Industrial Policy and Decarbonization: The Case of Nuclear Energy in France

Julius J. Andersson[1*] Jared J. Finnegan[2]

[1]Stockholm School of Economics

[2]University College London

June 2024

Abstract

We assess industrial policy's role in decarbonization by examining the expansion of nuclear energy in France following the 1973 oil crisis. Within a decade, France initiated construction of 51 new reactors. This resulted in a 62 percent reduction in carbon dioxide emissions from electricity and heat production, and over 20 percent reduction in total CO_2 emissions. Emission reductions began six years after policy announcement, with an average abatement cost of -$20 per metric ton of CO_2. We show that the government's ability to insulate the policymaking process from opponents was crucial for the political success of the reform.

JEL classification: O25; Q54; Q58

Keywords: industrial policy, decarbonization, nuclear energy, climate change, political economy

*Contact: julius.andersson@hhs.se and j.finnegan@ucl.ac.uk. We would like to thank Celina Tippmann and Ann-Charlott Pahl for excellent research assistance.

1 Introduction

The last few years have witnessed a dramatic shift in climate policymaking. Governments around the world have embraced industrial policy as a key strategy for reducing carbon emissions and promoting domestic economies. They are turning to subsidies, loan guarantees and local content requirements, in addition to, and in many cases instead of, conventional policies like carbon pricing. A recent example is the Inflation Reduction Act – "the largest climate bill in U.S. history" (Thompson, 2022) – through which the US is set to allocate over $390 billion toward decarbonization via industrial policy. However, despite this political shift, we know surprisingly little about the environmental and economic effectiveness of 'green' industrial policy, as well as its political economy (Rodrik, 2014; Mckenzie, 2023).

We study the case of the Messmer Plan in France to provide insight on the effect of large-scale industrial policy on carbon emissions and abatement costs, as well as on the conditions that make such a reform politically feasible. Adopted in 1974 in response to the oil price shock of 1973, the Messmer Plan sought to transform the French electricity sector by rapidly and dramatically expanding nuclear energy. The government used loan guarantees and public financing to enable the state-owned utility Électricité de France (EDF) to secure large amounts of capital (Campbell, 1986). EDF then ordered and began construction on 51 new reactors in the decade after the Plan's announcement. As a result, the share of nuclear power in electricity production rose from 8 percent in 1973 to 80 percent in 1990, while the share of fossil fuels declined from 65 percent to 7 percent (IEA, 2022a).

While the Messmer Plan was not originally aimed at carbon reduction, we analyze it as an early form of green industrial policy due to the resurgence of nuclear energy in modern climate policy discourse. In 2022, the European Commission endorsed nuclear energy as a 'green investment', underscored by Thierry Breton, the Commissioner for the Internal Market in the EU, who emphasized nuclear's "fundamental role" in the transition away from fossil fuels (Gröndahl, 2022). In parallel, French President Emmanuel Macron has championed a "nuclear renaissance" as part of his vision for Europe's low-carbon future (Alderman, 2022). On the other side of the Atlantic, the US has included production tax credits for nuclear energy as part of the climate provisions of the Inflation Reduction Act (Bistline, Mehrotra, and Wolfram, 2023). However, nuclear's role in climate policy remains divisive. Critics contend it is too slow and costly to build, and thus not as effective as renewables in addressing climate change (Schneider and Froggatt, 2021). This skepticism is exemplified by Germany, which has been decommissioning its nuclear reactors since 2011 and closed its last reactors in 2023.

Using a comparative case study design, we evaluate the effects of the Messmer Plan based on four pillars of effective climate policy: emissions reductions, timeframe for achieving reductions, cost of abatement, and political feasibility. In the context of climate change, delays between policy implementation and realised emission reductions are crucial, as the accumulating atmospheric stock of greenhouse gases exacerbates future warming. Additionally, abatement costs and political feasibility are factors that significantly influence the content, design, stringency and adoption of climate policies.

In the first part of the paper, we empirically estimate carbon emission reductions, the duration from project announcement until emission reductions began and the associated abatement cost. To achieve this, we employ the synthetic control method (Abadie, Diamond, and Hainmueller, 2010, 2015) to construct a credible counterfactual – a weighted average of other OECD countries that represents the outcome in France if the Messmer Plan had not been implemented. Comparing the outcome in France to this counterfactual scenario, we find that the extensive push for nuclear energy led to a 62 percent reduction in carbon dioxide (CO_2) emissions from electricity and heat production and a more than 20 percent reduction in total CO_2 emissions in an average year between 1980-2005. Importantly, we find substantial emission reductions outside of electricity and heat production, in the industrial, residential and services sectors, which we attribute to fuel-switching. Furthermore, we find that six years elapsed from the announcement of the Messmer plan until emission reductions commenced and compute an average abatement cost of -$20 per metric ton of CO_2 reduced, indicating that the policy reduced carbon emissions at a net economic gain. These results show that rapid and substantial decarbonization is possible through active state intervention, and that ambitious industrial policy in the energy sector can be an environmentally and economically efficient climate policy.

While a large-scale expansion of nuclear energy may appear as a straightforward means to reduce CO_2 emissions, the actual dynamics are more complex, rendering a simple 'back-of-the-envelope' calculation of emission reductions insufficient. For instance, evaluating the Messmer Plan's impact requires a credible counterfactual that mirrors France's energy profile in the 1970s – marked by high reliance on imported oil and a small but declining domestic coal industry. Countries such as the US, Canada and other non-European OECD countries had very different energy profiles than France at that time. By applying country-specific weights, we can give greater weight to countries that share a similar import dependence, thus creating a counterfactual that accurately reflects France's experience during the oil crises.

Using a weighted average also allows us to adjust for countries that significantly differ in their dependence on fossil fuels for electricity and heat production during the pretreatment period, thereby minimizing the risk of over- or underestimating the Messmer Plan's effectiveness in reducing emissions. The plan also facilitated further emission reductions through increased electrification and fuel-switching in other sectors of the economy, effects that cannot be captured with a limited focus on the electricity and heat sector alone.

Additionally, it remains critical to determine whether the added nuclear capacity would replace or merely supplement existing fossil fuel production. This distinction is crucial since only net emission reductions contribute to meeting the targets set by the Paris Agreement. Furthermore, understanding the timeline for these reductions is essential, especially given the lengthy construction periods associated with modern nuclear reactors and the urgency to achieve net-zero emissions within the next two to three decades (Masson-Delmotte et al., 2018).

Finally, the broader economic and distributional costs of such ambitious climate policies are frequently debated and cited as reasons to weaken current climate initiatives (e.g., Finnegan, 2023). In this context, employing a rigorous comparative case study design and establishing a credible counterfactual is essential for accurately assessing the scope, timing, and costs of emission reductions across various sectors of the economy.

However, even though the Messmer Plan eventually led to substantial emission reductions, at a time delay of only six years and at a negative abatement cost, it should not be taken as a foregone conclusion that the adoption and implementation of the Plan would be politically successful. In the latter part of our paper, we examine the political economy of the Messmer Plan. We show how France's dirigiste policy style during this period - characterized by a powerful executive, centralized decision making, state-ownership of key firms, and control over capital allocation - enabled the government to insulate the policymaking process and prevent the Plan's opponents from obstructing decision making. The analysis points to the key role that insulation plays in enabling governments to overcome opposition to adopt and implement large-scale reforms that upset incumbent interests (Finnegan et al., 2021; Meckling et al., 2022).

Our study contributes to existing literature in several ways. First, by analysing emission reductions relative to a counterfactual scenario, it provides causal estimates of the environmental effects of nuclear energy policy. Existing empirical research on potential emission reductions from nuclear energy deployment relies primarily on time-series data from individual countries, using Granger causality tests to estimate the causal relationship between nuclear energy and CO_2 emissions (Iwata, Okada, and Samreth, 2010; Menyah and Wolde-Rufael, 2010; Apergis et al., 2010). Although these studies generally conclude that increased nuclear energy usage leads to reduced CO_2 emissions, the lack of a counterfactual inhibits our ability to make causal inferences.

Second, this paper extends the empirical literature evaluating climate policies. A growing body of research has analysed the environmental effect of carbon pricing, finding that it effectively reduces carbon emissions (see, for example: Andersson, 2019; Colmer et al., 2022; Leroutier, 2022). However, fewer studies have explored the environmental effectiveness of green industrial policy and findings have been mixed. Research on the effect of Germany's nuclear energy phase-out and simultaneous support of renewable energy as part of the *Energiewende* has found that it has increased carbon emissions (Knopf et al., 2014; Jarvis, Deschenes, and Jha, 2022). In contrast, evaluations of China's green industrial policy, which promotes initiatives like electric vehicle and solar panel production and adoption, have found a decrease in carbon emissions and other air pollutants (Zhang et al., 2022; Song and Zhou, 2021). Additional causal analysis of green industrial policy across contexts is needed to better understand the effects of this important and increasingly utilized policy instrument.

Third, we add to the empirical literature on expansive industrial and research and development (R&D) policies, commonly termed as 'moonshot' or 'big push' initiatives. These policies, like the Messmer Plan, are distinguished by their targeted focus on specific technologies or regions, substantial public investments, and their aspiration for transformational outcomes (Juhász, Lane, and Rodrik, 2023). Most empirical research indicates prolonged positive economic impacts in the regions directly affected by these policies.[1] Our work extends this literature by examining the environmental consequences of large-scale initiatives.

Fourth, we contribute to the emerging literature in political science on the politics of green industrial policy. Scholars have shown how the ideas underpinning green industrial policy have risen to prominence over the past three decades (Meckling and Allan, 2020), as well as provided clear conceptualizations of green industrial policy and theorized its political dynamics both domestically and internationally (Allan, Lewis, and Oatley, 2021; Meckling, 2021). Moreover, work has shown the institutional underpinnings of national patterns of industrial specialization and innovation (Nahm, 2021). We add to this effort by uncovering the political conditions that foster large-scale industrial reform. Specifically, we identify one key mechanism for reform - insulation - and trace how it enabled the French government to adopt and implement expansive nuclear energy policy.

Last, our paper intersects with the literature on directed technical change (Acemoglu, 1998, 2002; Popp, 2019). One objective of the Messmer Plan was to actively shape the technological development of nuclear energy. A seminal paper by Acemoglu et al. (2012) explores directed technical change and climate mitigation policies, advocating for an optimal strategy that employs both carbon pricing and research subsidies for green technologies. Notably, carbon pricing affects the variable (fuel) costs of energy production, which are crucial for fossil fuels, while industrial policy reduces the fixed (capital) costs, which enhances the competitiveness of zero-carbon alternatives. Consequently, carbon pricing and industrial policy emerge more as complements than substitutes within climate policy in the energy sector, and empirical research should focus on both.

[1] Examples include analysis of the attempt to modernize the economy of the Tennessee Valley region in the US in the 1930s (Kline and Moretti, 2014); the massive spending on R&D by the US during WWII (Gross and Sampat, 2023); and the US space program in the 1960s (Kantor and Whalley, 2023).

2 Industrial Policy to Address Climate Change

One key way to mitigate climate change is to reduce the relative price of zero-carbon technologies. This can be done by either increasing the price of fossil fuels or by reducing the price of zero-carbon alternatives. While a variety of policy instruments can achieve these goals, economists have tended to focus on carbon pricing (Akerlof et al., 2019; Nordhaus, 2008). We turn attention to another instrument: industrial policy.

Industrial policy refers to government measures aimed at promoting the growth and transformation of sectors that it views as essential to future economic growth, employment and innovation (Krugman and Obstfeld, 2009). More recently, green industrial policy has emerged as a tool to address climate change (Rodrik, 2014; Meckling, 2021). Its purpose is twofold: environmental and economic. It seeks to mobilize government efforts towards decarbonization and to foster the development of zero-carbon technologies and domestic firms in an effort to increase employment, innovation and growth in green sectors. Governments can employ a range of tools to achieve these aims, including subsidies, direct loans, loan guarantees, local content requirements, tax credits and research grants to support and facilitate research and development (R&D). In this way, green industrial policy operates on a larger scale and encompasses broader objectives compared to carbon pricing or regulatory (command and control) approaches that focus solely on emissions.

Recent examples of green industrial policy include the Inflation Reduction Act passed in the US in 2022. The IRA involves more than $390 billion in government expenditure towards energy security and climate change mitigation, using tax credits, grants, loans and local content requirements to promote low-carbon energy production, the electrification of transport and support of domestic employment and manufacturing in low-carbon sectors (Bistline, Mehrotra, and Wolfram, 2023). Similarly, China has relied on a variety of green industrial policies to reduce emissions and grow its market share in zero-carbon technologies (Altenburg and Assmann, 2017; Harrison, Martin, and Nataraj, 2017). At the European Commission there are discussions about the possibility of responding with similar subsidies and incentives in support of low-carbon industries within Europe (Camps and Saz-Carranza, 2023). For policymakers, it is crucial to know whether implementing large-scale green industrial policies is indeed an effective climate mitigation policy.

The argument for green industrial policy stems from the existence of market failures caused by both positive and negative externalities, for which traditional market mechanisms often fail to account (Acemoglu, 2023; Rodrik, 2014). The further development of low-carbon technologies by one firm creates positive spill-over effects on other firms in the sector, such as technological innovation that reduces manufacturing costs and knowledge sharing, and the value of these spill-overs are not fully captured by investors in the developing firm. Without government support, the amount of private expenditure on R&D would thus be below the socially optimal. Furthermore, low-carbon technologies directly compete with fossil fuels, and in most markets, the social costs associated with carbon emissions from fossil fuel combustion are either insufficiently priced or not priced at all. Due to this market failure, the market equilibrium will allocate too many resources towards fossil-fuel technologies, and therefore the 'second-best' policy of government support for low-carbon substitutes is warranted and justified. Lastly, there are local co-benefits of improved health from switching from fossil fuels to low-carbon alternatives in the transport and energy sector, by a reduction in air pollutants such as nitrogen oxides and particulate matter (Parry, Veung, and Heine, 2015). As with carbon emissions, the market typically does not price the damages caused by these local air pollutants.

Economists commonly object to industrial policy on two main grounds (Pack and Saggi, 2006; Rodrik, 2008, 2014). First, they argue that policymakers lack the necessary information to accurately identify the industries or firms most deserving of support. Put differently, governments are bad at picking 'winners'. And there are indeed numerous examples of government support for specific firms that have later failed (Hufbauer and Jung, 2021). Second, they caution that government support can stimulate rent-seeking behavior and potentially foster corruption. In defense of industrial policy, Rodrik (2014) responds that with well-designed industrial policy we should see some supported firms fail, otherwise the government is underperforming by not taking on enough risk and thereby reducing their average return on investments. Furthermore, Rodrik points out that rent-seeking is a potential issue with all government policies, not only for industrial policy, and can be overcome with appropriate institutional designs. Lastly, Acemoglu (2023) emphasizes that because the negative externalities of fossil fuel usage are quantifiable, green industrial policy need not rely on government picking winners among technologies, industries or firms. Instead, it involves correcting these measurable distortions without requiring government agencies to possess superior predictive capabilities.

3 Background to the Messmer Plan

In less than a year, from October 1973 to March 1974, the global price of oil quadrupled from around \$3 to almost \$12 per barrel (Davenport and Wayth, 2023). This first oil crisis resulted from production cuts and embargoes by the Organization of Arab Petroleum Exporting Countries (OAPEC) in retaliation for the West's support for Israel in the Yom Kippur War – an armed conflict in October of 1973 between Israel and a coalition of Arab nations led by Egypt and Syria.

On the eve of the price shock, oil supplied nearly 70 percent of France's total energy needs, with the vast majority of that oil being imported (IEA, 2022c).[2] As a result, the

[2] In 1973, France's oil self-sufficiency was just 1.7 percent, defined as the share of indigenous oil production in the total energy supply of oil.

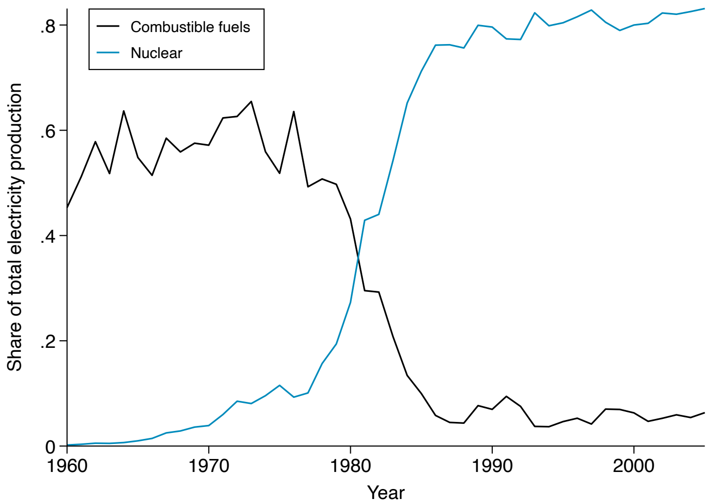


Figure 1: Electricity Production in France from Combustible Fuels and Nuclear Energy

country was economically vulnerable to rapid changes in the oil price. In response to the price shock, Prime Minister Pierre Messmer announced an ambitious nuclear energy program on March 6th, 1974 that would reduce France's reliance on imported oil and increase energy security (Wade, 1980; Ikenberry, 1986; Jasper, 1990).

At the same time, the Messmer Plan had economic aspirations. It aimed to generate growth, innovation, competitiveness and employment in the nuclear sector. During this period, the French state sought to restructure industries across a range of sectors into larger units, or 'national champions', that would be leaders in their sectors at home and abroad (Hall, 1986; Hall, Hayward, and Machin, 1994; Schmidt, 1996; Zysman, 1983). In the case of nuclear, the goal was for the country's firms to be internationally competitive and capture export markets along the entire supply chain (Lucas, 1985; Thomas, 1988). French firms would be world leaders in reactor design and manufacturing, plant engineering, operator training, fuel enrichment, waste disposal and reprocessing, and over the longer term have the technological lead in fast breeder reactors (Thomas, 1988).

The rapid expansion of nuclear power required large sums of capital. The government used a variety of industrial policies to channel capital to French firms, most notably state loans and loan guarantees. EDF financed the expansion through new loans, with US and French capital markets providing half each of the new capital. In 1976, EDF was the third largest borrower on US capital markets, just after Ford and General Motors. The backing of the French state through loan guarantees enhanced EDF's credit rating and reduced borrowing costs (Jasper, 1990).[3]

With the capital arranged, EDF ordered 16 new reactors in 1974, matching the total number of all reactors ordered before the Messmer Plan. These new reactors had a

[3]State loans and loan guarantees are among the most frequently used types of industrial policy, especially in high- and middle-income countries (Juhász, Lane, and Rodrik, 2023).

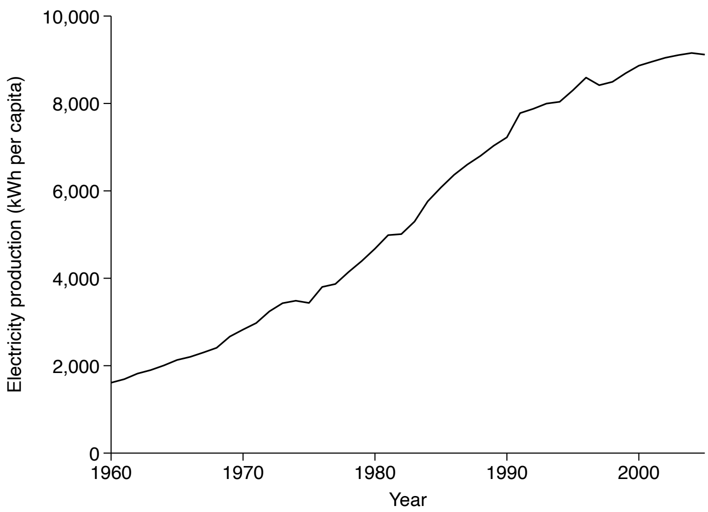


Figure 2: Electricity Production in France: 1960-2005

Note: Included is electricity from both main activity producers and autoproducers.

combined output of 14,400 MWe (megawatt electric). For comparison, the previously ordered reactors totalled less than 9,000 MWe (Thomas, 1988). In 1976, EDF ordered an additional 12 reactors, and a total of 51 reactors were ordered and began construction in the decade following the announcement of the Messmer Plan (Thomas, 1988; IAEA, 2023). The work on the first three plants – Tricastin, Gravelines, and Dampierre – started in late 1974, and they were connected to the grid in 1980. During the 1980s, the number of reactors in commercial operation in France increased from 15 to 55 (IAEA, 2023).

Figure 1 illustrates the proportions of combustible fuels and nuclear energy used in electricity production in France. Before the announcement of the Messmer Plan, between 1960 and 1973, combustible fuels accounted for approximately 50-60 percent of total electricity production. The share of oil increased in the early 1970s and reached a peak of 40 percent in 1973, making oil the primary energy source for electricity production at the time of the first oil crisis. Then, from 1980 and onward there is a significant decline in the use of combustible fuels and a simultaneous rapid increase in the use of nuclear energy. Since the late 1980s, nuclear energy has consistently provided around 80 percent of total electricity production in France, while combustible fuels contribute less than 10 percent, and the remainder is supplied by hydropower (IEA, 2022a).

Total electricity production also increased from 1960 to 2005. Figure 2 demonstrates this trend. In 1960, annual electricity production per person was approximately 1,600 kilowatt hours (kWh). By 2005, production had multiplied more than five times, exceeding 9,000 kWh per person. Hence, not only did electricity supply undergo significant fuel switching, but there was also a simultaneous increase in overall electricity production. This large increase in production will play a key role in the later analysis of emission reductions in sectors outside of electricity and heat production.

4 Data and Method

4.1 Data

To assess the environmental impact of the Messmer Plan, we employ annual panel data on CO_2 emissions for France and 23 other OECD countries, spanning the years 1960 to 2005.[4] While our primary analysis concentrates on emissions originating from the electricity and heat sector, we also examine total emissions and explore additional relevant sectors such as industry, residential and services. The data is gathered by the International Energy Agency (IEA, 2022b), and emissions from electricity and heat production contains the sum of emissions from plants that produce either electricity, heat or both (cogeneration plants). Included in the emissions data are CO_2 emissions from combustible fuels.[5] Energy produced using nuclear power plants is classified as a zero-carbon source. Last, CO_2 emissions are measured in metric tons per capita.

We focus on emissions from "main activity producers," plants that supply energy to the public, and exclude emissions from "autoproducers". Autoproducers are private plants that produce electricity and heat on-site for their own use to support their primary activity (e.g. a paper mill or a steel plant). As such, these emissions are commonly allocated elsewhere. For instance, in the IPCC guidelines on greenhouse gas inventories, autoproducers' emissions are primarily allocated to the industry sector (IPCC, 2006).

It is important to note, however, that for the years 1960-1973, the IEA data cannot separate emissions from main activity producers and autoproducers (IEA, 2021). As a consequence, when we depict the data (see Figure 3) the drop in emissions in the year 1974 is partly illusory since from then onward we use emissions data for main activity producers only. Regardless, all countries in the sample are treated identically in terms of how the emissions data is computed over time. Additionally, emissions from autoproducers are much smaller relative to main activity producers. On average, autoproducer emissions account for 16 percent of total emissions from electricity and heat production across our OECD sample between 1974-2005. Given this, we do not expect that combining the two emission sources for the time period of 1960-1973 will create issues for our identification strategy. We present evidence in support of this assertion later on.

Our analysis ends in 2005. We chose this year because it marks the start of the European Union Emissions Trading System (EU ETS), which is a potential confounder for our study since it incentivized fuel switching in the electricity sector by putting a price on CO_2 emissions from electricity and heat production within the EU. In total, our sample period of 1960-2005 offers us 14 years of pretreatment data and 32 years of posttreatment data.

[4]Included are all the countries that were OECD members in 1973.

[5]In our dataset, CO_2 emissions primarily stem from fossil fuel combustion – oil, coal (including peat), and natural gas – with minor contributions from biofuels and waste in later years of the sample period.

From the original donor pool of OECD countries we exclude Luxembourg and Turkey. Luxembourg is excluded due to missing data on CO_2 emissions from electricity and heat production in the years 1974-1976 and we exclude Turkey to avoid interpolation bias. Interpolation bias can occur when we include countries in the donor pool that are too dissimilar to the treated unit – especially on important predictors of the outcome variable (Abadie, Diamond, and Hainmueller, 2015). In 1973, GDP per capita – a key predictor of CO_2 emissions – is much lower in Turkey compared to other OECD countries. For example, it is around a third of the level for France. Similarly, CO_2 emissions per capita from electricity and heat in Turkey are less than one seventh of the level in France. That said, excluding Turkey has no impact on our main results since, when included in the sample, Turkey obtains zero weight in synthetic France – our constructed counterfactual.

4.2 The Synthetic Control Method

To establish the causal impact of the Messmer Plan on CO_2 emissions from electricity and heat production we contrast France with a selection of countries similar to it in relevant aspects but unaffected by a 'treatment' equivalent to the Messmer Plan.

Let $J + 1$ be the number of countries in our sample, and let $j = 1$ denote France. The countries are observed for time periods $t = 1, 2, \ldots, T$ with periods both prior to treatment $1, 2, \ldots, T_0$ and after $T_0 + 1, T_0 + 2, \ldots, T$. The counterfactual, 'synthetic France', is constructed as a time-invariant weighted average of the unaffected control countries and represented by a vector of weights $W = (w_2, \ldots, w_{J+1})'$. The weights are restricted to be non-negative $0 \leq w_j \leq 1$ and sum to one $w_2 + \cdots + w_{J+1} = 1$.

Our selection of W is designed to minimize the difference between France and the control units on key predictors of the outcome variable, as well as on the outcome variable itself during the pretreatment period. We use four key predictors: two economic indicators, GDP per capita and degree of urbanisation, and two emission-related indicators, electricity production using combustible fuels and domestic oil and coal production.[6] Electricity production from combustible fuels is included to match with countries with a similar reliance on fossil fuels before treatment, while domestic production is an indirect measure of the ability to switch from imported to domestically produced fossil fuels.

With a long pre-intervention period, an accurate match on the outcome variable indicates that both observed predictors and unobserved factors with possibly time-varying effects impact France and its synthetic counterpart similarly (Abadie, Diamond, and Hainmueller, 2015). We have 14 years of pre-treatment data (1960-1973) and an additional 6 years (1974-1979) before the first new nuclear reactors became operational. A close fit on CO_2 emissions between France and its counterfactual during this 20-year period suggests successful matching on all relevant variables.

[6] More details and sources are available in Appendix A1.

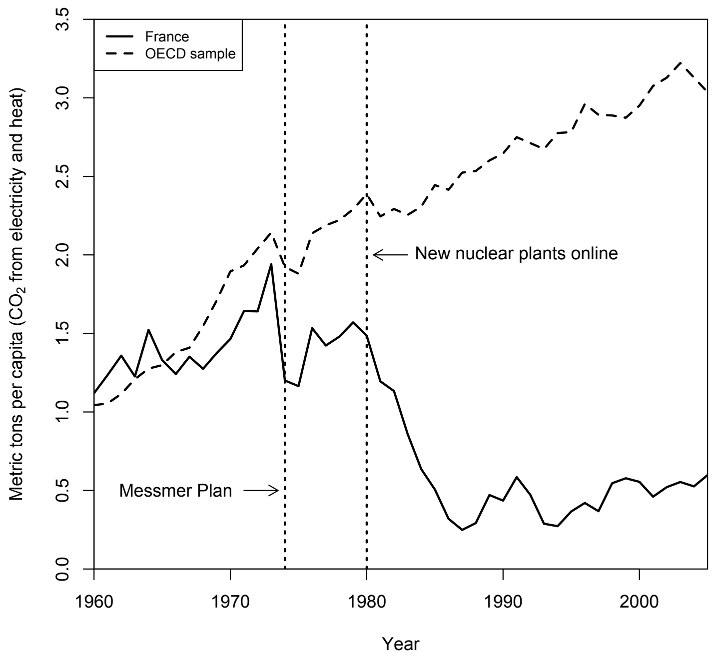


Figure 3: Path Plot of per capita CO_2 Emissions from Electricity and Heat during 1960-2005: France versus OECD average

5 The Environmental Effect of the Messmer Plan

Figure 3 compares per capita CO_2 emissions from electricity and heat production in France with the (unweighted) average of the 21 OECD countries in our donor pool. The figure illustrate why we prefer to use the synthetic control method and a weighted country average over a difference-in-differences approach for our analysis. First, the growth rate in emissions is significantly different in the pretreatment period. From 1960 to 1973, annual per capita emissions in the OECD sample increases by an average of 0.088 tons per year, compared to only 0.041 tons in France, a difference that is statistically significant. Second, we can assign more weight to countries with energy profiles similar to France's prior to treatment. In the 1960s and early 1970s, France became increasingly dependent on imported oil and had a small but declining domestic coal industry. This was a markedly different situation than what the US and many other non-European OECD countries experienced at the time. While France and the OECD average had similar levels of energy self-sufficiency in the first half of the 1960s, a bit above 50 percent, by 1973, France was below 25 percent whereas the OECD average was around 43 percent and rising. Using country weights, we can give more weight to countries with similar import dependence and create a counterfactual that closely mirrors France's experience of the two oil crises in the 1970s and their impact on emissions. Furthermore, with weights we minimize the influence of countries that either rely heavily on or barely use fossil fuels for electricity and heat production in the pretreatment period. This targeted weighting mitigates over- or underestimation of emission reductions in the posttreatment period.

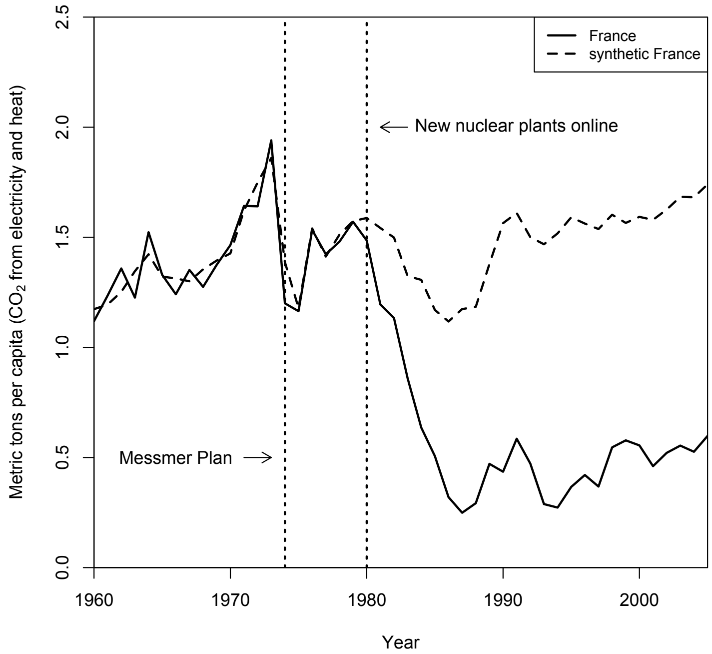


Figure 4: Path Plot of per capita CO_2 Emissions from Electricity and Heat during 1960-2005: France versus Synthetic France

5.1 France and its Synthetic Counterfactual

Figure 4 shows the evolution of CO_2 emissions per capita from electricity and heat production in France and its synthetic (weighted) counterfactual from 1960-2005. The two series closely track each other in the pretreatment period of 1960-1973 and in the transitional period of 1974-1979. There are rather large movements in the outcome variable during this time frame, but the tight co-movement between France and synthetic France indicate that the volatility is due to common factors, such as the oil price shock in 1973. Then, as newly commissioned reactors come online in 1980 and onward, there is a sharp drop in emissions in France, which is not matched by a similar emissions trajectory in the counterfactual scenario. Interestingly, there is a drop in emissions in synthetic France in the first half of the 1980s, that is later reversed by the end of that decade. This drop is likely in response to the second oil crisis in 1979, caused by supply fears after the Iranian Revolution. An advantage of using aggregated empirical data on emissions and a comparative case study approach with weights is that we are able to capture the likely confounding effect of this oil price increase since it affects France and the synthetic counterfactual similarly.

For the validity of the identification assumption, it is crucial that there is a good fit on the outcome variable between 1974-1979 – immediately after the Messmer Plan was enacted, but before its expected impact on emissions. The similarity in emission levels during this intermediate period indicates that we have successfully matched on observed and unobserved predictors of emissions and that the inability to separate autoproducers'

Table 1: Country Weights in Synthetic France

Country	Weight	Country	Weight	Country	Weight
Australia	0	Greece	0.002	Norway	0
Austria	0.262	Iceland	0	Portugal	0.143
Belgium	0.351	Ireland	0	Spain	0
Canada	0	Italy	0	Sweden	0
Denmark	0	Japan	0	Switzerland	0.198
Finland	0	Netherlands	0	United Kingdom	0
Germany	0.043	New Zealand	0.001	United States	0

Note: All weights are between $0 \leq w_j \leq 1$ and $\sum w_j = 1$.

Table 2: Predictor Means for CO_2 Emissions from Electricity and Heat

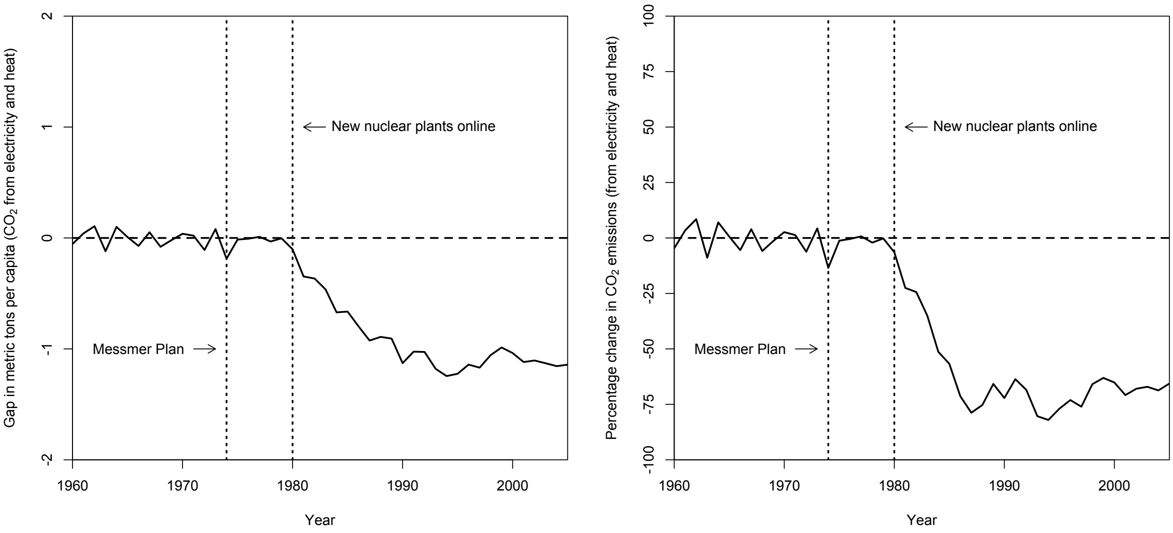
Variables	France	Synth France	OECD Sample
GDP per capita	13705.0	13703.5	13116.7
Urban population	69.8	69.8	69.4
Electricity from combustible fuels per capita	1555.4	1546.1	1810.2
Oil and coal production per capita 1972	423.1	443.8	872.7
CO_2 emissions from electricity and heat per capita 1973	1.9	1.9	2.1
CO_2 emissions from electricity and heat per capita 1969	1.4	1.4	1.7
CO_2 emissions from electricity and heat per capita 1964	1.5	1.4	1.3

Notes: All key predictors, except oil and coal production, are averaged for the ten year period before treatment, 1964-73. GDP per capita is Purchasing Power Parity (PPP) adjusted and measured in 2005 U.S. dollars. Urban population is measured as the percentage of total population. Electricity production from combustible fuels is measured in kWh per capita. Oil and coal production in 1972 is measured in kilogram of oil equivalent per capita. CO_2 emissions are measured in metric tons. The last column reports the averages of the 21 OECD countries in the donor pool.

emissions in the pretreatment period did not compromise our identification strategy.

The country weights W used to construct synthetic France are reported in Table 1. CO_2 emissions from electricity and heat production during the pretreatment period in France are most accurately replicated by a weighted combination of Belgium, Austria, Switzerland, Portugal, and Germany, with descending weights in that order. The remaining countries in the donor pool receive weights that are smaller than one percent.

The country weights are chosen using predictors of CO_2 emissions from electricity and heat production. To safeguard against specification searches and p-hacking (Abadie, 2021), we only use data from 1960-1973 to determine the country weights and exclude data from after the Plan was announced. Table 2 compares the pretreatment values for these predictors in France with those in synthetic France and the arithmetic mean for the 21 OECD countries in the donor pool. On all predictors, France and its counterfactual have almost identical values and a better fit compared to France and the average of the OECD sample. For the first four key predictors, the difference between France and synthetic France is less than one percent, except for domestic oil and coal production where the value for France is five percent lower.



(a) Metric tons per capita

(b) Percentage change

Figure 5: Gap in per capita CO_2 Emissions from Electricity and Heat between France and Synthetic France

As predictors we also include three years of pre-intervention values of the outcome variable, emissions in 1973, 1969, and 1964 – one, five and ten years prior to the implementation of the Messmer Plan. We include lagged values for two reasons. First, we are interested in matching not only the growth rate of CO_2 emissions but also the overall level of those emissions. Second, adding these lags improves matching on unobservable variables that may have time-varying effects (Abadie, Diamond, and Hainmueller, 2010; Abadie, 2021). Table 2 shows that there is a good match also on these lagged predictors.

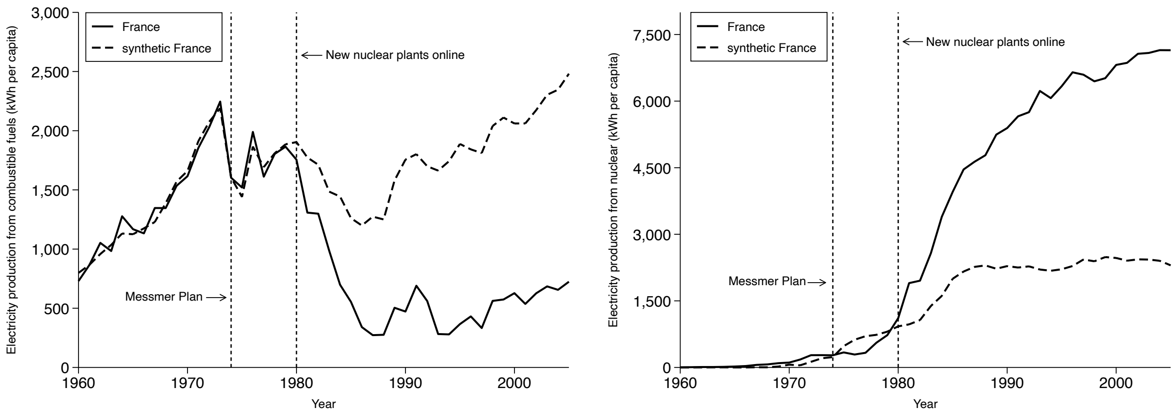
5.2 Emission Reductions from Electricity and Heat Production

To quantify the scale of the Messmer Plan, we evaluate the difference in the number of nuclear reactors either under construction or in operation in France and its counterfactual, before and after the Plan's announcement. Using this metric, the Messmer Plan significantly bolstered the nuclear energy program in France, leading to a five-fold expansion in reactors constructed post-1974 compared to the counterfactual scenario.[7]

This marked increase in reactor construction had a significant impact on CO_2 emissions. The gap plots in Figure 5 show the difference in emissions from electricity and heat production between the two 'countries' from 1960-2005, highlighting the Messmer Plan's causal effect on posttreatment emission reductions. Panels (a) and (b) are computed as the difference in emissions in each year and measured in metric tons per capita and percentage change, respectively.

There is a smooth and steady increase in the size of emission reductions in the 1980s

[7]Additional details on how we quantified the Messmer Plan's scale can be found in Appendix A2.



(a) Combustible fuels (b) Nuclear energy

Figure 6: Electricity Production between 1960-2005: France versus Synthetic France

Note: Electricity production is measured in kWh per capita and only includes electricity from main activity producers between 1974 and 2005.

as more and more reactors come online. Emission reductions level off thereafter. In an average year between 1980-2005, the Messmer Plan reduced CO_2 emissions from electricity and heat production in France by 62 percent, which equates to 0.92 metric tons per capita. The largest emission reduction is achieved in 1994 at 82 percent, a reduction of 1.25 metric tons per capita. Absolute emissions are also substantially reduced from an annual average of 75.8 Mt of CO_2 between 1974-1979 to an average of 33.0 Mt between 1980-2005.

The causal effect of the Messmer Plan on France's energy mix is illustrated in Figure 6. Panel 6 (a) reveals a strong similarity between France and its synthetic counterpart regarding the volume of electricity generated from combustible fuels between 1960 and 1979. However, from 1980 onwards, the trajectories diverge significantly, with synthetic France producing over three times more electricity from combustible fuels than France by 2005. The trend for nuclear energy production, displayed in Panel 6 (b), mirrors the decoupling observed for combustible fuels, but in the opposite direction. Starting from similar low levels in the two decades from 1960 to 1979, nuclear energy production in France begins to surge relative to the counterfactual from 1980 onwards. By 2005, France's nuclear energy production was roughly triple that of synthetic France.

Lastly, the Messmer Plan was also successful in acheiving its stated aim of increasing energy security by reducing France's dependence on imported oil. Figure 7 shows that France and its counterfactual experience a similar decline in energy self-sufficiency in the pretreatment period but as new nuclear reactors come online, the two series diverge. From 1990 onward, France is again above 50 percent in self-sufficiency, returning to the level observed at the start of our sample period.

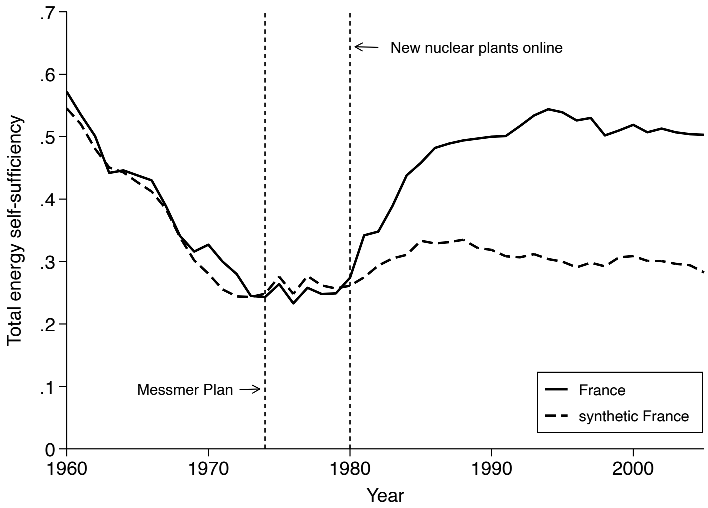


Figure 7: Energy Self-Sufficiency between 1960-2005

Note: Energy self-sufficiency is the ratio between national production and consumption of primary energy in a year. As such, the measure shows how dependent the country is on imports for its energy needs.

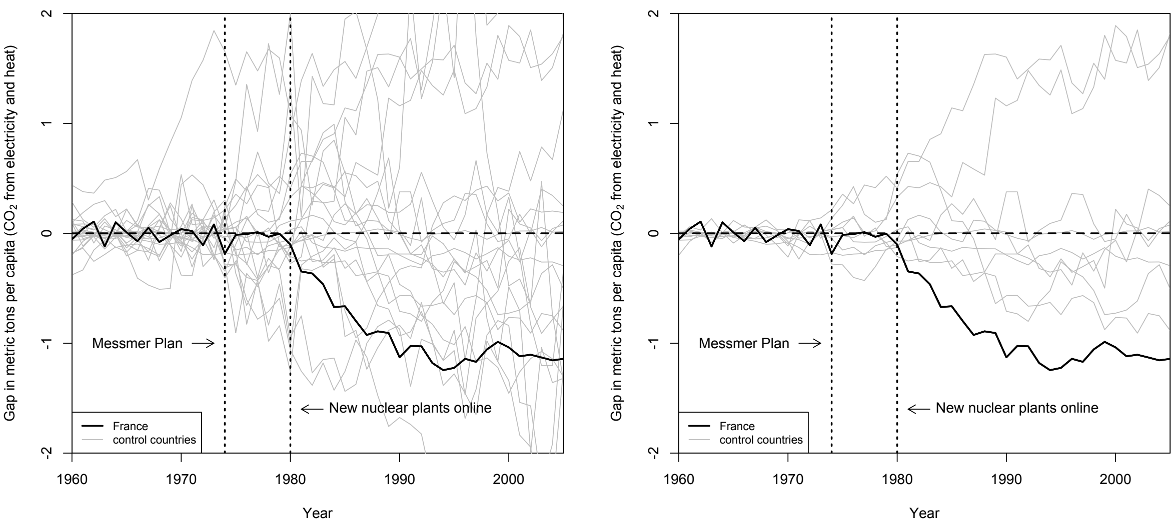
5.3 Significance Testing of Main Results

To determine the statistical significance of the estimated emission reductions from electricity and heat production we perform two tests: the in-space placebo test (Abadie, Diamond, and Hainmueller, 2015) and a t-test for synthetic controls (Chernozhukov, Wuthrich, and Zhu, 2023).[8]

For the in-space placebo analysis, each country in the donor pool is iteratively treated as if it had experienced the intervention, with synthetic counterparts derived using the predictors from Table 2. This approach allows us to assess whether the estimated emission reductions obtained for France are particularly large by comparing them to the placebo outcome for all other countries in the donor pool. This kind of permutation test draws inferences and calculate p-values by finding the percentage of countries with outcomes as large as, or larger than, the result found for France.

The results of the in-space placebo test are shown in Figure 8. As frequently observed, the synthetic control method can fail to find convex combinations of other countries that accurately reflect pretreatment period emissions (Abadie, Diamond, and Hainmueller, 2011; Andersson, 2019). This is especially true for 'outliers'; in our case, countries with consistently the highest (e.g., the US) or the lowest (e.g., Norway) emission levels before treatment. When we exclude countries with a poor pretreatment fit, defined here as having a mean squared prediction error (MSPE) more than twice as large as France's, we

[8]The results from robustness tests – in-time placebo, 'leave-one-out', specification searching and a placebo sector test – are presented in Appendix A3.



(a) France and 21 control countries

(b) France and 9 control countries

Figure 8: Permutation Test: Per capita CO_2 Emissions Gap in France and Placebo Gaps for the Control Countries

Note: The left figure shows the gap in CO_2 emissions in France and placebo gaps in all 21 control countries. The right figure shows the gap in France and placebo gaps in 9 control countries (excluding those with a pretreatment MSPE double that of France).

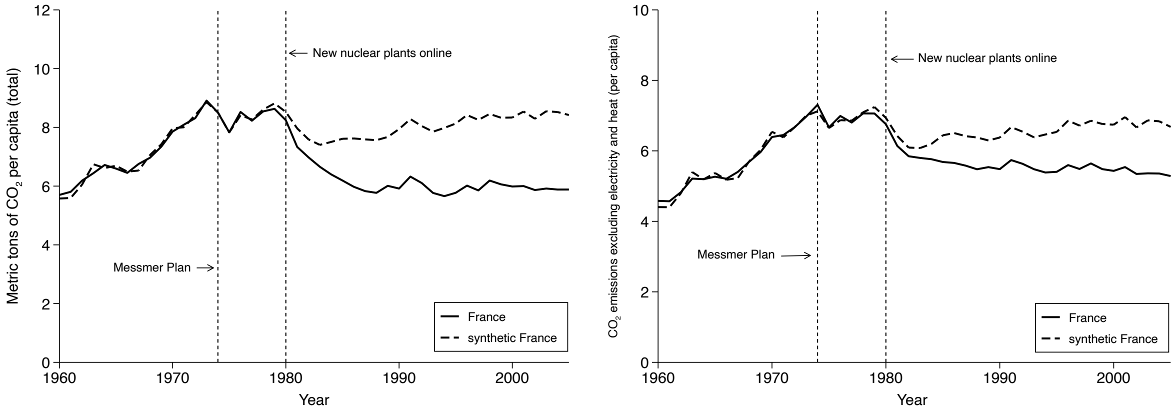
are left with the ten countries illustrated in Panel (b).[9] France here displays the largest emission reduction in the posttreatment period, especially from 1980 and onwards, and the p-value of estimating an emission reduction of this size is thus $1/10 = 0.10$.

A method complementary to the (classical) in-space placebo test is the "t-test for synthetic controls" (Chernozhukov, Wuthrich, and Zhu, 2023). It facilitates the estimation and inference of the average treatment effect over time, without the necessity of permutations, and yields confidence intervals against which we can assess the significance of the results.[10] Setting the posttreatment period to start in 1980, we find an average emission reduction after treatment of 1.003 metric tons of CO_2 per capita, which is significant at both the 10% level (confidence interval of 1.279 to 0.732) and the 5% level (confidence interval of 1.408 to 0.602).[11]

[9]The pretreatment MSPE is defined as $MSPE = \frac{1}{T_0} \sum_{t=1}^{T_0} \left(Y_{1t} - \sum_{j=2}^{J+1} w_j^* Y_{jt} \right)^2$

[10]Note that the t-test methodology proposed by Chernozhukov, Wuthrich, and Zhu (2023) utilizes only the lagged values of the outcome variable as predictors. As a result, this specification does not include our full set of predictors from Table 2. Despite this, the emission reduction estimates are similar to our main results.

[11]The results are also significant at the 10 and 5% level if we set the posttreatment period to start in 1974. We have set $K = 3$. Chernozhukov, Wuthrich, and Zhu (2023) use a K-fold cross-fitting procedure to correct for potential bias of the synthetic control approach. The method divides the pretreatment period into K number of blocks, and there is a tradeoff in the choice of K – larger K leading to shorter confidence intervals but affects coverage accuracy – with the authors recommending setting $K = 3$, arguing that this choice "yields a good balance between coverage accuracy and length" (p. 7). For more



(a) Total CO_2 emissions

(b) Excluding electricity and heat emissions

Figure 9: Path Plot of CO_2 Emissions 1960-2005: France versus Synthetic France

Note: Panel (a) depicts total CO_2 emissions per capita, while panel (b) excludes emissions from electricity and heat production.

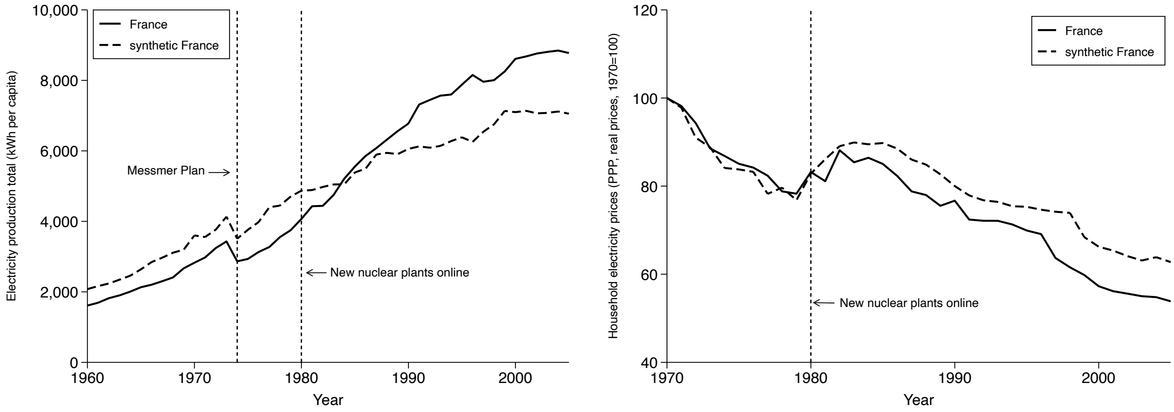
5.4 Total Emission Reductions

While the Messmer Plan primarily impacts electricity and heat production, it may also indirectly influence CO_2 emissions in other sectors. Using the country weights specified in Table 1, we evaluate the consequences of the Messmer Plan on France's total CO_2 emissions. Figure 9(a) indicates that from 1980 onward, the average per capita reduction in emissions amounts to 1.88 metric tons, which is a 23 percent reduction in total CO_2 emissions. This number is almost exactly double the emissions reduction we observed solely in the electricity and heat sector, which was 0.92 metric tons per capita. As shown in Figure 9(b), the remaining 0.96 metric ton reduction in emissions between 1980 and 2005 comes from sectors other than electricity and heat production. Specifically, industry accounts for a relative reduction of 0.51 metric tons, while the residential and services sectors together contribute another 0.45 metric tons.[12] Interestingly, the emission reductions from these sectors also coincide with the roll-out of new nuclear reactors from 1980 onward.

To account for this additional emissions cut of almost 1 ton, we explore two separate hypotheses, which are not necessarily mutually exclusive. The first posits that fuel-switching occurred. If the Messmer Plan led to an increase in electricity production, beyond merely replacing fossil fuels with nuclear energy, it would likely result in a decrease in electricity prices. This price reduction could prompt a shift away from fossil fuels in other sectors, encouraging greater electricity consumption instead, particularly in the

information about the method, see section 2.2 of their paper.

[12] We merged the residential and services sector data, as the IEA was unable to differentiate oil consumption between these sectors before 1985 (IEA, 2022, p. 129). Furthermore, we allocated emissions from autoproducers to the industry sector, as recommended by the IPCC guidelines. Lastly, no relative emission reductions were observed in the transport, agriculture, and forestry sectors between 1980-2005.



(a) Total electricity production (b) Household electricity prices

Figure 10: Total Electricity Production and Prices: France versus Synthetic France

Note: Electricity production is measured in kWh per capita, and only includes electricity from main activity producers between 1974-2005. Electricity prices include taxes and are measured in real terms and adjusted for differences in purchasing power. To ease comparisons over time, the prices are given as an index, with 1970=100. Note that panel (b) starts in 1970, due to missing data for years prior.

industrial, residential and services sectors.[13] This would result in a comparative emissions reduction relative to a counterfactual scenario. The second hypothesis suggests that a relative economic downturn in France during the post-treatment period suppressed CO_2 emissions.

Figure 10 charts the trajectories of electricity production and household electricity prices between France and its synthetic counterpart. Until 1980, electricity production followed parallel trends. Subsequently, France witnessed a faster growth rate for a decade, coinciding with the extensive rollout of new nuclear reactors. Although the growth rates re-aligned in the 1990s, France's total electricity production consistently outpaced that of its synthetic counterpart. This elevated level of production contributed to lower household electricity prices in France from 1980 onward, as illustrated in Panel 10(b).

For a rise in electricity production and a concurrent drop in household electricity prices to occur, the supply curve for electricity would need to shift outward (rightward). Such a shift typically occurs when there is a decrease in the marginal cost of electricity production, which might be attributed to technological advancements or labor cost reductions. In the French case, however, we attribute the supply shift primarily to EDF's anticipation of increasing future demand. This anticipation was spurred by the Messmer Plan's focus on electrification of the economy and the projections of future growth of electricity demand (Brouard and Guinaudeau, 2015). As a result, there was a surge

[13]These three sectors combined account for nearly 90 percent of France's total electricity consumption during our study period. Since electric vehicles were not a meaningful part of the vehicle fleet during our study period, the transport sector could not benefit from an increased supply of electricity as an energy source. In 2005, electricity provided less than 3 percent of the energy consumed in the transport sector in France, and the average during the period 1980-2005 was around 1.5 percent.

in the number of electricity producers, through the expansion of nuclear power plants. This influx of new producers led to an outward shift of the supply curve. Additionally, the technological transition from fossil fuels to nuclear energy may have also contributed to reducing the marginal cost of electricity production, thereby reinforcing this outward shift.

To investigate the validity of the fuel-switching hypothesis, we examine energy consumption across the economy, focusing on both electricity and combustible fuels. In Figure 11, we observe a notable increase in the proportion of energy consumption derived from electricity within the residential, services and industry sectors. Concurrently, there is a corresponding decline in the proportion of energy obtained from combustible fuels. This trend supports the notion of fuel-switching, which offers an explanation for the observed reductions in CO_2 emissions from sectors other than electricity and heat production.

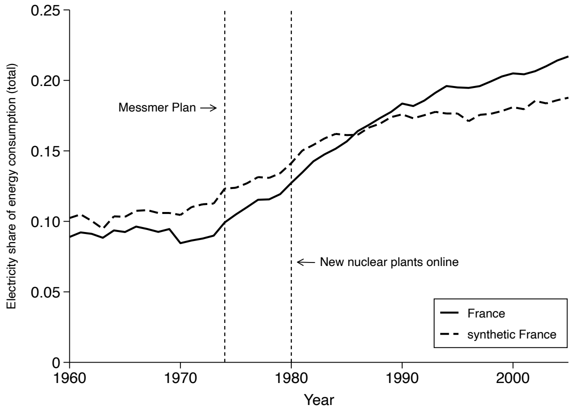
To explore the alternative hypothesis regarding potential emissions reductions driven by an economic downturn, we analyze the two macro variables of gross domestic product (GDP) and unemployment. In Figure 12, the evolution of real GDP per capita during the pretreatment period aligns closely, followed by a slightly higher GDP level in France after the initial oil crisis and until the mid-1980s. However, from 1990 onwards, France's GDP level shows a relative decline. This trend is reflected in the unemployment rate, with France consistently experiencing a notably higher unemployment rate—on average, 2.8 percentage points higher—compared to synthetic France between 1980 and 2005. These macroeconomic indicators lend credence to the alternative hypothesis, suggesting the presence of a relative economic downturn, which, in turn, may have contributed to reduced CO_2 emissions, given the well-established correlation between economic growth and CO_2 emissions (Holtz-Eakin and Selden, 1995; Sheldon, 2019; Mardani et al., 2019).

We have evidence in support of both hypotheses, and they do not need to be mutually exclusive. To establish which hypothesis has the largest effect on relative emission reductions, we conducted a regression analysis aimed at determining the magnitude of the confounding effect originating from the macro variables of GDP and unemployment. This analysis was compared against the effect resulting from the increased share of nuclear energy in electricity production, with all variables calculated as the gap between France and synthetic France.

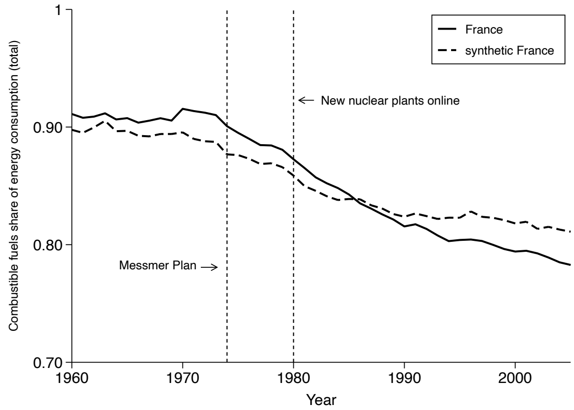
The following OLS regression model was tested:

$$\Delta CO2_t = \alpha + \Delta X_t \beta + \epsilon_t \tag{1}$$

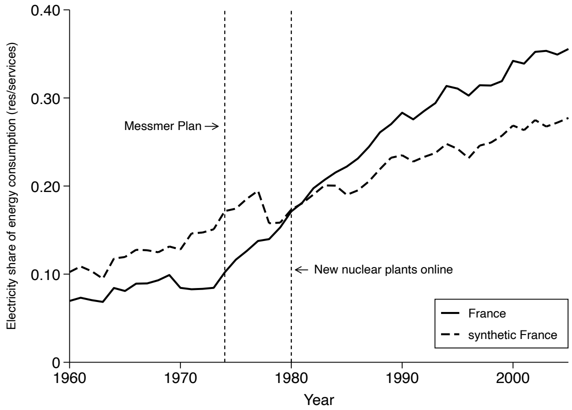
where $\Delta CO2_t$ is the annual gap between France and its synthetic counterpart in total CO_2 emissions; ΔX_t is a vector of the key explanatory variables: the annual gaps in the share of nuclear in electricity production, GDP, and unemployment; and ϵ_t is idiosyncratic



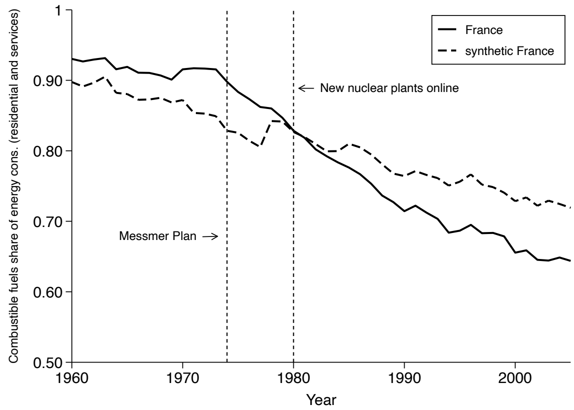
(a) All sectors: Electricity share



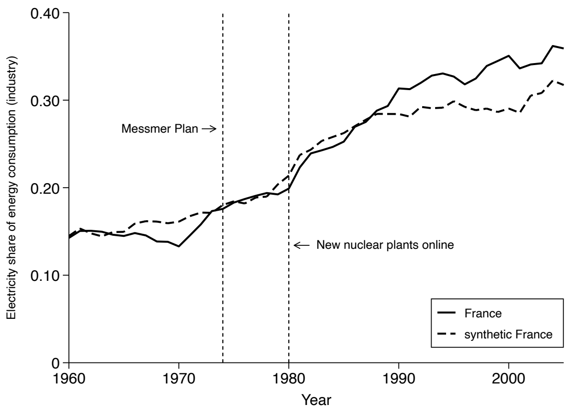
(b) All sectors: Combustible fuels share



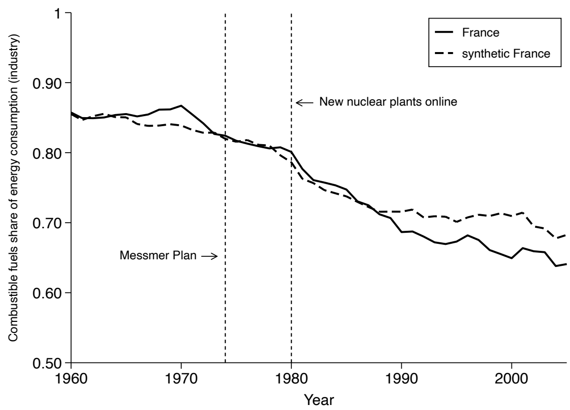
(c) Res/Services: Electricity share



(d) Res/Services: Combustible fuels share



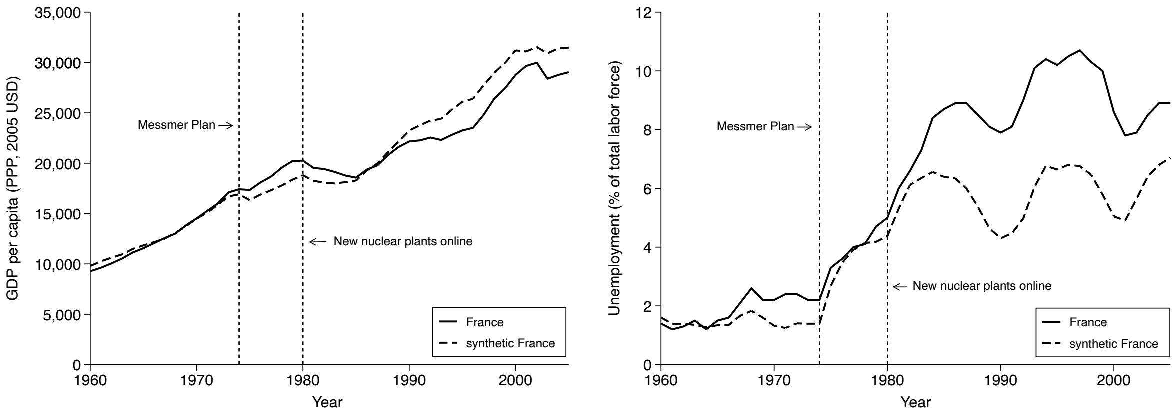
(e) Industry: Electricity share



(f) Industry: Combustible fuels share

Figure 11: Electricity and Combustible Fuels share of Energy Consumption

Note: The figure shows the share of energy consumption coming from electricity (left-hand side) and combustible fuels (right-hand side), respectively. To make aggregation and comparisons possible, all energy sources were first converted into oil equivalents. Panels (a)-(b) depict the shares out of total energy consumption – the combination of industry, residential, services, transport, agriculture and forestry, fishing and other. Panels (c)-(d) depict the shares in the residential and services sectors, and panels (e)-(f) depict the shares in the industrial sector.
Source: International Energy Agency (2022) – World Energy Balances.



(a) GDP per capita

(b) Unemployment

Figure 12: GDP per capita and Unemployment between 1960-2005: France versus Synthetic France

Note: GDP per capita is Purchasing Power Parity (PPP)-adjusted and measured in 2005 U.S. dollars. Unemployment is measured as percentage of total labor force.

shocks. The time period runs from 1960-2005, with 46 observations in total.

Table 3 provides the results. When running each explanatory variable separately, all the coefficients are statistically significant and have the expected signs, with the gap in the share of nuclear showing the largest predictive power with an R^2 of 0.95. However, when running the full model (column 7) the coefficient for GDP is reduced by almost 80 percent in size and the coefficient on unemployment is now close to zero and no longer statistically significant. The coefficient for the nuclear gap is, however, significant and similar in size in all regression models where it is included.

Using the average gap in the share of nuclear between 1980-2005 of 39.2 percentage points we compute an average emission reduction in the posttreatment period of 1.74 metric tons of CO_2 per capita. The average gap in GDP is -$1169 in the same time period, which gives an average emission reduction of 0.15 metric tons per capita. Lastly, the average gap in unemployment of 2.8 percentage points gives an average emission reduction of $<$0.01 metric tons per capita.

Adding up the effects of the three key explanatory variables we calculate a total average emission reduction of 1.89 metric tons in the posttreatment period, which matches the 1.88 metric tons that we compute from Figure 9(a). Of this total, the gap in nuclear explains 92 percent, and the macro variables of GDP and unemployment explains the remaining 8 percent. The conclusion we draw from the regression result is that fuel-switching likely accounts for the largest share of the emission reductions found in the non-electricity and heat sectors in the posttreatment period, and that the relative economic downturn, while significant, is less impactful.

Table 3: Regression Results for Gap in Total CO_2 Emissions Estimations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Nuclear share	-5.089***			-4.455***		-4.782***	-4.443***
	(0.286)			(0.307)		(1.018)	(0.690)
GDP per capita		0.594***		0.125***	0.226***		0.125***
		(0.093)		(0.042)	(0.065)		(0.040)
Unemployment			-0.640***		-0.482***	-0.047	-0.002
			(0.054)		(0.063)	(0.112)	(0.081)
Observations	46	46	46	46	46	46	46
R^2	0.953	0.624	0.794	0.966	0.836	0.953	0.966

Note: All variables are computed as the gap between France and Synthetic France. The dependent variable is the gap in total per capita CO_2 emissions (metric tons). The gap in the share of nuclear is measured in percentage points (divided by 100). Real GDP per capita is Purchasing Power Parity (PPP)-adjusted and measured in 2005 U.S. dollars (thousands). Unemployment is measured as percentage of total labor force. Newey-West standard errors in parentheses; heteroscedasticity and autocorrelation robust. The constant is omitted from the output.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5.5 Timeframe for Emission Reductions

As shown in Figures 4 and 5, our results indicate a delay of six years between the policy announcement and the onset of emission reductions – what we term the "transitional period". Yet, despite this initial lag, the emission reductions were substantial and swift once the reactors became operational. By 1984, ten years after the Messmer Plan's announcement, France's CO_2 emissions from electricity and heat production had halved, compared to the counterfactual scenario, and by 1987 they had dropped almost 80 percent.

The length of the transitional period matches well the average build time of the new reactors. From construction start to commercial operation, the reactors ordered between 1974-1976, just following the announcement of the Messmer Plan, had an average build time of 75.4 months (just over six years), with a standard deviation of 9.7 months and a range of 59 months to 100 months (IAEA, 2023). This average is similar to the average build time of seven years for all nuclear reactors that have ever been completed in France. While this time frame does not include planning and permit acquisition, it remains notably shorter than the most recent European examples. For instance, Finland's Olkiluoto 3 reactor, which began construction in 2005, only became commercially operational in 2023. Similarly, construction of Flamanville 3 in France started in 2007 but was yet to conclude by 2023.

The average build time in France was also shorter than reactor construction times in other countries during this time period, such as Sweden, the US, and Germany. A likely explanation for the relatively shorter construction times in France was the standardized reactor type used throughout the implementation of the Messmer Plan (Campbell, 1988).

5.6 Abatement Cost

For the final part of our empirical analysis we calculate the average abatement cost associated with the Messmer Plan. This cost represents the total expense incurred for reducing emissions through the policy, divided by the total reduction in CO_2 achieved.

To estimate the total cost of emission reductions, we first calculate the cost of electricity production in France from 1980 to 2005. We then subtract the cost of the same amount of electricity production in the counterfactual scenario where the Messmer Plan was not implemented. This counterfactual scenario reflects how France's electricity source mix would have evolved without the adoption of the industrial policy.

To compare electricity production costs across different sources, we use the concept Levelized Cost of Electricity (LCOE). LCOE accounts for all costs related to the entire lifespan of a power plant, including capital construction, operation, maintenance, fuel, decommissioning and waste management. These costs are adjusted for inflation and discounted back to their present value, summed up and then divided by the expected amount of electricity produced. Note that the LCOE estimates are sensitive to the specific circumstances of each country, considering factors such as labor and fuel costs. This means that the LCOE for a particular technology will vary from one country to another in the same year. When done properly, the LCOE gives an estimate of the cost of producing one unit of electricity for each technology in a specific year and country, often expressed as the cost per megawatt-hour (MWh) in US dollars. Thus, while having limitations (see, for instance, Joskow, 2011; IEA, 2015), LCOEs allow for cost comparisons across technologies, countries and time.

Using the levelized cost concept, we compute the average abatement cost (AAC) of the Messmer Plan as follows:

$$AAC = \frac{1}{N} \sum_{t=1980}^{2005} \left(\frac{(LCOE_t^{FRA} - LCOE_t^{synFRA}) * elecprod_t^{FRA}}{(CO2_t^{synFRA} - CO2_t^{FRA})} \right) \tag{2}$$

where $LCOE_t$ represents the average levelized cost, taking into account the fuel mix in year t; $elecprod_t$ denotes electricity production from main activity producers in year t; and $CO2_t$ is the total amount of carbon dioxide emissions from the economy.

When using equation (2), we make three simplifying assumptions. First, to compute $LCOE_t^{synFRA}$ we use the fuel mix in synthetic France in each year, but the levelized cost estimates for different technologies in France. This is done to reflect the likely 'true' cost of electricity production within France in the scenario where the Messmer Plan is not adopted. Second, we assume that electricity production from hydropower remains unaffected by the Messmer Plan.[14] Consequently, we measure electricity production from

[14]Electricity production from hydropwer is relatively stable in France between 1960-2005 at an average annual production of around 1,000 kWh per capita.

Table 4: Data for Abatement Cost Calculation

	1981	1984	1989	1992	1998	2005
Nuclear LCOE	60.66	40.44	56.20	58.50	47.93	32.12
Coal LCOE	47.63	72.72	81.22	90.25	68.95	41.17
Nuclear share France	59.0	82.7	91.1	91.0	91.9	90.5
Nuclear share synthetic France	35.4	52.7	58.5	57.3	53.9	47.1
Electricity production	3.22	4.10	5.76	6.32	7.02	7.89
Total reduction in CO_2	0.63	1.10	1.66	1.94	2.27	2.54
Abatement cost	15.0	-36.6	-28.7	-35.2	-24.7	-10.0

Notes: The levelized cost of nuclear and coal is computed using a 5% discount rate and measured in 2013 USD/MWh. Nuclear share refers to the proportion of nuclear energy in total electricity production from main activity producers, excluding hydropower. Electricity production represents output from main activity producers (excluding hydropower) and measured in MWh per capita. CO_2 emission reductions are measured in metric tons per capita. Finally, abatement cost is measured in USD per metric ton of CO_2.

main activity producers net of hydropower, and the average LCOE is computed based on the shares of nuclear and combustible fuels in this adjusted electricity production. Third, we use the levelized cost of coal to represent all combustible fuels. This choice is primarily influenced by data availability, as the IEA (2015) provides consistent LCOE estimates for coal and nuclear in France between 1980-2005, but only sparsely for natural gas and no estimates are given for oil. However, coal constitutes more than three fourths of the combustible fuels used for electricity production in France between 1980-2005, and the levelized cost of natural gas consistently exceeds that of coal for those years that an estimate for natural gas is given. Thus, using the levelized cost of coal to represent all combustible fuels reduces the overall cost of the counterfactual scenario.

We sourced our LCOE data from the IEA (2015). The data originates from reports prepared in collaboration by the IEA, the OECD and the Nuclear Energy Agency, with figures provided for the years 1981, 1984, 1989, 1992, 1998, and 2005. While these estimates are not annual, they do span most of the post-treatment period we are interested in. The LCOE calculations were done using a 5% discount rate and presented in units of 2013 USD per MWh. The estimates are given in Table 4, along with information on fuel shares, electricity production figures and the reductions in total CO_2 emissions.

Using equation (2) and the data in Table 4, we find an average abatement cost of -$20 per metric ton of CO_2. The negative average abatement cost indicates that the Messmer Plan turned out as an opportunity to reduce carbon emissions with a net economic gain. The substitution away from combustible fuels and towards nuclear energy in France reduced the overall cost of electricity production relative to the counterfactual scenario. On top of the cost savings from electricity production, the substitution towards nuclear energy also resulted in a reduction of carbon emissions – directly from the production of electricity and heat, but also in other sectors due to fuel-switching. The total net effect was an average abatement value of $20 per metric ton of CO_2 reduced.

Keep in mind that it is the relative cost advantage of nuclear compared to coal that matters for the average abatement cost. And while the LCOE of nuclear was relatively flat from 1980 to early 1990s, the levelized cost of coal almost doubled during the same time period. This increase in the cost of coal was likely due to efforts in the 1980s to reduce sulphur dioxide (SO_2) emissions that contributes to acid rain. These efforts resulted in a phase-out of the cheapest forms of coal, which had a high sulphur content, and the adoption of more expensive technologies at coal fired power plants, such as scrubbers (Smith et al., 2011).[15]

A potential objection to our estimated negative abatement cost is that the LCOE of coal we use is too high since the numbers include construction cost. If the fossil fuel plants were already built, we should exclude the construction cost from our LCOE estimates. However, it is essential to consider four key factors. First, the substantial increase in electricity production during our sample period (see Figure 2) suggests that France would have needed to build numerous new combustible fuel plants even if it had not adopted nuclear power. Second, fuel, operation and maintenance costs constitute the largest portion – around two thirds – of the levelized cost for coal-fired power plants in France (IEA, 2005). Third, even if a plant is already constructed, spreading out construction costs over the plant's lifetime aligns with common accounting practices, similar to how capital expenditures are handled in a firm's financial reports. Lastly, the social costs of local air pollution from coal plants are not accounted for, which, if included, would increase the LCOE estimates for coal.

6 The Political Economy of the Messmer Plan

The sections above establish the large and significant emissions reductions associated with the Messmer Plan, as well as its costs. Here we explain the political economy of adopting and implementing the reform. It was not obvious ex-ante that the Messmer Plan would be politically successful. It entailed a large-scale and capital-intensive intervention in the economy to restructure a pre-existing electricity sector of a major industrialized country. Such dramatic reforms to the status quo are difficult for any government to achieve. To be sure, similar large-scale nuclear plans in other industrialized democracies, such as Project Independence in the US or those in the UK, failed to achieve their goals (Campbell, 1988; Helm, 2004; Jasper, 1990; Williams, 1980). Moreover, as we describe

[15] The convention on Long-Range Transboundary Air Pollution (LRTAP) went into affect in 1983, and the protocol on the Reduction of Sulphur Emissions was implemented in 1985, both with the aim of reducing SO_2 emissions in Europe.

below, the Plan faced intense opposition from many groups in French society. We explain the political success of the Plan by focusing on a key set of variables that enabled the government to insulate policymaking from the Plan's opponents. However, before doing so, we briefly outline a number of important conditions that set the scene for reform.

6.1 The Conditions for Reform

6.1.1 Exogenous shock

Scholars of political economy have long pointed out how exogenous shocks and crises can facilitate far-reaching reforms (e.g., Baumgartner and Jones, 1993; Collier, Collier et al., 1991; Gourevitch, 1986; Ikenberry, 1988). During these 'critical junctures' the limitations of existing policy arrangements are laid bare, and actors search for new ideas, instruments, and institutions that can respond to the challenge of the times. Politics and policymaking are rendered more fluid and ideas previously considered radical become practical. The 1973 oil price shock constituted such a critical juncture and presented governments with a clear and present crisis that needed a response. Indeed, in its aftermath all industrialized democracies sought to reform their energy sectors to reduce dependence on imported oil (Finnegan et al., 2021).

6.1.2 Technological capacity

In many ways, the infrastructure for a large-scale nuclear program was in place in France when the oil shock hit (Brouard and Guinaudeau, 2015, 141-43; Grubler, 2010; Jasper, 1990, Ch 5; Lucas, 1985, Ch 1; Naudet, 1993; Thomas, 1988, Ch 8). On the eve of the price shock, the country had eight reactors in commercial operation and five under construction. It had developed significant expertise in nuclear engineering through long-standing investments in research and development to the public nuclear research body Commissariat à l'Énergie Atomique (CEA). The firms Framatome and COGEMA, as well as a broader national supply chain of electro-mechanical producers, had expertise and experience related to reactor design, manufacturing, fuel production and commission and maintenance services. Finally, EDF, the national utility, could construct and operate nuclear power stations.

Technologically, EDF and CEA had resolved their conflicts over reactor choice, settling on US-licensed Westinghouse pressurized water reactors (PWRs) and abandoning the domestic graphite-gas design. This enabled an initially fragmented French nuclear supply chain to standardize exclusively on the Westinghouse PWR design (Campbell, 1988, Ch 8; Thomas, 1988, 218). This was not the case in the UK, for example, where political debates about reactor choice endured throughout the 1970s and stymied its nuclear rollout (Helm, 2004; Williams, 1980).

Lastly, an off-the-shelf plan for rapid expansion was available when the price shock hit. The PEON (Production d'Électricité d'Origine Nucleaire) Commission, which advised the government on nuclear energy development, had coincidentally laid out a roadmap for a significant nuclear build out of 13,000 MWe in its April 1973 report, six months before the price shock.

Consequently, by the time the oil price spiked in October 1973, the French government did not need to develop a nuclear industry from scratch nor design a policy for rapid expansion, but rather only put its weight behind existing plans and actors.

It is crucial to point out, however, that while exogenous shocks and technological capacity are important for understanding the French case, these factors alone do not explain the political success of the Messmer Plan. All industrialized countries were affected by the oil price shock and many had pre-existing nuclear programs similar to those of France, yet not all expanded nuclear power at a similar pace and scale. The key variable that set France apart from otherwise similar countries was its political and policymaking institutions.

6.1.3 Political and policymaking institutions

Institutions are formal and informal rules that structure political, economic, and social interaction (North, 1991; Thelen and Steinmo, 1992). They vary across countries and shape politics and policymaking by affecting the degree of power actors have over policy outcomes.

In the postwar period, French political institutions were characterized by *dirigisme* – a type of 'statist' policymaking whereby governments play a strong directive role in the economy in pursuit of national goals (Hall, 1986, Ch 6; Hall, Hayward, and Machin, 1994, Ch 9; Schmidt, 1996, Ch 2). Dirigisme describes institutional arrangements as well as policies, and contrasts with neoliberal policymaking styles that minimize state intervention. Under dirigisme, governments tend to focus on steering production and investment and can unilaterally intervene in the economy without necessarily needing to consult with affected parties, such as business, trade unions or civil society. While this route was not always taken by French governments, it was typically used to pursue 'heroic' policies that were central to the government's agenda and/or national security, such as nuclear energy (Schmidt, 1996).

Several key institutions undergirded French dirigisme during this period. First, decision-making was centralized within a powerful executive headed by the President with a majority in the National Assembly (Keeler, 1993). Opposition parties and, given the unitary nature of the French state, regional authorities had little influence. Second, a state bureaucracy comprised of highly trained civil servants recruited from the elite grandes écoles with deep technical expertise and long-term employment security was the primary locus of policymaking and tended to be impermeable to outside interests (Suleiman, 1974; Schmidt, 1996, Ch 7). Third, and relatedly, civil servants in the Planning Commission used indicative economic plans to outline the allocation of resources among the major sectors of French industry (Hall, 1986, Ch 7; Hall, Hayward, and Machin, 1994, Ch 9). Fourth, the financial system was based primarily on bank lending, which empowered the French state to use the nationalized banking sector to selectively provide capital to firms and industries in alignment with its broader economic goals (Hall, Hayward, and Machin, 1994, Ch 9; Zysman, 1983, Ch 3).

Beyond these general factors, characteristics of energy policymaking and the energy sector in particular offered the state additional capacity for intervention. State engineers belonging to the Corps d'État (Corps des Mines and Corps des Ponts) strongly identified with the national goal of energy independence and were responsible for the nuclear program within the ministries, especially the Ministry of Industry, as well as holding top management positions within EDF and the CEA (Finon and Staropoli, 2001, 185). Additionally, authorities responsible for nuclear safety and siting were integrated within the Ministry of Industry and the CEA, which worked to streamline implementation (Finon and Staropoli, 2001, 185). Last, the state was a majority shareholder in the country's most important energy-related firms, including EDF, the nuclear manufacturer Framatome and the nuclear fuel producer COGEMA, and nuclear research and development was coordinated through the CEA, a public body. Taken together, this provided the conditions for a centralized and technocratic policymaking process that could be controlled from the executive branch.

The case was very different in other industrialized democracies. Institutions in nearly all other similar countries were less centralized under the control of the executive. Countries like the US had strong legislative and judicial branches that could obstruct or veto executive action. Many countries had bureaucracies that were permeable to the influence of outside interests groups, including both corporatist countries like Germany and Sweden and pluralist ones like the US and UK. Policymaking processes also offered more access to the public and outside critics, in the form of public hearings and consultations, than in most other countries. At the same time, almost no other industrialized country had a state planning system as powerful as France. Similarly, financial systems in peer countries tended to be private and outside of direct state control, as were key nuclear-related firms.

6.2 Explaining Political Success

To understand why the Messmer Plan was politically successful we must focus on the ways in which the French government was able to outmanoeuvre and overcome the Plan's opponents. Virtually all major reforms generate opposition in some form and, as we describe below, the Messmer Plan was no different. Theoretically, recent work in political science points to two mechanisms that governments can use to overcome opposition to far-reaching reforms (Finnegan et al., 2021; Meckling, 2021). The first is insulation, which entails shielding, or insulating, the policymaking process from opponents so as to reduce their ability to influence the outcome. It can be enabled in a number of ways, for example, centralized policymaking with few veto points, the delegation of policymaking to technocratic bodies, as in the case of central banks, and low levels of electoral competition and electoral accountability. With insulation, policy change occurs despite continuing opposition for opponents. The second mechanism is compensation, which aims to reduce the costs that opponents face as they transition to the new status quo in order to incentivize them to cooperate and support reform. Here policy change occurs with the approval or indifference of opponents. Compensation can also take a number of forms, including direct financial payments, tax cuts, phased implementation, transitional assistance and retraining. As we show below, in the case of the Messmer Plan, the government relied primarily on insulation.

6.2.1 Opposition to the Plan

Opposition to the Plan came from virtually all corners of French society (Brouard and Guinaudeau, 2015; Papon, 1979; Jasper, 1990, Ch 9). Organized groups of nuclear scientists and engineers criticized the government's secrecy on nuclear matters and opposed the Plan on the grounds that it was too large and that there were unsolved challenges related to nuclear energy. At the same time, groups of economists came out against the Plan, challenging its assumptions around future energy demand, costs and possible risks. The country's second largest trade union, the French Democratic Confederation of Labour (CFDT), opposed the Plan and proposed a three-year moratorium on nuclear construction on the basis that France had little experience building the new PWR reactors and such a massive build out was costly and risked worker safety.

Environmental groups vociferously opposed the expansion of nuclear energy (Chafer, 1985; Kitschelt, 1986; Jasper, 1990, Ch 9). Groups had called for a moratorium on nuclear energy before 1973 and intensified their calls in response to the Messmer Plan. They mobilized opposition at the national level in Paris and at the local level, especially in areas where reactors were to be built. Indeed, almost every site chosen for reactor construction was met with local opposition. Opposition turned violent in the late 1970s when protesters bombed EDF buildings and a newly built, but unloaded, reactor. In addition to direct action, groups used the courts to try to block policy change.

Opposition political parties did not take an expressly antinuclear position (Brouard and Guinaudeau, 2015; Nelkin and Pollak, 1980; Jasper, 1990, Ch 5 and 9). However, they attacked the size and suddenness of the Plan, the way that EDF could 'buy off' local governments to get their reactors approved, the lack of public discussion and that the Plan would only profit large industry. By 1977, the Socialists, one of the largest opposition parties, was calling for a two-year moratorium on nuclear construction.

Last, public opinion oscillated during the period (Brouard and Guinaudeau, 2015, 146; Fagnani and Moatti, 1984, 272; Nelkin and Pollak, 1980, 135). While initially positive, the public mood turned antinuclear by 1977. By the early 1980s it was slightly positive again before turning negative after the Chernobyl disaster in 1986.

While antinuclear opposition was pronounced in France, it is not obvious that it was altogether more pronounced than in other industrialized democracies. Indeed, governments across countries faced opposition to nuclear expansion from experts, opposition political parties, legal challenges and civil society (Campbell, 1988; Jasper, 1990; Kitschelt, 1986). Though, as we describe below, none were as effective at overcoming it as governments in France.

6.2.2 Overcoming opposition via insulation

The key variable in the French case was the capacity of the government to overcome the Plan's opponents via the institutions of dirigisme. Once the executive had decided to pursue the Messmer Plan, it put the full weight of the dirigiste state into action behind it. First, a strong executive vis-à-vis parliament meant that the President and the bureaucracy that it controlled could adopt and implement the Messmer Plan without it needing to be debated or voted on in the National Assembly. Indeed, the Messmer Plan was never debated or subjected to parliamentary scrutiny and it was implemented by decree rather than parliamentary lawmaking (Fagnani and Moatti, 1984, 265; Papon, 1979, 94). Such an institutional setting insulated the Plan from a wide variety of potentially oppositional forces. It prevented opposition parties, as well as government parliamentarians, from obstructing it. Furthermore, it prevented private sector and civil society actors from obstructing the Plan via parliamentary or bureaucratic channels, for example by lobbying opposition lawmakers to oppose it. The case was much different in places like the US or UK, where legislatures and bureaucracies were less insulated and opponents were able enable to lobby politicians, legislative committees and civil servants on energy policy (Campbell, 1988, Ch 5; Helm, 2004, Ch 5).

Second, the state's ownership stake in the most important nuclear energy-related firms made it difficult for business to mount an effective opposition. Even though EDF operated as a private sector firm, because the state wholly owned it, it could be compelled to act in a way that was consistent with the goals of the Messmer Plan. The same was true for Framatome and COGEMA. In contrast, private firms dominated the nuclear sector in most other industrialized democracies. Importantly in the French case, state ownership stakes in key fossil fuel firms, such as the oil producer Compagnie française des pétroles, coal producer Charbonnages de France and gas producer Gaz de France, meant that the government could, if needed, use inside leverage to head off and reduce opposition from firms that would lose out from a nuclear transition. This was not the case in countries like Germany and the US where coal and oil companies were beyond state control.

Third, and related, the state's capacity to influence the allocation of capital enabled it to channel finance to the nuclear industry (Jasper, 1990, 174-75; Lucas, 1985, 37). This happened in two ways. Capital was directly lent to EDF to build nuclear plants via the nationalized banking sector and the Ministry of Finance. Additionally, the state used loan guarantees to underwrite the debt that EDF took on in foreign credit markets, especially the US. The result was that the state could channel large amounts of capital to the sector and insulate key firms from the pressures of investors and capital markets. This was not the case in places like Germany, Sweden and the US where governments had fewer tools to directly allocate capital (Campbell, 1988). Indeed, given its ownership structure, EDF was not as tightly constrained by financial considerations. It had little need to return short-term profits, which meant it could stick to its long-term plan of nucelar expansion, even in the face of rising near-term costs (Fagnani and Moatti, 1984, 266). The situation was very different in the US, for example, where the sector was crippled as private companies, unsupported by government, were unable to bear the rapidly increasing short-term costs of nuclear expansion in the late 1970s (Campbell, 1988, Ch 6; Fagnani and Moatti, 1984, 266; Thomas, 1988, Ch 4 and 5).

Last, the government could be impermeable to civil society opposition if it chose to. As mentioned, these actors could not influence policy via opposition parties or parliament. And unlike in other countries where referenda can be called by parliament or citizens, only presidents can call them under the French constitution. While there were some consultative processes, such as those associated with the Ornano Plan and the siting of reactors, they tended to be mere formalities and offered no opportunity to affect the rollout of the policy or block it (Campbell, 1988, Ch 8; Fagnani and Moatti, 1984, 265; Jasper, 1990, 165). Furthermore, nuclear licensing decisions had the status of government decrees and were practically immune from legal challenge (Campbell, 1988, Ch 8). The end result was that virtually all channels were blocked for civil society apart from direct action, which, unsurprisingly, was the primary strategy of antinuclear groups. However, street demonstrations and protests were unable to have much influence on policy (Jasper, 1990, Ch 9).

The closed and insulated policy process in France contrasts markedly with other industrialized democracies, where institutions enabled outside groups to influence, and in many cases block, nuclear expansion. In places like Sweden and Italy, antinuclear referenda were initiated by opposition parties and civil society, and in both cases succeeded. In Germany, antinuclear advocates leveraged the courts and opposition political parties to slow down nuclear expansion (Campbell, 1988, Ch 8). Federalism and separation of powers meant that nuclear policymaking in the US was especially decentralized and fragmented, and therefore porous to outside influence, particularly in the implementation phase. Federal policymaking was stymied by civil society and state and local governments, who used legal challenges, laws and referenda to block nuclear expansion (Campbell, 1988, Ch 5). Because of the inability of many governments to insulate nuclear policy from opponents, by the early 1980s nuclear expansion had slowed considerably in many countries and altogether collapsed in the US (Campbell, 1988).

6.2.3 Policy stability

Simply because a policy is adopted and implemented does not mean that it will stay in place over the long term. This is especially true in the context of deeply fractious issues such as nuclear energy. A critical ingredient for achieving the deep emissions reductions that we estimate above was that France's nuclear policy was not reversed. It survived decades of changing governments, shifting political winds, oscillating public approval and political and economic crises of all kinds. Without this policy stability, it is unlikely that it would have resulted in such large reductions. Indeed, the stability of French nuclear policy makes it an outlier compared to many of its peers, where nuclear energy faltered significantly in the 1980s as a result of referenda and policy reversal from newly-elected governments .

In France, the Plan was sustained because the state continued to support it and no political coalition emerged that was strong enough to overturn it. As described above, the opposition Socialist Party was hostile to the policy early on, and their reticence continued throughout the 1970s. In the lead up to the 1981 election, the party ran on a platform of nuclear policy reform, including a moratorium on nuclear orders pending a national debate and referendum and the expansion of coal and renewables (Thomas, 1988, 213). However, after winning power, the new Socialist President François Mitterand did not dramatically change course or call a referendum. The most significant of his reforms was to reduce new reactor orders from an average of five per year after 1973 to three in 1982 and two in 1983, 1984, and 1985 (Fagnani and Moatti, 1984; Thomas, 1988, 213-15). Though, this was likely due as much to sharply reduced electricity demand forecasts as to partisanship. Additionally, planning procedures were amended to allow greater local participation in site selection.

By the mid-1980s, French political parties had depoliticized nuclear power and a cross-party consensus had emerged in support of it (Brouard and Guinaudeau, 2015; Fagnani and Moatti, 1984; Nelkin and Pollak, 1980). This is unsurprising given that, as we describe above, most nuclear plants were under construction or completed by this time, meaning that any phaseout would be costly and leave many stranded assets. Furthermore, the rapid growth of the sector meant that nuclear industrial interests, including companies and labor unions up and down the supply chain, had become consolidated as a powerful political force that resisted major changes to policy (Thomas, 1988, Ch 8; Jasper, 1990, Ch 13).

Beyond political parties, there is little evidence that significant calls for reversal emerged either within the state bureaucracy or from other parts of the business community. Moreover, the antinuclear movement within civil society had all but disappeared by the early 1980s (Jasper, 1990, 237) and public opinion turned more positive (Brouard and Guinaudeau, 2015). Though, even if these events had not transpired, it is unlikely to have mattered much given the prevailing cross-party consensus on the issue and the lack of possibilities for a national referendum.

7 Discussion

We use the example of nuclear energy as a case for studying green industrial policy. Today, governments have a range of zero-carbon energy technologies to choose to support, including nuclear, but also wind and solar. The choices governments make will be shaped by the political economy of each technology. In the case of nuclear, the economic and political conditions are different now than they were during the study period. First, the Messmer Plan's reactors had a notably, and historically, short average construction time of only six years. More recent European examples present a contrasting picture. Olkiluoto 3 in Finland took 18 years to construct, Flamanville 3 in France started in 2007 and was still unfinished by 2023, and the Hinkley Point C reactors in the UK, initiated in 2016, have experienced repeated delays, projecting 2027 as the earliest operation year (IAEA, 2023; Lawson, 2022). Similar trends have been observed in other OECD countries, like the US, where construction times have at least doubled since the first reactors were built (Lévêque, 2015). Even President Macron has acknowledged that today "it takes 15 years to build a nuclear reactor" (Alderman, 2022). These lengthened timelines likely arise from evolving safety regulations, and the design of larger and more complex reactors (Lévêque, 2015). In contrast, the construction times for the other prominent zero-carbon energy sources of wind and solar PV plants have trended down, averaging below 2 years in 2018 (IEA, 2019).

Second, is the question of costs. The extended construction times for reactors increases not only environmental costs, since they delay emission reductions, but also inflates economic costs, which elevates construction expenses and the resulting levelized cost of electricity from nuclear power. France achieved significant emission reductions with a negative abatement cost thanks to nuclear power's once-lower LCOE compared to fossil fuels. However, this dynamic has since shifted. Reports indicate rising construction costs for nuclear in France even during the implementation of the Messmer Plan (Grubler, 2010; Court of Audit, 2012), and the LCOE of nuclear energy in France doubled between 2005 and 2015 (IEA, 2015). Simultaneously, the cost of wind and solar has plummeted. In

2020, onshore wind and utility-scale solar PV was France's most cost-effective electricity sources, with solar PV's LCOE nearly halving that of new nuclear (IEA, 2020). Similar cost dynamics appear in top emitting nations like the US, China, and India, with wind and solar PV being the lowest-cost options of all energy sources (IEA, 2020; Bilicic and Scroggins, 2023). Contrary to most technologies, which typically decrease in cost when adoption increases, nuclear power has seen its costs rise, meriting the label of "a very strange beast" (Lévêque, 2015, p. 44). New nuclear power thus struggles to compete economically. While fossil fuel costs have stagnated, wind and solar PV have emerged as today's most affordable energy sources. As recently as 2010, their LCOEs exceeded those of coal and nuclear in the US, but the roles have reversed (Bilicic and Scroggins, 2023).

At the same time, what needs to be kept in mind is that regardless of the chosen zero-carbon technology, their levelized costs depends heavily on the cost of capital. This was true in the 1970s and is still true today (IEA, 2020; Worland, 2023). Therefore to achieve rapid decarbonization, government intervention, including industrial policy, is needed to lower the cost of capital, especially amidst high real interest rates in today's capital markets.[16] In contrast, the cost of fossil fuel generation predominantly relies on variable fuel costs. Hence, carbon pricing is needed to increase fuel costs. One effective climate policy strategy would be to reduce the relative price of zero-carbon energy sources through a dual approach of green industrial policy and carbon pricing. This approach could be revenue-neutral if the proceeds from the carbon price are used to fund green industrial policy.[17]

Third are the politics. In the case of nuclear power, they have not changed dramatically since the 1970s. Concerns about safety, costs, construction time and waste still predominate. That said, the politics play out differently in different countries. For example, the 2011 Fukushima accident pushed several countries to reduce their reliance on nuclear power, including Germany, Japan, Belgium and Spain. However, neither France nor the UK made serious reforms.

Political opposition to dramatic energy transitions is also similar now to as it was during the Messmer Plan. These transitions impose costs as they upend existing economic structures and alter existing power relationships. Decarbonization upsets incumbent GHG-intensive industries, as well as consumers that want low energy prices. The nature of opposition is likely to vary by policy instrument. Carbon pricing often faces intense opposition from producers and consumers. Green industrial policies on the other hand, may garner less intense opposition, especially if they are engineered to impose few short-

[16]Economists agree that the long-term social discount rate to use for evaluations of climate change mitigation is relatively low, around 2 percent (Drupp et al., 2018).

[17]This idea echoes Pigou's early discourse on taxation and market failures: "it is always possible [...] to correct them by imposing appropriate rates of tax on resources employed in uses that tend to be pushed too far and employing the proceeds to provide bounties, at appropriate rates, on uses of the opposite class" (Pigou, 1928, p. 99).

term costs and generate short- to medium-term benefits. One way to do this is to fund them out of general revenues or debt while at the same time ensuring that economic benefits are created quickly (e.g., jobs, growth and investment).

More broadly, carbon pricing and green industrial policies have different political economies. Carbon pricing creates a first-mover disadvantage, as the implementing country can incur an economic cost, including higher energy prices for producers and consumers and deindustrialization and unemployment as firms relocate to countries with less stringent climate policy. Green industrial policy can invert this narrative by incentivizing low-carbon firms to relocate to countries offering substantial support. When one country adopts generous green subisidies, it puts political pressure on other countries to do the same for fear of job loss and diminished competitiveness. This dynamic can be seen currently with European leaders fearing the impact on European competitiveness of the IRA in the US and green industrial policy in China. In this sense, subsidies offer a first-mover advantage, encouraging early adoption. The introduction of climate subsidies in one country thus potentially sets off a domino effect.

Secondly, the timing of costs and benefits is different. Carbon taxes impose short-term and visible costs on consumers and producers to generate long-term and globally disperse benefits. Conversely, green industrial policy can generate short-term and visible benefits to households and business, while spreading the costs nationally (e.g., if funded through general taxation), internationally (e.g., if funded through international climate finance) or pushing them into the future (e.g., if funded through deficit spending).

These differences in the incentives for free-riding and the timing of costs and benefits may make the implementation of green industrial policy more politically feasible compared to carbon pricing.

8 Conclusion

Governments around the world are turning to green industrial policy and increased electrification to decarbonize their economies and drive economic competitiveness. We assess the ability of these policies to reduce emissions by analyzing the case of France. In response to the 1973 oil price shock, France launched the Messmer Plan, an ambitious industrial policy to both enhance energy security by replacing fossil fuels with nuclear in electricity production and grow an internationally competitive French nuclear industry. Using state financing and loan guarantees, the government channelled large sums of capital toward the sector. The Plan faced intense political opposition. To overcome it, the government relied on the dirigiste policymaking style of the French state to insulate decision making and implement nuclear expansion over the objections of opposition political parties, trade unions and the antinuclear movement. The French experience contrasts markedly with that of other industrialized democracies, such as the US, UK and Germany, where political forces prevented a radical transition toward nuclear.

As a result of the Messmer Plan, we find that carbon dioxide emissions from electricity and heat production fell by an average of 62 percent in the years that followed. For the economy as a whole, there was a more than 20 percent reduction in total CO_2 emissions in an average year, due, in large part, to increased electrification. It took around six years from the announcement of the policy until emission reductions commenced and the average abatement cost was -$20 per metric ton of CO_2. These findings show that ambitious industrial policy can be an environmentally and economically efficient, as well as politically feasible, tool for mitigating carbon emissions in the energy sector. Indeed, our results provide strong evidence that active state intervention in the form of industrial policy can quickly and dramatically decrease emissions. We are not aware of any other single policy that has been shown to decrease emissions on the same scale, and as rapidly, as the Messmer Plan in France.

While our study is ambitious in scope, there is opportunity for more research on the local effects of green industrial policy. Our analysis primarily addresses the global environmental impact of the Messmer Plan, focusing on the reduction of carbon dioxide emissions. However, the Plan likely also resulted in decreased local air pollutants, particularly in areas where fossil fuel plants were decommissioned due to the rise in nuclear energy production. This reduction in local pollutants could have significant benefits for nearby populations, as decreases in air pollution are linked to improved outcomes in areas like infant mortality and academic performance (Chay and Greenstone, 2003; Ebenstein, Lavy, and Roth, 2016). Moreover, our analysis has focused on the 'green' aspects of green industrial policy, without assessing local economic impacts, such as changes in employment and economic growth in the areas affected by the Messmer Plan. A comprehensive estimation of local costs and benefits of the Plan, considering local air pollution, employment, and economic growth, represents a promising area for further study.

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A Appendix – For Online Publication

A.1 Data Sources

- Carbon dioxide (CO_2) emissions. Measured in metric tons per capita. Source: IEA (2022b). Available at: https://doi.org/10.5257/iea/co2/2022.

- GDP per capita (PPP, 2005 USD). Expenditure-side real GDP at chained PPPs, divided by population. Source: Feenstra, Inklaar, and Timmer (2013), "The Next Generation of the Penn World Table". Available at: www.ggdc.net/pwt.

- Urban Population. Measured in percentage of total. Source: The World Bank (2015) WDI Database. Available at: data.worldbank.org/indicator.

- Electricity production. Measured in kWh per capita. Source: IEA (2022a). Available at: https://doi.org/10.5257/iea/elec/2022.

- Domestic oil and coal production. Measured in kilogram of oil equivalent per capita. Sources: International Energy Agency: Oil Information (2022 Edition) https://doi.org/10.5257/iea/oil/2022; International Energy Agency: Coal Information (2022 Edition) https://doi.org/10.5257/iea/coal/2022.

- Unemployment rate in OECD countries. Percentage of total labor force. Source: AMECO (2018) database. Available at:
ec.europa.eu/economy_finance/ameco/user/serie/SelectSerie.cfm.

- Household electricity prices. Source: International Energy Agency: World Energy Prices (2020 Edition). Available at: https://doi.org/10.5257/iea/wep/2020.

- Energy consumption from electricity and combustible fuels. Measured in oil equivalents. Source: World Energy Balances (IEA 2022c).
Available at: https://dx.doi.org/10.5257/iea/web/2022.

A.2 The Scale of the Messmer Plan

Measuring the magnitude of an industrial policy can be challenging (Juhász, Lane, and Rodrik, 2023). Especially compared to quantifying policy instruments like carbon taxes, which can be expressed in tangible terms such as cents per litre of gasoline or the percentage increase in coal prices. Accurately assessing the scope of an industrial policy is nonetheless important. It allows us to grasp the policy's scale and expected impact in easily comprehensible units.

To quantify the scale of the Messmer Plan, we computed the difference in the number of nuclear reactors either under construction or in operation in France and its counterfactual, before and after the plan's announcement. This calculation was adjusted to account for variations in population sizes across countries in 1974. By the time the Messmer Plan was announced in 1974, France already had nuclear power plants in commercial operation or under construction. Of the five countries in the donor pool that receive a positive weight, Portugal never deploys nuclear power plants during our sample period. Austria, Belgium, Switzerland, and Germany, on the other hand, all have nuclear power plants in operation – or where construction had started – both before and after the Messmer Plan was enacted.[18]

Prior to 1974, both France and synthetic France had a similar number of reactors under construction or in operation, with about 3 reactors per ten million people. However, following the announcement of the Messmer Plan, France began construction on an additional 7.5 reactors per ten million people, whereas synthetic France only added 1.5 reactors. Thus, according to this measure, the Messmer Plan resulted in a five-fold increase in the number of nuclear reactors constructed after 1974, compared to the counterfactual scenario.

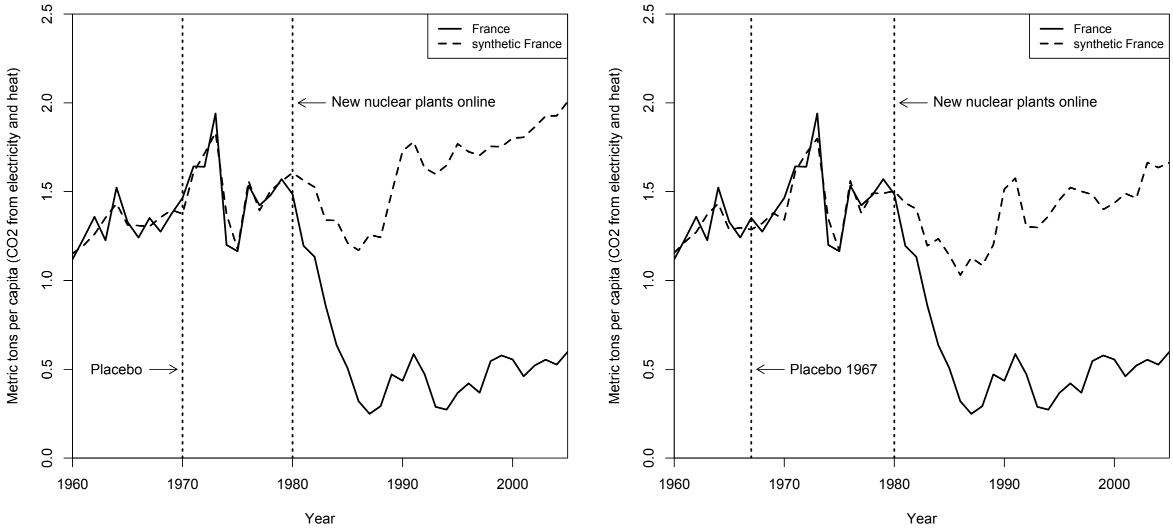
The increase in nuclear reactors due to the Messmer Plan is further reflected in the net electricity capacity that comes from nuclear energy. While France and synthetic France had similar nuclear capacity in the transitional period, an average of 0.85 gigawatt-electric (GWe) per ten million people between 1974-1979 in France and 0.89 GWe in synthetic France, this grew to just over 10 GWe in France by 2005 but only 2.9 GWe in synthetic France.

A.3 Robustness Tests

To test the robustness of the main results, we perform a range of tests: in-time placebo, leave-one-out, specification searching, and placebo sector.

With the "in-time" placebo test, we adjust the treatment year to 1970 and 1967, periods before the Messmer Plan's implementation, constructing counterfactuals with

[18] Austria built and finished the Zwentendorf nuclear power plant between 1972-1978, but the plant was never put into commercial operation following a referendum on nuclear energy in November of 1978.



(a) 1970

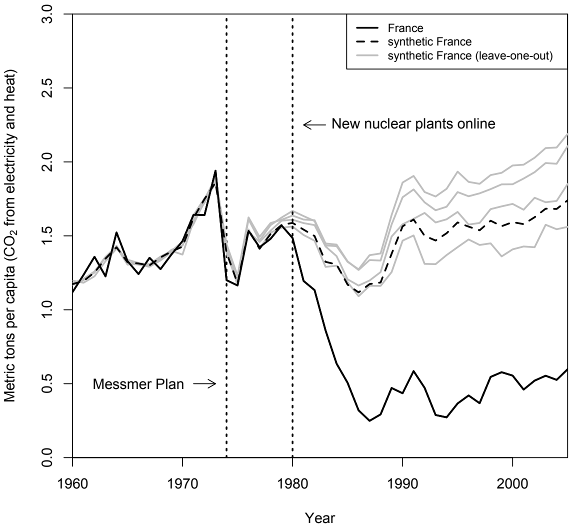
(b) 1967

Figure 13: Placebo In-Time Tests: 1970 and 1967

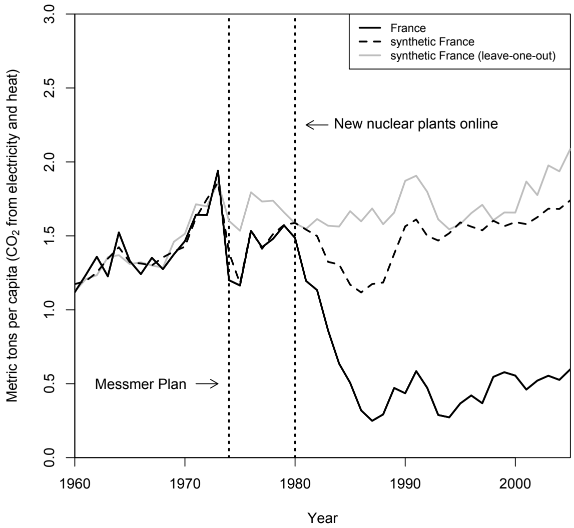
data only from years before these dates. Our objective is to verify the absence of a divergence in the emissions trajectories between France and synthetic France before 1980 – prior to the operationalization of the first new nuclear reactors. An observed placebo effect would raise questions about our claimed causal effect from the Messmer Plan. Figure 13 shows that no placebo effect is found as the two series remain aligned until 1980. This is consistent with the results from the main specification and the existence of the transitional period between 1974-1979 in this study reduces the need for the in-time placebo test.

In the leave-one-out test, we aim to investigate whether the posttreatment results primarily depend on one or more control countries, and whether the accuracy of the pretreatment fit relies on the inclusion of a specific control country. For this purpose, we iteratively eliminate one of the five countries that received a weight larger than one percent. The results, presented in Figure 14, indicate that we obtain similarly large emission reductions from 1980 and onwards in all specifications; only when Portugal is excluded do we obtain a smaller estimated emission reduction compared to the main result. The inclusion of Belgium, however, seems necessary to capture the effects on emissions from the two oil crises. In panel (b), where Belgium is excluded, we obtain a poorer fit in the transitional period compared to the main specification, and we also don't obtain the "slump" in emissions in synthetic France in the 1980s. Similar to France, Belgium used oil as the primary energy source for electricity production in the early 1970s and was still heavily dependent on oil at the time of the second oil crisis. Furthermore, Belgium also had existing nuclear power plants at the time of the first oil crisis.[19] Taken

[19]Belgium has two nuclear power plants, Doel and Tihange, that began construction in 1969 and 1970,



(a) Excluding AT, DE, PT, and CH



(b) Excluding Belgium

Figure 14: Leave-One-Out Tests

Notes: In panel (a) we have iteratively excluded Austria, Germany, Portugal, and Switzerland from the donor pool. In panel (b) we have excluded Belgium.

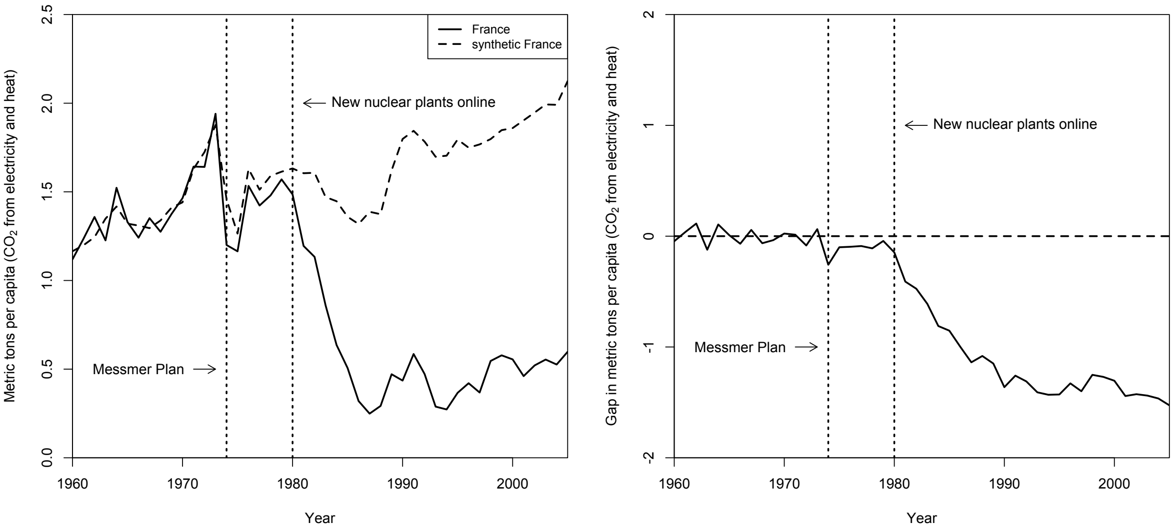


Figure 15: Benchmark Specification

together, Belgium is likely the country most similar to France when it comes to the fuel mix in the pretreatment period – and thus an important inclusion in the donor pool to be able to create a credible "twin" – which may explain why it is given the largest weight

respectively, and with seven reactors in commercial operation – four in Doel and three in Tihange. The decision to build the first three reactors, Doel 1 and 2, and Tihange 1, was taken in 1966 and the decision to expand with four more reactors, Dole 3 and 4, and Tihange 2 and 3, was taken in 1973 (IAEA, 2020).

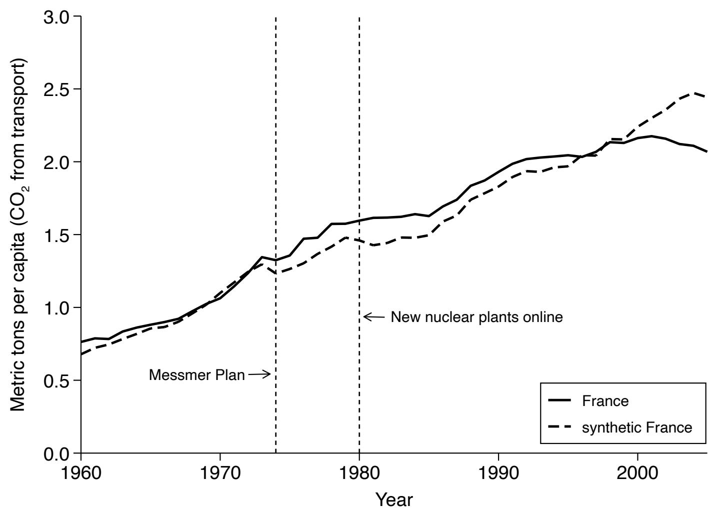


Figure 16: Placebo Sector: Transport

in synthetic France, of around one third.

A potential concern with the synthetic control method is that the choice of key predictors of the outcome variable and the chosen lags of the outcome variable has a large impact on the estimated results and thus creates opportunities for specification searching. Following the recommendation of Ferman, Pinto, and Possebom (2020) we therefore constructed a counterfactual using all (and only) the pretreatment lags of the outcome variable. This benchmark specification produces similar results as our main specification. The largest weight in synthetic France is still given to Belgium and Austria, and Germany and Portugal still receive meaningful weights. In the path and gap plots in Figure 15, we see a good fit in the pre-treatment period, and, compared to the main specification, slightly poorer fit in the interim period and larger relative emission reductions from 1980 and onwards.

For the last robustness check, we do a placebo sector test: comparing the trajectories of emissions in a sector that arguably should not be affected by the Messmer Plan. For this purpose we picked the transport sector, where the level of emissions is similar in size to emissions from electricity and heat production, and where, during the sample period, oil was always the main source of energy – electric vehicles is not a meaningful portion of the vehicle fleet at this time.

Figure 16 shows that transport emissions in France and synthetic France closely match in the years before the Messmer Plan was implemented. Then, from 1974 until the mid-1990s, emissions were relatively higher in France, around 7.5 percent on average, before decreasing in the final years of our observation period. The significant relative reduction in emissions within the electricity, heat, industry, residential, and services sectors from 1980 and onwards was not mirrored in the transport sector.

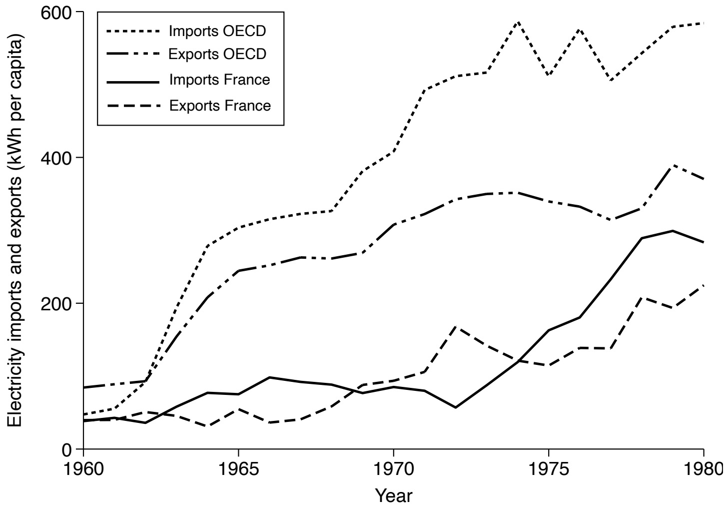


Figure 17: Electricity Imports and Exports in France and OECD: 1960-1980

A.4 Potential Spill-Over Effects

Our estimated emission reductions attributed to the Messmer Plan could be biased if the Plan affected energy policy in the countries that constitute synthetic France. However, if there is a 'spill-over' on energy policy, and thus emissions, it is not clear beforehand in which direction this would bias our estimated emission reductions. In this section we analyse the possibility of spill-over effects and argue that, if any, they are likely small.

If neighboring countries reduced their nuclear energy deployment following the announcement of the Messmer Plan, we would overestimate the emission reductions in France—since emissions in synthetic France would now be higher than they would have been in the absence of the Messmer Plan. This argument, however, hinges on the possibility of neighboring countries buying electricity from France – and thus becoming less energy self-sufficient – and anticipating an overbuilding of nuclear energy in France, which would result in increased exports and lower overall electricity prices on the European market.

In the 1970s, the European electricity market was not nearly as integrated as it is today, and trading of electricity across country borders was much less prevalent (Batalla-Bejerano, Paniagua, and Trujillo-Baute, 2019).[20] It's evident from Figure 17 that France did neither export nor import much electricity in the 1960s and 1970s, especially compared to the OECD average. For instance, electricity exports were only around 40 percent of the level in an average OECD country in the 1970s. On average, France exported three percent of its annual electricity production in the 1960s and 1970s. For a spill-over in the direction of an overestimation of the emission reductions to occur, the countries in synthetic France need to have anticipated both an increased integration of the electricity

[20]Since 1996, a single European electricity market has been promoted by the European Commission through legislation.

market and a too ambitious build-out of nuclear energy in France leading to increased electricity exports, two factors that were not apparent until at least a decade later.

On the other hand, if the countries in synthetic France increased their nuclear energy ambitions as a result of the Messmer Plan, this would lead to an under-estimate of the emission reductions following the Plan – as emissions in synthetic France will now be lower than they would have been in the absence of the Messmer Plan. However, the data on deployment of nuclear energy in the counterfactual countries do not lend support to this scenario.

Austria had a nuclear power program in place in the early 1970s, with a plan for three nuclear power plants. The first, the Zwentendorf nuclear power plant, began construction in 1972 and was finished in 1978. However, the plant never went into commercial operation following a referendum on nuclear energy in November of 1978. After this, no new nuclear reactors where initiated.

Belgium has two nuclear power plants, Doel and Tihange, that began construction in 1969 and 1970, respectively, and with seven reactors in commercial operation – four in Doel and three in Tihange. The decision to build the first three reactors, Doel 1 and 2, and Tihange 1, was taken in 1966 and the decision to expand with four more reactors, Dole 3 and 4, and Tihange 2 and 3, was taken in 1973, before the announcement of the Messmer Plan. No more reactors or nuclear power plants were ordered after this.

Germany has built 36 nuclear reactors in total. Of these, 13 began construction after the Messmer Plan was announced, between 1974-1982. Many of these were, however, ordered before 1974 and with a drastic reduction in orders after 1976 (Campbell, 1988). Nevertheless, Germany's weight in the synthetic counterfactual is just four percent, so any potential spill-over effect should be small.

Portugal has never had any nuclear reactors. Switzerland had five nuclear reactors at its peak, with four still in operation. All nuclear reactors, however, began construction before the Messmer Plan was announced. The last reactor to begin construction was Leibstadt that began construction on January 1st, 1974. Taken together, there is no evidence that the countries in synthetic France increased their nuclear energy ambitions in response to the Messmer Plan.

In conclusion, we expect few spill-over effects. Any that do exist are likely small and unlikely to significantly bias our results upwards or downwards.