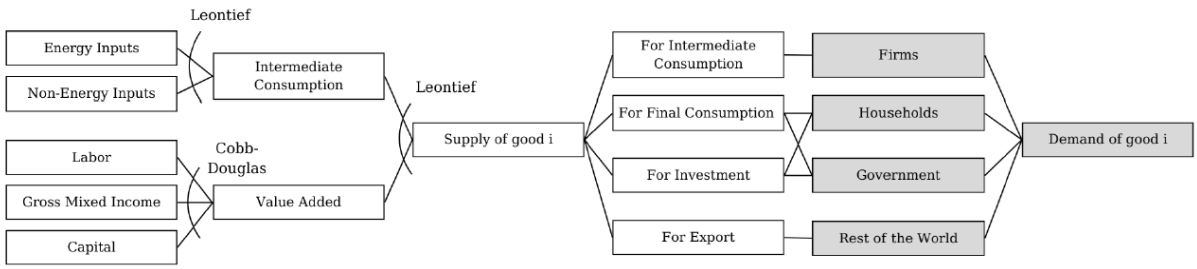
The government is modeled as an agent that participates in investment markets, consumes goods and services, and makes transfers to households. It has a Cobb–Douglas utility function. Its main source of income is tax collection net of subsidies, although it also engages in financial transactions through the bonds account.

The external sector purchases domestic exports, sells imports to the domestic economy, collects dividends from investments, and participates in bond transactions. In this model, Argentina is a small open economy in which some goods are tradable while others are non-tradable.

The model also incorporates unemployment, which arises from rigidities in the labor market. These rigidities are captured through downward inflexibility of real wages, an approach commonly used in other CGE studies such as Ramos et al. (2017) or Chisari et al. (2016).

On the demand side, the output of each sector may be allocated to four destinations: intermediate use by other firms, final consumption by households and government, investment demand, or exports to the rest of the world. Goods and services markets clear simultaneously, ensuring that supply equals demand for each commodity. Figure 3.8 shows the general CGE structure used in the model.

Figure 3.8 – Supply and demand structure of the general equilibrium model.



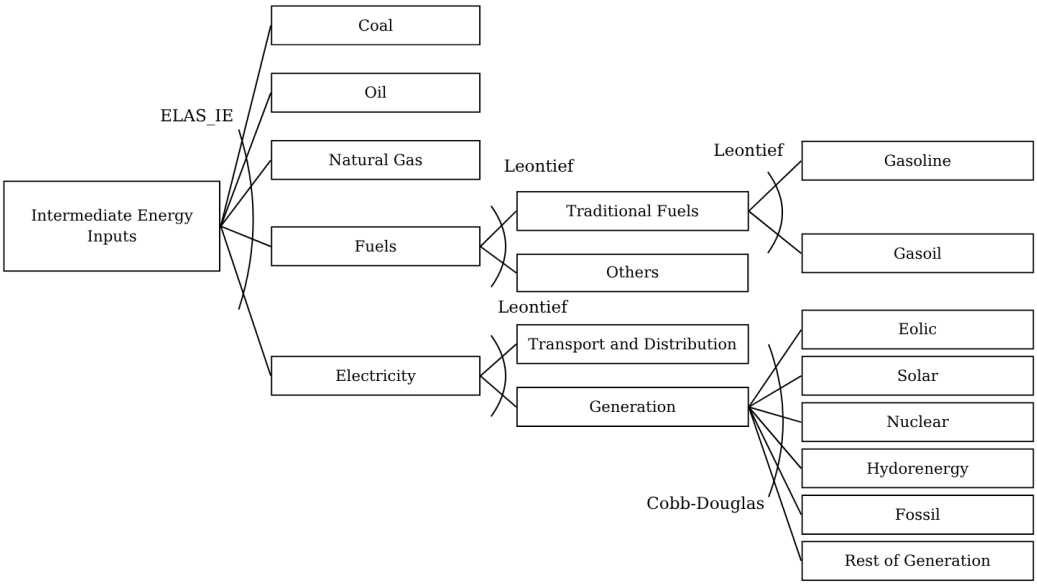
Note: Figure 3.8 illustrates the structure of demand and supply in the general equilibrium model.

The model provides detailed treatment of energy inputs. Firms demand primary energy resources, including coal, oil, natural gas, fuels, and electricity. These energy goods are combined in a nested structure, distinguishing between traditional fuels, electricity, and other energy sources. Electricity supply, in turn, is decomposed into generation technologies (e.g., hydro, nuclear, fossil, and renewables) and transportation and distribution services, aggregated using a Leontief function. Even though electricity is a homogeneous good and there is substitutability between generation sources, I aggregate generation using a Cobb-Douglas function to reflect the existence of capacity and network constraints. As a result, the operator cannot freely shift generation from one technology to another. Households demand energy products through a separate nest, which distinguishes between electricity, gas, and fuels.

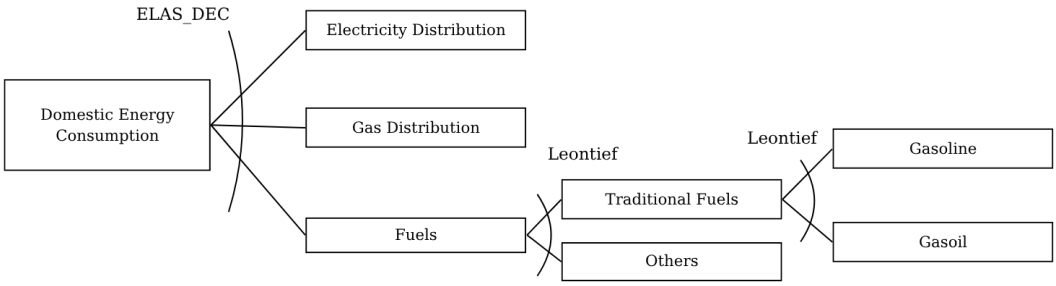
The degree of substitutability among different energy types is governed by elasticity parameters: $ELAS_{IE}$ for intermediate energy inputs and $ELAS_{DEC}$ for domestic energy consumption. These parameters measure how easily firms and households can substitute

between different energy goods within each branch of the nesting structure. This structure is shown in the following figure. For this paper, I assume that $ELAS_{IE} = ELAS_{DEC} = 0$, meaning that there is no substitution between electricity and other energy goods. In other words, the model does not incorporate electrification. There are two main reasons behind this assumption. First, there is insufficient information to reliably estimate both elasticities of substitution. Second, the electrification process is highly complex, as it is sector-specific and typically requires incurring fixed costs to upgrade technologies. This assumption implies that the results should be interpreted as lower-bound estimates. If electrification were considered, the effects would be amplified in the presence of reductions in the average cost of electricity.

Figure 3.9 – Structure of energy supply to firms and households.



(a) Energy consumption by sectors (productive use)



(b) Energy consumption by households (residential use)

Note: Figure 3.9 shows the structure of energy supply to firms and household in different branches with the corresponding elasticities of substitution.

Note that this model is recursive-dynamic, which means that, by iterating the static model, endowments are updated period by period generating a dynamic simulation. Agents decide how much to save in period t using information from that period only while, in the next period $(t + 1)$, those savings are transformed into new capital, which is mobile across sectors. Thus, it is allocated while returns and prices are defined in the model. In this line, the final allocation of the new capital is endogenously determined

by sectoral relative productivities, and it is reallocated until the marginal benefit of new capital is the same in all industries. Therefore, the final industrial scale in the next period depends on market incentives determined by the model. Note that, on the one hand, new capital enters the model, and, on the other, depreciation (5%) diminishes the stock of capital. Finally, labour endowment evolves according to the population growth rate (1.09%).

Overall, this CGE model provides a flexible framework to capture the interactions between sectors and agents in the economy, incorporating both the complexity of energy markets and the broader economic linkages critical for policy evaluation.

Table 3.1 presents the indicators used to conduct the general equilibrium simulations.

Table 3.1 – Indicators reported for each simulation.

Indicator	Measure	Formula
GDP growth index	Percentage	$\left(\frac{GDP_t}{GDP_{base}} - 1\right) 100$
Unemployment rate	Percentage	$\frac{UL_t}{TL_t} 100$
Trade balance index	Percentage	$\left(\frac{TB_t}{TB_{base}} - 1\right) 100$
Tax collection index	Percentage	$\left(\frac{TC_t}{TC_{base}} - 1\right) 100$
Welfare index	Equivalent Var. (%)	$\left(\frac{EV_t^h}{EV_{base}^h} - 1\right) 100$
Gini index	[0–100]	$\frac{1}{n}\left(n + 1 - 2\frac{\sum_{i=1}^{n}(n+1-i)y_i}{\sum_{i=1}^{n} y_i}\right) 100$
GHG emissions index	Percentage	$\left(\frac{GHG_t}{GHG_{base}} - 1\right) 100$
Kuznets index s	Percentage	$\frac{\Delta Em}{\Delta GDP} 100$

Note: GDP = Gross Domestic Product; TB = Trade Balance; TC = Tax Collection; EV = Equivalent Variation; UL_t = Unemployed Labor; TL_t = Total Labor; n = Number of households; y_i = Income of household i; GHG = Greenhouse Gas Emissions; ΔEm = Percentage change in emissions; ΔGDP = Percentage change in GDP.

A GDP indicator is used to measure the impact on aggregate economic activity. I also report indicators for the effects on the trade balance and tax collection. Household and government welfare impacts are assessed using the equivalent variation, which represents the income change that would generate the same utility level as the simulated scenario (Guerra and Sancho, 2018). Income distribution effects are measured using the Gini Index. To evaluate environmental impacts, a GHG emissions index is constructed using the model's emissions data. Finally, the Kuznets index reports the percentage change in emissions per unit of GDP. Each simulation of the model yields a 10-year trajectory for the relevant variables. This trajectory is summarized using the Net Present Value (NPV) for flow variables, and the simple average for non-flow variables such as the unemployment rate. The NPV is computed using a discount rate of 3%, consistent with the U.S. Treasury bond rate.

3.5 Counterfactual Exercises and Results

This section examines the impacts of changes in the average cost of electricity enabled by storage technologies. Electricity costs can significantly influence economic performance, energy consumption, and environmental outcomes. The first subsection describes the counterfactual scenarios simulated and their transmission mechanisms. This framework provides insight into how changes in electricity costs affect different economic dimensions

and contribute to structural adjustments within the economy. The second subsection reports the simulation results at both the aggregate and sectoral levels. This approach allows us to assess the effects on macroeconomic variables (such as GDP and tax revenues) while also identifying winners and losers across sectors. Understanding these dynamics is essential for policymakers seeking to design strategies that maximize the benefits of energy storage infrastructure while mitigating potential negative impacts on vulnerable sectors.

3.5.1 Counterfactual Exercises and Mechanisms

I use the dynamic dispatch model to evaluate the impact on the average cost of electricity under four different storage scenarios:

1. The installation of energy storage capacity equal to 5% of total generation capacity.
2. The installation of energy storage capacity equal to 7% of total generation capacity.

For the last two scenarios, I evaluate the impact of the same storage configurations but under the projected conditions for 2030. To model the 2030 scenario, I use projections from the National Secreatiat of Energy. These projections assume a 22% increase in electricity demand, based on the historical growth rate, and the following expansions in generation capacity: an additional 13.77 GW of renewables, 2.89 GW of hydropower, 2 GW of nuclear power, and 8.7 GW of combined-cycle capacity. This expansions are in line with the goal of 25% of renewable set by Law No. 27,191 to 2030.

3. The installation of energy storage capacity equal to 5% of total generation capacity in the projected 2030 scenario.
4. The installation of energy storage capacity equal to 7% of total generation capacity in the projected 2030 scenario.

For this simulation, I assume lithium-ion battery systems with an energy loss rate (ϵ) of 10%, an infrastructure lifetime of 15 years, and a 4-hour charge–discharge duration, in line with the European Union Report on Energy Storage Technologies.

To evaluate the impacts of electricity cost changes associated with storage technologies, I use the general equilibrium model to simulate the effects of each price change estimated with the dynamic dispatch model. A key assumption in these simulations is that there is complete pass-through from changes in the average cost of electricity to final electricity prices.

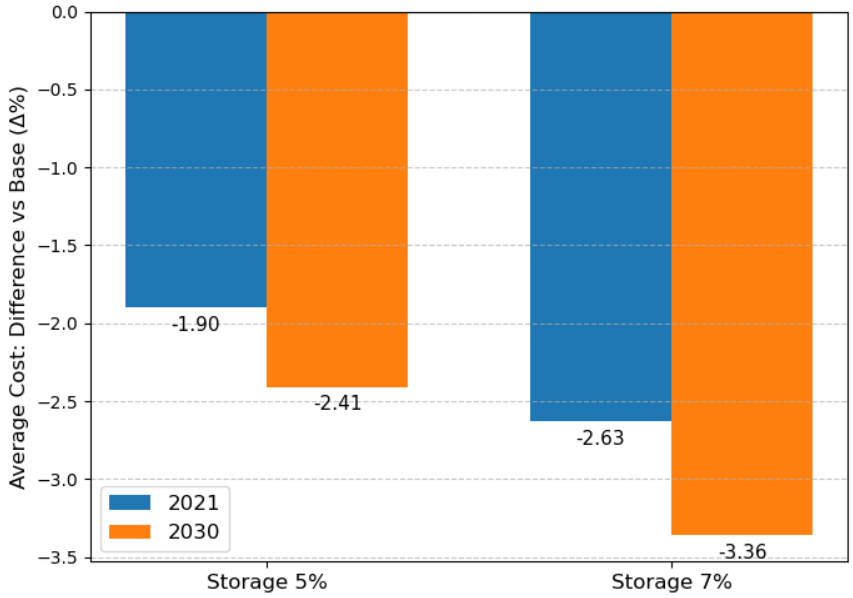
The transmission mechanisms through which these shocks propagate in the economy are multiple. To illustrate them, consider a decrease in the electricity price. First, household energy savings play a central role: lower energy costs relax household budget constraints, leading to increased consumption of other goods and higher levels of investment. Second, reduced domestic production costs generate network benefits through the input–output structure of the economy, improving efficiency across sectors. A further mechanism is resource reallocation, as the economy shifts resources toward sectors with improved relative profitability. Finally, although not explicitly modeled here, electrification would also contribute by enabling substitution between fossil fuels and electricity, thereby enhancing efficiency and fostering structural change.

These simulations provide a characterization of how storage-induced cost changes affect macroeconomic aggregates, sectoral outputs, environmental indicators, and energy use patterns. The following subsection presents the results while Appendix B reports the complete dynamic simulations.

3.5.2 Results

Figure 3.10 shows the percentage change in the average cost of electricity resulting from the addition of energy storage.

Figure 3.10 – Counterfactual Impact of Energy Storage: Simulated effects of different levels of energy storage (5% and 7%) in two contexts, 2021 and 2030 on the average cost of electricity.



Note: This figure reports the percentage change in the average cost of electricity for each energy storage scenario.

The results indicate that, under these scenarios, the cost of electricity decreases between 1.90% and 3.36%, with respect to baseline depending on the configuration. In the 2021 electricity system, the average cost decreases by 1.90% under the 5% storage scenario and by 2.63% under the 7% scenario. As expected, increasing storage capacity enhances the system's ability to perform price arbitrage. In the projected 2030 system, the reductions amount to 2.41% and 3.36% for the 5% and 7% storage scenarios, respectively. These results show that cost reductions from storage increase when renewable penetration is higher, as greater variability in generation amplifies the value of shifting energy across time.

In Table 3.2 and Figure 3.11, I use the results in Figure 3.10 to calculate the wide economic and sectorial impacts of increasing energy storage capacity. For each scenario, I report key macroeconomic, fiscal, welfare, distributional, and environmental indicators. Table 3.2 reports the results for aggregated variables. Flow variables are presented as Net Present Value which was calculated using a 3% discount rate in line with the interest rate of the US bonds.

Table 3.2 – Counterfactual Impact of Energy Storage: Reductions in Electricity Costs. 10 years simulation.

		(1)	(2)	(3)	(4)
Simulation Characteristics					
Structure	Year	2021	2021	2030	2030
Storage Capacity / Total Capacity	Percentage	5.00	7.00	5.00	7.00
Avg. Cost Reduction	Percentage	1.90	2.60	2.40	3.60
Activity					
GDP	P.P.	0.473	0.646	0.775	1.108
Unemployment Rate	Avg. P.P.	-0.071	-0.096	-0.137	-0.196
Trade Balance	P.P.	0.473	0.647	0.774	1.107
Fiscal Variables					
Fiscal Revenue	P.P.	0.433	0.551	0.789	1.128
Government Welfare	P.P.	0.182	0.248	0.341	0.485
Welfare					
Quintile 1	P.P.	0.516	0.704	0.862	1.232
Quintile 5	P.P.	0.437	0.597	0.617	0.886
Gini Index	Avg. P.P.	-0.003	-0.003	-0.008	-0.011
Environment					
Emission Index	P.P.	-1.900	-2.605	-2.082	-3.018
Kuznets Index	P.P.	-2.291	-3.137	-2.782	-4.015

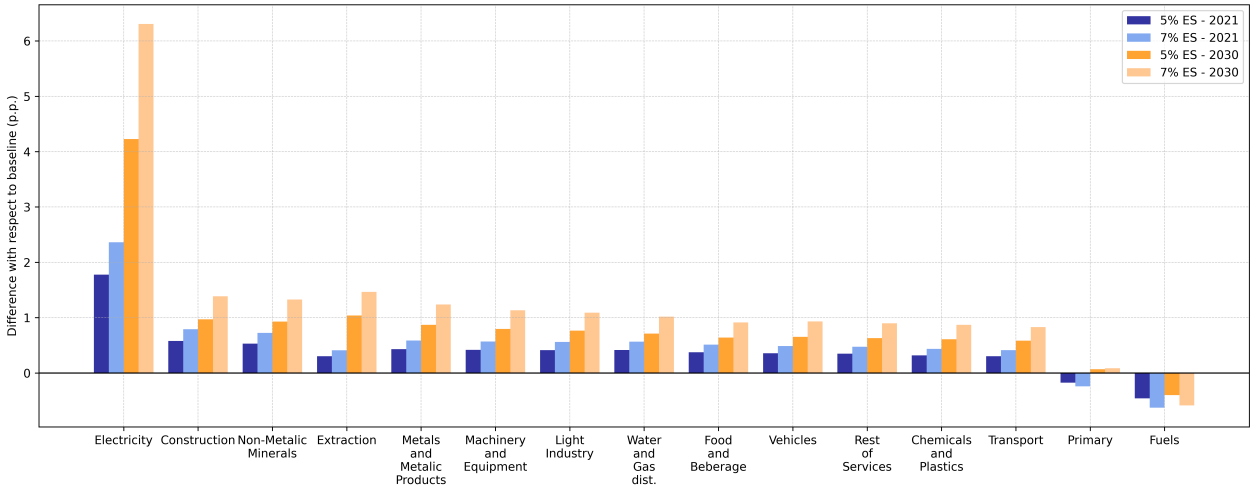
Note: This table presents the estimated impact of reductions in electricity costs due to energy storage on key aggregated variables. Net Present Value are calculated with a discunt rate of 3%.

In terms of activity-related variables, the results show that GDP increases and unemployment decreases across all scenarios. Depending on the case, GDP rises between 0.47 and 1.11 percentage points relative to the baseline. The unemployment rate falls between 0.07 and 0.19 percentage points. The trade balance also improves, following the overall expansion of the economy. Fiscal revenues rise as well, increasing between 0.43 and 1.13 percentage points over the ten-year period. Regarding welfare, all households experience gains, but lower-income households benefit more than higher-income ones, leading to an improvement in income distribution. This pattern arises because electricity constitutes a larger share of the consumption basket for low-income households. Finally, due to the increased profitability of renewables, emissions decline relative to the baseline, with total emissions falling between 1.9% and 3.02%. According to the Kuznets index, the economy also becomes cleaner in terms of emissions per unit of GDP.

When considering a riskier context, the results and interpretation of the indicators remain the same, but their magnitudes differ. High levels of risk significantly reduce the benefits of energy storage when measured in present value terms. Economic flows such as GDP and fiscal revenue are the only variables affected by the increase in the discount rate.

Figure 3.11 reports the winners and losers in terms of sectors. It reports, for each activity, the impact in terms of cumulated GDP.

Figure 3.11 – Counterfactual Impact of Energy Storage: Simulated effects of different levels of energy storage (5% and 7%) in two contexts, 2021 and 2030 on sectoral activity.

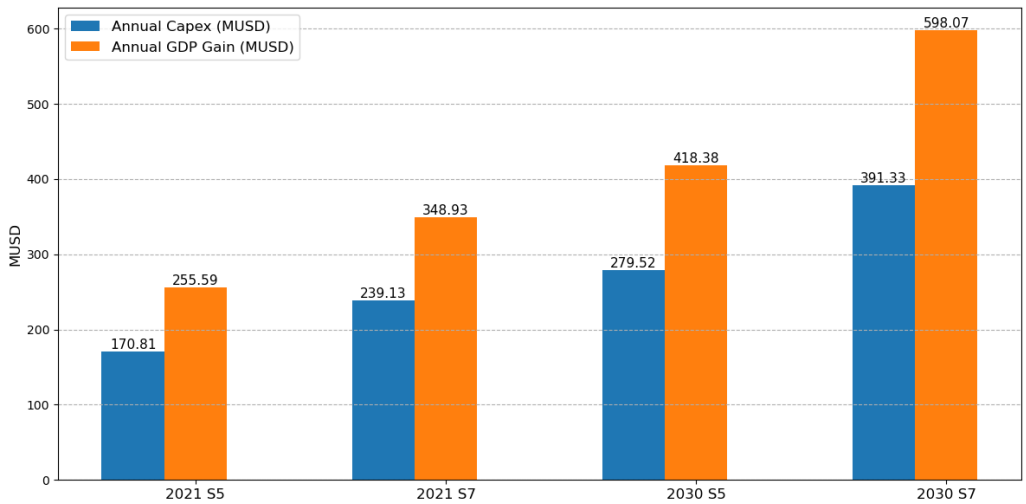


Note: This figure reports the decrease in the average cost of electricity for different levels of storage capacity.

Beyond the electricity sector, the most positively impacted are Construction, Non-Metallic Minerals, and Extraction. These sectors are highly electricity-intensive and closely linked through input-output relationships. Gains in one sector create positive spillovers in others. On the losing side, Fuels and Primary sectors experience negative impacts. In the first case, energy storage substitutes their role, reducing demand for fossil-based energy in the generation segment of the electricity market. For Primary activities, the low electricity intensity makes them less competitive, pushing capital and labor toward more dynamic sectors.

To conclude, Figure 3.12 compares the annualized cost of deploying energy storage in each scenario with the annualized gains in GDP, allowing us to assess the social profitability of investing in this infrastructure.

Figure 3.12 – Annualized Capital Expenditure in Energy Storage and Annualized Gains in Terms of GDP for Each Storage Scenario



Note: This figure compares, for each storage scenario, the annualized capital expenditure required to finance the infrastructure with the annualized gains in terms of GDP.

As shown in the figure, the social benefits of lower electricity costs (measured in terms

of GDP) are consistently higher than the required capital expenditures across all scenarios. This highlights the social profitability of these investments, even though in some cases they may not be profitable from a private perspective due to still-elevated costs. These results suggest that there is a clear role for public policy in promoting the adoption of energy storage technologies.

3.6 Conclusions

This study has examined the macroeconomic and sectoral impacts of energy storage deployment in Argentina, focusing on changes in electricity costs enabled by increased storage capacity. By simulating a set of storage scenarios, I show that significant reductions in the average cost of electricity (ranging from 1.9% to 3.3%) can be achieved through strategic investments in storage technologies, with corresponding improvements in economic performance, welfare, and environmental outcomes. Our results highlight the positive effects of energy storage on economic growth, fiscal revenues, and welfare, particularly for lower-income households, who benefit the most from lower electricity costs. In addition, energy storage contributes to a cleaner economy by reducing emissions. The findings underline that, while storage technologies help address intermittency and volatility in renewable energy supply, they also induce sectoral reallocation, favoring eletricity-intensive industries.

The analysis shows that, in every scenario, the annual gains in GDP brought about by lower electricity costs exceed the annualized investment required to install storage capacity. This indicates that storage deployment yields positive social returns, even if private investors may still face cost barriers that limit profitability. These findings underscore the importance of public policy in supporting the diffusion of energy storage technologies.

Although energy storage delivers substantial long-term benefits, the overall impact depends on key factors such as the speed of battery charge and discharge, the share of energy losses, and the scale of the storage infrastructure deployed. Policymakers must take these dynamics into account when designing energy transition strategies, ensuring that the gains from energy efficiency improvements are maximized while potential adverse effects are minimized.

Ultimately, this paper provides insights into the role of energy storage in decarbonizing the electricity sector and advancing the transition toward a more efficient, sustainable, and equitable energy system. The findings offer a framework for evaluating the broader economic implications of energy storage and inform policymaking processes that can guide Argentina (and similar economies) through the complexities of the energy transition.

Appendices

Appendix A: The Social Accounting Matrix

Appendix A presents the main results derived from the 2021 Argentine Social Accounting Matrix (SAM) both the aggregate and sectoral levels. Table 3.3 displays the composition of total supply and demand for Argentina.

Table 3.3 – Argentina 2021. Global Supply and Demand.

	Millions ARS
Total Supply	**53,132,422.5**
GDPmp	46,219,083.5
Imports	6,913,339.0
Total Demand	**53,132,422.5**
Private Consumption	29,090,837.6
Public Consumption	7,356,145.2
Investment	8,354,695.2
Exports	8,330,744.5

Note: *GDP*: Gross Domestic Product; *mp*: Market Prices; ARS: Argentine Local Currency Unit.

Table 3.4 presents the household accounts included in the SAM, disaggregated by income quintile. The matrix distinguishes five household groups, each corresponding to a different quintile. It reports the primary sources of income and main expenditure components for each group.

Table 3.4 – Argentina 2021. Households Incomes and Expenses by Income Group.

	H1	**H2**	**H3**	**H4**	**H5**
Total Expenses	**3,963,190.4**	**4,996,567.5**	**5,631,495.0**	**6,723,535.5**	**16,376,113.1**
Consumption	97.5%	97.0%	96.2%	91.3%	53.9%
Investment	0.6%	0.5%	1.4%	5.7%	44.1%
Direct Taxes	1.9%	2.5%	2.5%	3.1%	2.0%
Total Income	**1,728,432.3**	**2,961,059.7**	**3,631,350.8**	**6,168,037.6**	**27,830,328.7**
Labour	68.6%	66.5%	60.1%	52.0%	18.6%
Gross Mixed Income	7.6%	8.3%	12.6%	14.5%	12.6%
Capital	3.1%	1.8%	5.0%	14.8%	61.8%
Transfers	20.7%	23.4%	22.3%	18.8%	6.9%
Result	**-2,234,758.1**	**-2,035,507.8**	**-2,000,144.2**	**-555,498.0**	**11,454,215.6**

Note: Hi: Quintile i. Note: ARS: Argentine Local Currency Unit.

Table 3.5 presents the aggregate results from the account that captures the relationship between the national economy and the rest of the world. It reports both inflows and outflows, along with the resulting net balance.

Table 3.5 – Argentina 2021. Foreign account of the economy.

	Millions ARS	Share GDP
Income	**8,330,744.50**	**0.18**
Exports	8,330,744.50	0.18
Expenses	**7,773,165.85**	**0.17**
Imports	6,913,338.96	0.15
Factor Flows	859,826.89	0.02
Result	**557,578.65**	**0.01**

Note: ARS: Argentine Local Currency Unit.

Table 3.6 presents the results for the government account. It includes both revenue and expenditure, as well as the overall fiscal balance for the year 2021.

Table 3.6 – Argentina 2021. Government Incomes and Expenses.

	Millions ARS	Share GDP
Income	**12,739,560.5**	**0.276**
Taxes on Products	9,160,562.5	0.198
Taxes on Factors	2,699,026.8	0.058
Direct taxes	879,971.1	0.019
Expense	**16,810,289.4**	**0.364**
Public Expenditure	7,356,145.2	0.159
Public Capital Expenditure	634,602.3	0.014
Economic Subsidies	1,592,085.4	0.034
Transfers	4,944,484.1	0.107
Net other Incomes and expenses	2,282,972.4	0.049
Result	**- 4,070,728.9**	**- 0.088**

Note: ARS: Argentine Local Currency Unit.

Table 3.7 presents the sectoral disaggregation of the SAM, which includes 50 productive activities grouped into 15 categories. While the general equilibrium model is calibrated using the full 50-sector detail, the results presented in the paper are aggregated by group to maintain clarity and a manageable scale. Table 3.8 reports the main indicators per productive activity. To conclude with the presentation of the SAM, Table 3.9 reports an aggregated version of the SAM.

Table 3.7 – Argentina 2021. Sectoral Opening and Grouping of the National Social Accounting Matrix.

Sector	**Group**
Agriculture	Primary
Cattle Rising	Primary
Silviculture	Primary
Fishing	Primary
Coal	Extraction
Oil	Extraction
Gas	Extraction
Oil and Gas Related Acts.	Extraction
Minery	Extraction
Food and Beverage	Light Industry
Textil	Light Industry
Shoes	Light Industry
Wood and Wood Prods.	Light Industry
Paper	Light Industry
Edition and Printing	Light Industry
Gasoil	Fuels
Gasoline	Fuels
Fuel Oil	Fuels
Rest. Fuels	Fuels
Biodiesel	Fuels
Bioethanol	Fuels
Chemicals	Chemicals and Plastics
Plastics and Rubber	Chemicals and Plastics
Non-Metallic Minerals	Non-Metallic Minerals
Metallic Products	Metals
Machinery and Equipment	Machinery and Equipment
Vehicles	Vehicles
Other Transport Equipent	Vehicles
Rest of Industry	Light Industry
Electricity - Termic Generation	Gen. Transp. And Dist of electricity
Electricity - Hydroelectric Generation	Gen. Transp. And Dist of electricity
Electricity - Nuclear Generation	Gen. Transp. And Dist of electricity
Electricity - Eolic Generation	Gen. Transp. And Dist of electricity
Electricity - Solar Generation	Gen. Transp. And Dist of electricity
Electricity - Rest Generation	Gen. Transp. And Dist of electricity
Transport and Dist. Of Electricity	Gen. Transp. And Dist of electricity
Transport and Dist. Of Gas	Transport and Distribution of Gas
Transport and Dist. Of Water	Transport and Distribution of Water
Construction	Construction
Commerce	Rest of Services
Hotels and Restaurants	Rest of Services
Rail Transports	Transportation and Telecomunications
Road Transport	Transportation and Telecomunications
Rest of Transport and Comunications	Transportation and Telecomunications
Financial Servives	Rest of Services
Bussiness and Real State Activities	Rest of Services
Public Administration	Rest of Services
Education	Rest of Services
Health	Rest of Services
Rest of Servicies	Rest of Services

Table 3.8 – Argentina 2021. Sectoral Indicators.

Sector	VA Intensity	Share VA	Share of Imported Supply	Share of Private Cons. In Final Demand	Share of Exports In Final Demand
Agriculture	54.22	5.78	5.86	22.70	62.92
Cattle Rising	52.22	2.11	0.22	80.02	8.74
Silviculture	67.94	0.10	10.84	91.27	8.90
Fishing	68.05	0.35	2.81	29.29	70.23
Coal	53.54	0.01	82.82	-	100.00
Oil	48.40	1.35	10.42	7.90	41.66
Gas	42.54	0.38	12.53	-	15.91
Oil and Gas Related Acts.	60.16	0.62	0.69	-	-
Minery	68.12	0.93	15.08	10.42	88.97
Food and Beverage	40.67	9.02	1.60	70.47	29.38
Textil	48.71	1.02	11.57	85.19	12.73
Shoes	58.80	0.18	21.55	99.00	0.43
Wood and Wood Prods.	51.80	0.39	4.98	30.39	51.67
Paper	44.60	0.60	12.08	88.80	11.29
Edition and Printing	52.48	0.64	4.09	92.28	6.05
Gasoil	29.55	0.48	10.66	99.95	0.05
Gasoline	41.29	0.68	9.69	99.79	0.21
Fuel Oil	9.56	0.02	5.70	-	100.00
Rest. Fuels	23.60	0.25	20.16	71.50	26.31
Biodiesel	22.95	0.01	26.20	-	100.00
Bioethanol	37.56	0.01	15.78	-	100.00
Chemicals	46.00	2.51	29.85	73.12	17.22
Plastics and Rubber	35.81	1.39	24.30	29.84	48.38
Non-Metallic Minerals	49.92	0.90	7.46	51.85	21.75
Metallic Products	41.70	2.10	21.78	15.16	35.78
Machinery and Equipment	39.54	1.79	39.19	37.27	4.57
Vehicles	34.95	1.52	25.66	34.84	31.55
Other Transport Equipent	54.35	0.16	39.19	89.77	3.98
Rest of Industry	56.24	0.65	14.49	66.25	8.38
Electricity - Termic Generation	20.57	0.26	1.38	-	-
Electricity - Hydroelectric Generation	79.62	0.06	1.89	-	100.00
Electricity - Nuclear Generation	57.12	0.04	1.47	-	-
Electricity - Eolic Generation	79.13	0.01	1.39	-	-
Electricity - Solar Generation	90.16	0.00	1.65	-	-
Electricity - Rest Generation	55.58	0.00	1.31	-	-
Transport and Dist. Of Electricity	30.44	0.43	3.03	100.00	-
Transport and Dist. Of Gas	36.51	0.27	0.21	74.44	25.41
Transport and Dist. Of Water	62.95	0.19	-	100.00	-
Construction	48.10	4.30	0.10	-	0.05
Commerce	71.15	16.93	1.20	65.14	22.11
Hotels and Restaurants	43.38	1.71	4.84	98.45	1.54
Rail Transports	57.23	0.04	-	100.00	-
Road Transport	32.48	1.66	-	90.09	9.91
Resto of Transport and Comunications	46.84	3.79	2.40	90.84	9.16
Financial Servives	72.27	5.83	0.78	95.15	0.94
Bussiness and Real State Activities	69.34	9.99	6.43	75.77	17.20
Public Administration	69.52	6.29	0.09	10.47	0.04
Education	83.98	4.73	0.00	32.22	0.00
Health	61.10	4.65	0.03	51.25	0.02
Rest of Servicies	61.89	2.88	3.61	96.49	2.63

Note: Values are measured as percentage (%).

Table 3.9 – Argentina 2021. Social Accounting Matrix. Millions of Local Currency Units.

	S1	S2	S3	S4	VA	T	H1	H2	G	I	X
S1	1,403,185.6	3,816,714.0	656,827.5	225,904.6	0.0	0.0	639,189.3	279,271.0	0.0	686,020.5	2,150,547.9
S2	771,438.2	5,362,639.5	4,436,796.8	158,266.8	0.0	0.0	5,350,630.6	5,178,531.5	179,635.4	1,715,944.0	3,937,714.1
S3	2,035,442.1	2,920,933.9	10,783,611.3	108,965.3	0.0	0.0	7,484,351.5	8,891,770.9	7,176,509.8	4,531,014.7	2,213,692.3
S4	65,449.7	222,677.1	370,576.3	373,155.2	0.0	0.0	147,613.0	104,073.5	0.0	-6.4	28,790.2
M	237,587.8	3,601,683.3	823,219.2	74,518.4	0.0	0.0	417,048.0	416,461.4	0.0	1,342,820.7	-6,913,339.0
VA	4,616,407.6	6,607,176.0	24,451,153.9	276,842.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TF	327,796.1	583,781.8	1,768,018.7	19,430.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TP	400,353.2	3,975,991.4	2,856,088.1	75,245.9	0.0	0.0	88,617.2	93,279.5	0.0	78,901.8	0.0
TD	0.0	0.0	0.0	0.0	0.0	0.0	342,175.3	537,795.8	0.0	0.0	0.0
G	0.0	0.0	0.0	0.0	-2,282,972.4	11,147,475.1	0.0	0.0	0.0	0.0	0.0
I	0.0	0.0	0.0	0.0	0.0	0.0	121,628.0	7,598,464.9	634,602.3	0.0	0.0
H1	0.0	0.0	0.0	0.0	6,459,775.8	0.0	0.0	0.0	1,861,067.1	0.0	0.0
H2	0.0	0.0	0.0	0.0	30,914,949.3	0.0	0.0	0.0	3,083,417.0	0.0	0.0
RM	0.0	0.0	0.0	0.0	859,826.9	0.0	0.0	0.0	0.0	0.0	0.0
Result	0.0	0.0	0.0	0.0	0.0	0.0	-6,270,410.1	10,898,717.6	-4,070,728.9	0.0	-557,578.7

Note: This table presents a simplified version of the 2021 Argentine Social Accounting Matrix. The values of the transactions between accounts are measured in millions of local currency units (ARS) for the year 2021. The original matrix includes 50 productive sectors, 5 households, one government, and the rest of the world. That version is available with the submission of the thesis.

Appendix B: Dynamic Results

Table 3.10 – Results for the scenario with 5% energy storage in total generation in the base year (2021). Differences relative to the baseline.

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Activity										
GDP	0.054	0.055	0.055	0.055	0.056	0.056	0.056	0.056	0.056	0.056
Unemployment Rate	-0.069	-0.070	-0.069	-0.070	-0.071	-0.071	-0.072	-0.072	-0.072	-0.072
Trade Balance	0.054	0.055	0.055	0.055	0.056	0.056	0.056	0.056	0.056	0.056
Fiscal Variables										
Fiscal Revenue	0.048	0.049	0.049	0.050	0.051	0.051	0.052	0.052	0.053	0.053
Government Welfare	0.023	0.023	0.023	0.022	0.022	0.021	0.020	0.019	0.020	0.019
Welfare										
Quintile 1	0.059	0.059	0.060	0.060	0.061	0.061	0.061	0.061	0.062	0.062
Quintile 2	0.051	0.051	0.052	0.052	0.052	0.051	0.051	0.050	0.051	0.050
Gini Index	-0.002	-0.002	-0.002	-0.002	-0.002	-0.003	-0.003	-0.003	-0.003	-0.003
Environment										
Emission Index	-0.182	-0.184	-0.184	-0.187	-0.189	-0.191	-0.193	-0.196	-0.196	-0.198
Kuznets Index	-0.236	-0.235	-0.234	-0.232	-0.231	-0.229	-0.227	-0.224	-0.223	-0.221
Sectoral Activity										
Primary	-0.017	-0.018	-0.017	-0.018	-0.019	-0.021	-0.022	-0.024	-0.024	-0.026
Extraction	0.032	0.033	0.034	0.034	0.035	0.036	0.037	0.038	0.039	0.040
Food, Beverages, and Tobacco	0.043	0.043	0.044	0.044	0.044	0.044	0.045	0.045	0.045	0.045
Light Manufacturing	0.046	0.047	0.047	0.048	0.048	0.049	0.049	0.049	0.050	0.050
Fuels	-0.050	-0.051	-0.051	-0.052	-0.053	-0.054	-0.056	-0.057	-0.057	-0.059
Chemicals and Plastics	0.036	0.037	0.037	0.037	0.038	0.038	0.038	0.038	0.038	0.038
Non-Metallic Minerals	0.060	0.061	0.061	0.062	0.062	0.063	0.063	0.064	0.064	0.064
Metals and Metal Products	0.048	0.048	0.049	0.050	0.050	0.051	0.052	0.052	0.053	0.053
Machinery and Equipment	0.047	0.048	0.048	0.049	0.049	0.049	0.050	0.050	0.050	0.051
Vehicles	0.040	0.041	0.041	0.041	0.042	0.042	0.043	0.043	0.043	0.043
Electricity	0.135	0.156	0.156	0.177	0.200	0.223	0.247	0.271	0.270	0.294
Water and Gas Distribution	0.047	0.048	0.048	0.048	0.049	0.049	0.049	0.049	0.050	0.050
Transport	0.035	0.035	0.036	0.036	0.036	0.036	0.036	0.035	0.036	0.035
Construction	0.066	0.066	0.067	0.067	0.068	0.068	0.069	0.069	0.070	0.070
Other Services	0.040	0.040	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041

Table 3.11 – Results for the scenario with 7% energy storage in total generation in the base year (2021). Differences relative to the baseline.

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Activity										
GDP	0.074	0.075	0.075	0.075	0.076	0.076	0.077	0.077	0.077	0.077
Unemployment Rate	-0.094	-0.095	-0.094	-0.095	-0.096	-0.097	-0.097	-0.098	-0.098	-0.098
Trade Balance	0.074	0.075	0.075	0.075	0.076	0.076	0.077	0.077	0.077	0.077
Fiscal Variables										
Fiscal Revenue	0.062	0.063	0.063	0.064	0.065	0.065	0.066	0.066	0.067	0.067
Government Welfare	0.031	0.031	0.031	0.031	0.030	0.029	0.028	0.027	0.027	0.025
Welfare										
Quintile 1	0.080	0.081	0.081	0.082	0.083	0.083	0.084	0.084	0.084	0.084
Quintile 2	0.070	0.070	0.071	0.071	0.071	0.070	0.070	0.069	0.069	0.069
Gini Index	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.004	-0.004	-0.004	-0.004
Environment										
Emission Index	-0.249	-0.253	-0.253	-0.256	-0.259	-0.262	-0.265	-0.268	-0.268	-0.271
Kuznets Index	-0.323	-0.321	-0.320	-0.318	-0.316	-0.313	-0.310	-0.307	-0.306	-0.303
Sectoral Activity										
Primary	-0.024	-0.024	-0.024	-0.025	-0.027	-0.029	-0.031	-0.033	-0.033	-0.036
Extraction	0.043	0.045	0.045	0.046	0.048	0.049	0.050	0.052	0.052	0.054
Food, Beverages, and Tobacco	0.058	0.059	0.059	0.060	0.060	0.061	0.061	0.061	0.061	0.062
Light Manufacturing	0.063	0.064	0.065	0.065	0.066	0.067	0.067	0.067	0.068	0.068
Fuels	-0.068	-0.070	-0.070	-0.071	-0.073	-0.074	-0.076	-0.078	-0.078	-0.080
Chemicals and Plastics	0.050	0.050	0.051	0.051	0.051	0.051	0.052	0.052	0.052	0.052
Non-Metallic Minerals	0.082	0.083	0.083	0.084	0.085	0.086	0.086	0.087	0.088	0.088
Metals and Metal Products	0.065	0.066	0.066	0.068	0.069	0.070	0.071	0.071	0.072	0.073
Machinery and Equipment	0.064	0.065	0.065	0.066	0.067	0.067	0.068	0.068	0.069	0.069
Vehicles	0.055	0.055	0.056	0.056	0.057	0.058	0.058	0.058	0.059	0.059
Electricity	-0.131	-0.114	-0.115	-0.098	-0.081	-0.063	-0.045	-0.026	-0.028	-0.010
Water and Gas Distribution	0.065	0.065	0.066	0.066	0.066	0.067	0.067	0.067	0.068	0.068
Transport	0.048	0.048	0.049	0.049	0.049	0.049	0.049	0.048	0.049	0.048
Construction	0.090	0.090	0.091	0.092	0.093	0.093	0.094	0.095	0.095	0.096
Other Services	0.055	0.055	0.055	0.056	0.056	0.056	0.056	0.056	0.057	0.056

Table 3.12 – Results for the scenario with 5% energy storage in total generation in the projected 2030 scenario. Differences relative to the baseline.

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Activity										
GDP	0.094	0.093	0.094	0.093	0.092	0.091	0.089	0.086	0.087	0.085
Unemployment Rate	-0.136	-0.136	-0.136	-0.137	-0.137	-0.138	-0.138	-0.139	-0.139	-0.139
Trade Balance	0.094	0.093	0.094	0.093	0.092	0.091	0.089	0.086	0.087	0.084
Fiscal Variables										
Fiscal Revenue	0.095	0.095	0.095	0.095	0.094	0.093	0.091	0.089	0.090	0.087
Government Welfare	0.050	0.048	0.048	0.046	0.043	0.039	0.035	0.030	0.030	0.024
Welfare										
Quintile 1	0.104	0.103	0.104	0.104	0.102	0.101	0.099	0.097	0.098	0.095
Quintile 2	0.082	0.080	0.080	0.078	0.075	0.071	0.067	0.063	0.063	0.058
Gini Index	-0.006	-0.007	-0.007	-0.007	-0.007	-0.008	-0.008	-0.009	-0.009	-0.009
Environment										
Emission Index	-0.193	-0.197	-0.197	-0.202	-0.206	-0.211	-0.215	-0.219	-0.219	-0.222
Kuznets Index	-0.287	-0.285	-0.285	-0.283	-0.281	-0.278	-0.275	-0.271	-0.270	-0.266
Sectoral Activity										
Primary	0.027	0.022	0.023	0.018	0.012	0.006	-0.001	-0.009	-0.008	-0.017
Extraction	0.117	0.118	0.119	0.120	0.121	0.122	0.124	0.126	0.127	0.129
Food, Beverages, and Tobacco	0.077	0.077	0.077	0.077	0.076	0.075	0.074	0.072	0.073	0.071
Light Manufacturing	0.092	0.091	0.092	0.091	0.091	0.090	0.088	0.087	0.088	0.085
Fuels	-0.037	-0.040	-0.039	-0.042	-0.045	-0.048	-0.052	-0.056	-0.055	-0.060
Chemicals and Plastics	0.076	0.075	0.075	0.074	0.073	0.071	0.069	0.067	0.068	0.065
Non-Metallic Minerals	0.110	0.110	0.111	0.110	0.110	0.109	0.108	0.107	0.108	0.106
Metals and Metal Products	0.101	0.101	0.102	0.103	0.103	0.103	0.102	0.102	0.103	0.102
Machinery and Equipment	0.095	0.095	0.095	0.095	0.094	0.093	0.092	0.090	0.091	0.089
Vehicles	0.078	0.077	0.078	0.078	0.077	0.077	0.076	0.075	0.075	0.074
Electricity	0.358	0.397	0.398	0.437	0.478	0.521	0.566	0.612	0.614	0.661
Water and Gas Distribution	0.086	0.086	0.086	0.086	0.085	0.083	0.082	0.080	0.081	0.078
Transport	0.074	0.073	0.073	0.072	0.070	0.068	0.065	0.062	0.063	0.059
Construction	0.115	0.115	0.116	0.115	0.115	0.114	0.113	0.111	0.112	0.110
Other Services	0.078	0.077	0.078	0.077	0.075	0.073	0.071	0.069	0.070	0.067

Table 3.13 – Results for the scenario with 7% energy storage in total generation in the projected 2030 scenario. Differences relative to the baseline.

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Activity										
GDP	0.134	0.133	0.135	0.134	0.132	0.130	0.127	0.124	0.125	0.121
Unemployment Rate	-0.193	-0.194	-0.194	-0.195	-0.196	-0.196	-0.197	-0.198	-0.197	-0.198
Trade Balance	0.134	0.133	0.135	0.134	0.132	0.130	0.127	0.124	0.125	0.121
Fiscal Variables										
Fiscal Revenue	0.135	0.135	0.136	0.135	0.134	0.133	0.130	0.127	0.129	0.125
Government Welfare	0.071	0.068	0.069	0.065	0.061	0.056	0.049	0.042	0.043	0.035
Welfare										
Quintile 1	0.148	0.148	0.149	0.148	0.146	0.144	0.142	0.139	0.140	0.136
Quintile 2	0.117	0.114	0.115	0.111	0.107	0.103	0.097	0.091	0.092	0.084
Gini Index	-0.009	-0.009	-0.009	-0.010	-0.010	-0.011	-0.012	-0.012	-0.012	-0.013
Evironment										
Emmision Index	-0.280	-0.286	-0.287	-0.293	-0.299	-0.305	-0.311	-0.317	-0.317	-0.322
Kuznets Index	-0.414	-0.412	-0.411	-0.409	-0.406	-0.402	-0.397	-0.391	-0.390	-0.384
Sectoral Activity										
Primary	0.036	0.029	0.030	0.023	0.015	0.006	-0.003	-0.014	-0.013	-0.026
Extraction	0.165	0.166	0.167	0.169	0.171	0.173	0.175	0.177	0.179	0.181
Food, Beverages, and Tobacco	0.110	0.110	0.110	0.110	0.109	0.107	0.105	0.103	0.104	0.102
Light Manufacturing	0.130	0.130	0.131	0.130	0.129	0.128	0.126	0.124	0.125	0.122
Fuels	-0.055	-0.058	-0.058	-0.062	-0.066	-0.071	-0.076	-0.081	-0.081	-0.087
Chemicals and Plastics	0.107	0.106	0.107	0.106	0.104	0.102	0.099	0.095	0.097	0.093
Non-Metallic Minerals	0.156	0.156	0.158	0.157	0.157	0.156	0.155	0.153	0.155	0.152
Metals and Metal Products	0.143	0.144	0.145	0.146	0.146	0.146	0.146	0.145	0.147	0.146
Machinery and Equipment	0.135	0.135	0.136	0.135	0.134	0.133	0.131	0.129	0.130	0.127
Vehicles	0.110	0.110	0.111	0.111	0.110	0.109	0.108	0.106	0.108	0.105
Electricity	0.540	0.596	0.597	0.654	0.714	0.776	0.841	0.908	0.911	0.979
Water and Gas Distribution	0.123	0.122	0.123	0.122	0.121	0.119	0.117	0.114	0.116	0.112
Transport	0.105	0.103	0.104	0.102	0.100	0.097	0.093	0.089	0.090	0.085
Construction	0.164	0.164	0.165	0.165	0.164	0.163	0.161	0.159	0.161	0.158
Other Services	0.111	0.110	0.111	0.109	0.107	0.105	0.102	0.099	0.100	0.096

Table 3.14 – Baseline results for the 2021 scenario.

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Activity										
GDP	0.000	1.731	2.172	3.952	5.795	7.696	9.655	11.668	12.175	14.212
Unemployment Rate	9.300	8.907	9.556	9.156	8.731	8.284	7.818	7.337	7.983	7.520
Trade Balance	0.000	3.803	4.770	8.654	12.650	16.754	20.962	25.270	26.361	30.703
Fiscal Variables										
Fiscal Revenue	0.000	1.934	2.227	4.186	6.198	8.259	10.368	12.521	12.837	14.989
Government Welfare	0.000	2.052	2.685	4.790	6.965	9.209	11.522	13.903	14.610	17.029
Welfare										
Quintile 1	0.000	1.670	2.003	3.710	5.471	7.283	9.143	11.050	11.422	13.340
Quintile 2	0.000	1.832	2.200	4.072	6.003	7.990	10.032	12.126	12.537	14.643
Gini Index	40.295	40.340	40.350	40.394	40.439	40.483	40.526	40.570	40.579	40.622
Evironment										
Emmision Index	100.000	101.600	101.890	103.412	104.890	106.315	107.681	108.979	109.192	110.372
Kuznets Index	100.000	99.872	99.725	99.480	99.145	98.718	98.200	97.592	97.341	96.638
Sectoral Activity										
Primary	0.000	3.348	4.046	7.361	10.712	14.100	17.525	20.986	21.643	25.065
Extraction	0.000	1.542	1.870	3.353	4.815	6.256	7.675	9.071	9.343	10.680
Food, Beverages, and Tobacco	0.000	1.110	1.230	2.367	3.544	4.758	6.007	7.290	7.443	8.733
Light Manufacturing	0.000	1.583	1.821	3.428	5.078	6.770	8.502	10.271	10.538	12.308
Fuels	0.000	1.387	1.599	3.012	4.466	5.961	7.495	9.065	9.308	10.883
Chemicals and Plastics	0.000	1.601	1.829	3.448	5.108	6.808	8.545	10.317	10.567	12.336
Non-Metallic Minerals	0.000	1.551	1.851	3.438	5.075	6.761	8.493	10.270	10.610	12.399
Metals and Metal Products	0.000	1.461	1.654	3.131	4.644	6.192	7.773	9.385	9.599	11.207
Machinery and Equipment	0.000	1.663	1.961	3.655	5.399	7.191	9.029	10.911	11.242	13.131
Vehicles	0.000	1.174	1.269	2.467	3.702	4.975	6.282	7.623	7.748	9.094
Electricity	0.000	1.389	1.612	3.025	4.477	5.968	7.495	9.056	9.308	10.872
Water and Gas Distribution	0.000	1.372	1.593	2.994	4.439	5.925	7.452	9.015	9.270	10.841
Transport	0.000	1.705	2.002	3.729	5.501	7.316	9.172	11.068	11.389	13.286
Construction	0.000	1.591	1.945	3.580	5.272	7.019	8.818	10.668	11.069	12.937
Other Services	0.000	1.558	1.828	3.410	5.035	6.702	8.406	10.146	10.443	12.184

Table 3.15 – Baseline results for the projected 2030 scenario.

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Activity										
GDP	-0.103	1.634	2.070	3.861	5.716	7.634	9.612	11.647	12.148	14.212
Unemployment Rate	9.589	9.200	9.853	9.454	9.030	8.583	8.116	7.632	8.282	7.814
Trade Balance	-0.228	3.594	4.549	8.459	12.486	16.627	20.877	25.234	26.313	30.713
Fiscal Variables										
Fiscal Revenue	-0.203	1.744	2.034	4.009	6.040	8.123	10.256	12.437	12.749	14.933
Government Welfare	-0.148	1.919	2.549	4.673	6.870	9.140	11.483	13.898	14.603	17.061
Welfare										
Quintile 1	-0.131	1.547	1.875	3.593	5.367	7.195	9.074	11.003	11.370	13.313
Quintile 2	-0.022	1.826	2.191	4.083	6.037	8.052	10.125	12.254	12.661	14.809
Gini Index	40.325	40.372	40.382	40.429	40.475	40.521	40.568	40.614	40.623	40.668
Evironment										
Emmision Index	99.448	101.062	101.351	102.886	104.377	105.815	107.192	108.499	108.709	109.896
Kuznets Index	99.551	99.437	99.296	99.062	98.733	98.310	97.793	97.181	96.934	96.221
Sectoral Activity										
Primary	-0.639	2.750	3.450	6.809	10.206	13.642	17.119	20.636	21.292	24.776
Extraction	-0.756	0.795	1.123	2.614	4.082	5.528	6.951	8.350	8.618	9.956
Food, Beverages, and Tobacco	-0.111	1.005	1.121	2.267	3.453	4.679	5.941	7.240	7.390	8.699
Light Manufacturing	-0.205	1.387	1.621	3.239	4.902	6.610	8.359	10.149	10.410	12.204
Fuels	-0.239	1.153	1.361	2.782	4.246	5.753	7.301	8.887	9.126	10.721
Chemicals and Plastics	-0.183	1.430	1.656	3.289	4.966	6.684	8.442	10.238	10.484	12.281
Non-Metallic Minerals	-0.177	1.379	1.675	3.269	4.916	6.615	8.362	10.156	10.491	12.301
Metals and Metal Products	-0.297	1.170	1.359	2.843	4.366	5.924	7.517	9.143	9.352	10.977
Machinery and Equipment	-0.211	1.459	1.752	3.455	5.212	7.018	8.873	10.773	11.099	13.011
Vehicles	-0.171	1.009	1.101	2.307	3.552	4.836	6.158	7.514	7.635	9.000
Electricity	1.876	3.319	3.546	5.015	6.528	8.082	9.675	11.307	11.563	13.201
Water and Gas Distribution	-0.132	1.247	1.464	2.874	4.331	5.831	7.373	8.956	9.206	10.799
Transport	-0.204	1.513	1.806	3.548	5.338	7.173	9.052	10.973	11.290	13.216
Construction	-0.132	1.464	1.811	3.454	5.157	6.916	8.731	10.599	10.996	12.886
Other Services	-0.154	1.413	1.680	3.274	4.914	6.597	8.320	10.082	10.375	12.141

Concluding Remarks

This thesis explores the energy transition in the context of a developing country: Argentina. It evaluates the impact of policies, regulations, and investments aimed at easing this transition. The analysis assesses whether these actions effectively support the shift toward cleaner energy and help reduce greenhouse gas emissions. By evaluating the impact of different energy transition scenarios, this thesis offers insights and practical recommendations for other countries shaping their own energy strategies. The urgency is clear: climate change is intensifying extreme weather events, and reducing carbon emissions is essential. Since energy production and consumption account for a large share of emissions, economies must rapidly adopt more sustainable systems. At the same time, energy underpins nearly every value chain. The transition must therefore balance environmental goals with the need to protect economic activity and social welfare. As the costs of inaction rise (with natural disasters and pollution causing increasing harm) delaying the transition only prolongs recovery. For that reason, energy transition should play a central part of national goals but it should not be pursued at any cost but it should be included in the development agenda.

Below, I describe detailed conclusion comments on each chapter.

The **first chapter**, called *What are the costs of rigidity? A General Equilibrium study of the fuel market in Argentina* focuses on the Argentine fuel market. Particularly, it focus on the role of first-generation biodiesel and bioethanol, and studies the costs and benefits induced by the mandatory blend. This policy has been widely applied to regulate how those fuels are mixed and to incentivize the use of biofuels. It sets a minimum level of biofuels that must be present in a unit of blended fuel. Argentina is a biofuel-producing country with proven comparative advantages in the production of the primary inputs for biofuels (Timilsina et al., 2013). Therefore, the conclusions from this work may be illustrative for other producing countries. Torroba and Orozco Montoya (2023) report that biofuel mandates are present, with varying rates and setups depending on the country. Thus, the modelling of this policy and the conclusions from this analysis relate to other countries applying this regulation. This research addresses the following questions: (i) What are the costs and benefits of a mandatory blend compared to a full flexibility scenario? (ii) Which policy is better to induce the use of biofuels: a blending constraint or a tax on fossil fuels? And, finally, (iii) what is the impact of international price shocks when considering different blending regimes?

To explore these questions, this paper develops a Computable General Equilibrium (CGE) model calibrated using a new own-developed 2018 Social Accounting Matrix of Argentina, with a focus on energy sectors. The modelling of the fuel and biofuel supply, together with an explicit representation of the blending constraint, are the most relevant methodological aspects of this paper. The model was recursively estimated from 2019 to 2030. There are three blocks of counterfactual exercises. The first one evaluates the cost and benefits of the mandatory blend with respect to a full flexibility scenario. The second one evaluates the best alternative to induce biofuel use by comparing previous mandatory blends with a scenario involving an additional fossil fuel tax to achieve equivalent blending levels. Finally, the third one measures the performance of the mandatory blend when the

international price of oil and the international prices of agricultural commodities increase. This paper finds that, if there is a shift from a mandatory blend regime to a flexible one, although upon calibration relative prices are in favour of fossil fuels, biofuels remain in the economy, and over time their share in the blend increases. It also finds that the mandatory blend presents a trade-off between efficiency and environmental outcome. Particularly, there are costs in terms of activity, welfare, income distribution, and energy affordability compared to the full flexibility scenario. However, in terms of environmental outcomes, the mandatory blend is an effective policy. As for the more convenient policy to induce a certain blend, this paper finds that the costs and benefits of a fossil fuel tax versus a mandatory blend are distributed differently over time. For the fossil fuel tax, benefits are derived in the short run while for the mandatory blend, in the long run. Finally, this paper finds that flexibility in the fuel market improves the country's performance when there are shocks on international prices.

The **second chapter**, called *Driving Change: Assessing the Impact of EV-promoting Policies in Argentina* assess the impact of different policy scenarios on EV penetration, emissions, battery disposals, household welfare, and fiscal revenue. The research questions are: (i) What is the impact of subsidizing new EVs and new charging infrastructure on adoption, emissions, battery disposals, welfare, and fiscal outcomes? (ii) What is the welfare-maximizing subsidy for new EVs, and how does it change when environmental externalities, network externalities, and tax policies change? (iii) If banning new ICE vehicle sales is considered, by how much should EV prices decrease to maintain pre-ban household welfare? In this chapter, I develop and estimate a dynamic structural model that considers trading patterns in the primary and secondary automobile markets of the type described in Gillingham et al. (2022). There are two distinctive aspects of this model: First, the modelling of a battery charging service market characterized by an optimal investment problem. Second, the introduction of indirect network effects arising from the interdependence between EV adoption and investment decisions regarding charging infrastructure. These effects can limit EV adoption and erode the effectiveness of the EV-promoting policies.

I evaluate three blocks of counterfactual scenarios. In the first block, I quantify the effects of subsidies to new EVs ($s \in [0, 0.3]$) and charging infrastructure ($s_c \in [0, 0.3]$), both with and without network effects. To account for price dynamics, I consider three EV price scenarios: (i) baseline, (ii) a 7% reduction, and (iii) a 15% reduction (IEA, 2025b). I find that subsidies to new EVs substantially encourage adoption: the residential EV share rises from 0.32% in the baseline to 11.88% at a 30% subsidy, while the share of households without a car falls from 60.41% to 58.09%. Network effects become more important as the subsidy increases. When network effects operate and households care about infrastructure availability, EV market penetration falls by up to 10.63 percentage points at a 30% subsidy with respect to the no network effects situation. Charging costs and the number of charging stations both increase significantly with the subsidy. Carbon emissions decline, while battery disposals increase from 0.97 to 27.09 thousand per year. Fiscal revenues remain stable, and average household welfare increases from 4.25 to 4.32 thousand USD. The results also show that the tax regime used to finance EV promotion is not distributionally neutral and plays a central role in shaping the policy's equity implications. By contrast, subsidies to charging infrastructure alone have negligible effects. These results indicate that the primary barrier to EV adoption is the high upfront cost of vehicles and that charging infrastructure responds mainly to increases in EV adoption rather than to direct subsidies.

In the second block, I estimate the welfare-maximizing subsidy to new EVs. The optimal subsidy equates marginal social benefits with marginal social costs. Benefits include (i) reduced noise and local pollution and (ii) lower travel costs due to EVs' higher efficiency in cost per kilometer. Social costs arise from the tax burden required to fund the subsidy. Under the status quo, the optimal subsidy equals 29%, yielding an EV share of 9.36% and a no-car share of 58.62%. Excluding environmental externalities reduces the optimal subsidy to 24%, with an EV share equal to 4.05%. Excluding network externalities further reduces the subsidy to 20%. Estimating the optimal subsidy jointly with the elimination of car taxes or VAT yields optimal subsidies of 17% and 25%, respectively. Eliminating car taxes generates the highest EV penetration, with an EV share of 29.33% and a no-car share of 53.86%. In the third block, I simulate a ban on new ICE vehicle sales by imposing prohibitively high transaction costs. To preserve pre-ban household welfare, EV prices must fall by 37%, which fully electrifies the fleet and raises the no-car share to 74.35%. Alternatively, to maintain the pre-ban share of carless households, EV prices must decline by 44%.

Finally, the **third chapter** called *Wide Economic Impacts of Energy Storage: The Case of Argentina* (written with Exequiel Romero-Gomez) focus on the impact of energy storage for the case of Argentina. The objective of this article is to study the wide-economic and sectorial impacts of installing energy storage capacity for the case of Argentina. Particularly, I discuss the following research questions: (i) How does the cost of electricity change under different levels of energy storage capacity? (ii) Given these new electricity costs, relative profitability between sectors changes: who are the winners and losers? (iii) What are the effects on aggregate variables and household welfare? (iv) Are the social benefits of installing this infrastructure greater than its costs? To answer this questions, I develop a stylized dynamic model of the power market in Argentina. This model accounts for optimal dispatch of electricity to satisfy hourly demand. There are two ways to smooth the prices curve: Either by managing a given charging infrastructure or by managing water reservoirs for hydroelectric production. I use hourly data on local supply and demand for Argentina 2021 provided by CAMMESA to estimate our model. The main objective of this model is to estimate how different level of storage infrastructure changes the average cost of electricity. Also, I develop a recursive General Equilibrium model that I use to evaluate the previous cost reductions in terms of aggregate and sectorial activity, fiscal variables, welfare, income distribution and emissions. To estimate this model we used an owned-developed Social Accounting Matrix (SAM) for Argentina 2021 with focus on energy activities.

I use the dispatch model to simulate four alternative storage scenarios: storage representing 5% and 7% of total generation capacity under current system conditions (year 2021), and the same storage shares in a projected 2030 system based on the National Secretariat of Energy's report, which incorporates a 22% increase in electricity demand and substantial expansions in renewable, hydro, nuclear, and combined-cycle capacity, consistent with Law 27,191. The analysis shows that expanding storage capacity reduces the average cost of electricity. Across all scenarios, electricity costs fall between 1.9% and 3.36% relative to the baseline. The smallest reduction corresponds to the 5% storage scenario under the 2021 system configuration, while the largest reduction occurs in the 7% storage scenario within the projected 2030 generation structure. These cost reductions become stronger in a system with higher renewable penetration: by 2030, the same storage shares yield the largest cost reductions, confirming that storage becomes more

valuable as variability in supply grows.

Reductions in the cost of electricity translate into improved macroeconomic performance. GDP increases in every scenario, with gains ranging from 0.47 to 1.11 percentage points over the ten-year horizon. Unemployment rate declines consistently as well, with reductions between 0.07 and 0.19 percentage points. The trade balance strengthens proportionally to overall economic activity, reflecting greater competitiveness from lower energy costs. Fiscal revenues also grow, rising between 0.43 and 1.13 percentage points, driven by higher production and household income. Altogether, these results point to a clear macroeconomic dividend from reducing electricity costs through energy storage. Welfare and distributional indicators reinforce the positive outlook. Every income group benefits, and gains are systematically larger for low-income households. Environmental outcomes improve as well. Total emissions decline between 1.9 percentage points and 3.02 percentage points, while the emissions intensity of the economy also falls, indicating a cleaner and more efficient production structure. The sectoral results show a clear pattern aligned with electricity intensity and input–output linkages. Besides the electricity sector, Construction, Non-Metallic Minerals, and Extraction are the main winners. These sectors are highly electricity-intensive and closely linked through input-output relationships. Gains in one sector create positive spillovers in others. By contrast, the Fuels sector and Primary activities are the main lossers. Lastly, comparing the annualized macroeconomic gains with the annualized capital expenditure required to deploy energy storage shows that the social benefits exceed the investment costs in every scenario. This means that, even when private profitability remains uncertain due to financing conditions or technology costs, the net social return is positive. These results underscore a role for public policy in fostering the adoption of storage technologies, ensuring that their broad economic and environmental benefits can be captured.

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