Carbon Pricing and Inflation Volatility*

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Carbon pricing initiatives, in the form of carbon taxes or emission trading systems (ETSs), have proliferated in the last two decades, providing an opportunity to better understand their economic consequences. This paper assesses the effects of carbon pricing initiatives on inflation volatility. We find evidence of ETS schemes inducing larger volatility in consumer price inflation, while no significant impact is found in the case of carbon taxes. This effect feeds through the energy component, which tends to be more closely related to carbon pricing, while it affects core inflation with some delay, suggesting indirect effects of ETSs on inflation. Finally, we explore several mechanisms contributing to the increase in the volatility of inflation, such as the volatility of underlying carbon prices, the sectoral coverage of these initiatives, the relevance of high-polluting sectors in the productive structure, or the role of free emission allowances in ETS schemes.

JEL Codes: E31, E32, E52, E58, Q48, Q58.

1. Introduction

Not only climate change but also its mitigation policies may affect the business cycle and inflation dynamics. The scientific consensus points to an increasing concern that, without a significant reduction

*The views expressed in this paper are those of the authors and do not necessarily reflect the views of the Banco de España or the Eurosystem. We would like to acknowledge Mario Alloza, Ángel Estrada, Filippo Natoli, Florens Odendahl, Javier J. Pérez, Pedro del Río, and the anonymous referees as well as other participants at the Banco de España, European Central Bank, and NGFS seminars, the 1st Workshop of the Eurosystem Research Cluster of Climate Change, the 2nd Workshop of the NGFS Expert Network on Research, and the 2023 Conference of the Association of Environmental and Resource Economists for their valuable comments. All remaining errors are obviously ours. Correspondence to Daniel Santabárbara (daniel.santabarbara@bde.es) and Marta Suárez-Varela (marta.suarez-varela@bde.es).

in greenhouse gas (GHG) emissions, the process of global warming will lead to devastating and potentially irreversible consequences for the planet (Intergovernmental Panel on Climate Change 2023). In light of this evidence, many governments have implemented significant mitigation policies and committed to expanding their ambition. Besides the physical risks derived from climate change, those policies aimed at the transformation to a low-carbon economy could also be associated with significant transition risks,[1] both of which affect macroeconomic outcomes. The realization that climate change and mitigation policies may reshape policy formulations has prompted the need for a better understanding of their consequences for economic policy.[2]

Among the various policy measures aimed at mitigating climate change, carbon pricing is widely regarded as the most efficient economic instrument for reducing emissions (Hepburn, Stiglitz, and Stern 2020). This approach allows for the internalization of the external costs associated with the production and consumption of GHG-intensive goods, effectively aligning the implicit cost of emissions with their social cost (Pigou 1933). In recent years, the implementation of carbon pricing initiatives has surged, not only in terms of the number of initiatives but also in their geographical spread and the proportion of emissions they cover (World Bank 2021).

Carbon pricing initiatives are designed to increase the prices for carbon emissions, providing economic agents with an incentive to conserve energy and switch to greener sources. Then, they should lead to higher prices of those goods and services intensive in

[1]These risks derive from the initiatives to mitigate climate change. For instance, to the extent that many of them lead to an increase in fossil fuel prices in the short term, this could affect the income and credit quality of those households and firms that depend more intensively on this source of energy. Moreover, uncertainty about the public policies and the structural transformation to come could influence economic agents' consumption and investment decisions, or generate financial markets' turbulence episodes. The probability of the realization of these risks and their intensity will depend on how the transition to a low-carbon economy is designed and implemented.

[2]Both climate change and the transition to a low-carbon economy could affect the delivery of the central bank's price stability mandate. They may hinder the transmission of monetary policy to the extent that these structural processes may induce changes in business cycle and inflation dynamics, affect the equilibrium level of the real interest rate, or generate distortions in the financial system (in particular, in credit allocation).

GHG emissions, pushing up (at least temporarily) inflation. However, incentives from carbon pricing to increase energy efficiency and foster innovation in low-carbon sources of energy, especially in the electricity sector, combined with the diminishing weight of fossil fuels in the consumption basket, act in the opposite direction.[3] In this regard, most of the empirical literature so far has focused on the effects of carbon prices on the level of inflation, the interaction between underlying inflationary and disinflationary forces, and, in some cases, on the persistence of inflation (McKibbin, Konradt, and Weder di Mauro 2021; Moessner 2022; Känzig 2023; Konradt and Weder di Mauro 2023). These studies show that carbon pricing initiatives generally produce a transitory effect on the level of headline inflation.

In contrast, inflation volatility has received comparatively less attention.[4] Inflation volatility is nevertheless crucial for monetary policy, as it may complicate both its communication and implementation. Firstly, sectoral price shocks linked to carbon pricing risk affecting inflation expectations, possibly triggering second-round effects (Batten, Sowerbutts, and Tanaka 2020). Secondly, higher inflation uncertainty has been found to be associated with higher inflation levels (see Cukierman and Meltzer 1986 for a discussion). Along these lines, recent research has shown that inflation volatility can intensify the impact of supply shocks on consumer prices. Specifically, during periods of heightened inflation volatility, the payoffs of swiftly responding to inflation developments may be more significant, thus boosting the incentives for firms to enhance their pricing flexibility (Arndt and Enders 2024). Finally, significant inflation volatility may lead to economic uncertainty, affecting agents' investment and consumption decisions (Judson and Orphanides 1999; Byrne and Davis 2004; Elder 2004), and introducing frictions on markets (Friedman 1977).

[3] As argued by Schnabel (2022), in order to limit the consequences of climate change, carbon prices should remain elevated in the medium term, while investments and innovation in decarbonized technologies to replace them may need some more time. Therefore, inflationary pressures may be more persistent.

[4] To our knowledge, the impact of carbon pricing on inflation volatility has only been addressed ex ante by means of environmental dynamic stochastic general equilibrium (DSGE) (Diluiso et al. 2021), focusing on carbon tax systems.

Importantly, carbon pricing initiatives could be expected to affect the inflation process differently depending on their design. Indeed, several works and reports have already suggested a relationship between certain types of carbon pricing systems and price volatility (see, for example, Diluiso et al. 2021; European Central Bank 2021; Metcalf 2021). This is because the presumed impact on inflation volatility of the two main carbon pricing initiatives, ETS schemes (also known as cap-and-trade schemes) and carbon taxes,[5] differs. Under an ETS, a cap is first set on pollution, followed by the issuance of a volume of emission allowances compatible with that cap. These allowances can then be traded by companies, determining a market-clearing price that could be potentially rather volatile. Conversely, under carbon tax schemes, policymakers directly set a price on emissions, letting the market determine the amount of pollution consistent with that price. Thus, carbon prices tend to be relatively stable as long as their tax rates and bases do not change frequently. All in all, while carbon taxes deliver relatively stable carbon prices, ETSs have been found to lead to substantial carbon price volatility (Goulder and Schein 2013; Metcalf 2021). Higher volatility of carbon prices could be transmitted into producer and consumer prices—especially of those goods and services related to those sectors under the coverage of carbon pricing—and thus increase inflation volatility. Thus, these initiatives could have only a temporary effect on the level of headline inflation but a more permanent effect on its volatility.

In this paper, we fill this gap in the literature by empirically assessing the effects of the two main types of carbon pricing initiatives (carbon taxes and ETSs) on consumer price inflation volatility. We extend this analysis to evaluate not only the volatility of headline inflation but also its impact on energy and core components, providing a more comprehensive understanding of the channels through which carbon pricing affects inflation dynamics. Furthermore, our study delves into various mechanisms and sources of heterogeneity contributing to increased inflation volatility, such as the sectors influenced by carbon pricing initiatives (e.g., the electricity sector),

[5] A carbon tax is a tax on the supply of fuel in proportion to its carbon content.

the significance of high-polluting sectors in the overall productive structure, and the role of free emission allowances in ETS schemes.

We find evidence of ETS schemes inducing larger volatility in consumer price inflation, while no significant impact is found in the case of carbon taxes. This effect feeds through the energy component, which tends to be more closely related to carbon pricing, while it affects core inflation with some delay, suggesting lagged indirect effects of ETSs on inflation. We also find that increased volatility patterns seem related to more volatile carbon prices rather than to differences in sectoral coverage among the two types of carbon pricing initiatives. Finally, our findings suggest that countries with higher weight in high-polluting sectors experience more volatile energy CPI inflation and that, under ETS schemes, a higher share of free emission allowances allocated to each country tends to reduce inflation volatility.

By shedding light on these dynamics and mechanisms, this paper adds to the growing body of literature exploring the impact of transition policies on the business cycle and on the nominal side of the economy with implications for the communication, implementation, and transmission of monetary policy (Annicchiarico et al. 2021; Carattini, Heutel, and Melkadze 2021; Diluiso et al. 2021; European Central Bank 2021; Network for Greening the Financial System 2021; Ferrari and Nispi Landi 2023; Nakov and Thomas 2023). Specifically, if carbon pricing only affects transiently the level of inflation, sharing the features of a negative supply-side shock, credible monetary policy authorities will generally "look through" this effect, as it shares the features of a temporary negative supply-side shock (Batten, Sowerbutts, and Tanaka 2020). But if carbon pricing schemes are also found to affect inflation volatility, those relative price shocks could further complicate the conduct of monetary policy, as the central bank's signal-extraction problem becomes more challenging. Moreover, if indeed, as suggested by previous research, inflation volatility may affect the level of inflation (Cukierman and Meltzer 1986) and increase the pass-through of supply shocks to consumer prices (Arndt and Enders 2024), central banks may have to recalibrate their policies to consider those additional (upward) pressures. Finally, our results contribute to the ongoing debate on the choice of the optimal carbon pricing instrument (Parry, Black, and Zhunussova 2022; Nakov and Thomas 2023) by shedding light on novel side effects associated with ETS initiatives compared to carbon taxes.

The rest of the paper is structured as follows. Section 2 reviews the literature. Section 3 explains the constructed database, including its descriptive statistics. Section 4 deals with the empirical model and the econometric approach considered. The results are discussed in Section 5 and, finally, Section 6 concludes.

2. Literature Review

Despite the increasing presence of carbon pricing schemes in the last decades, the literature on their economic impact has remained relatively scarce, and mostly centered on ex ante (model-based) evaluations. That is the case of an expanding body of research on the impact of transition policies on the business cycle, with significant contributions from scholars such as Annicchiarico et al. (2021), Carattini, Heutel, and Melkadze (2021), or Diluiso et al. (2021). Regarding the ex post economic impact of carbon pricing, a growing body of research has recently addressed the study of their effects on economic growth (Metcalf and Stock 2023), industrial and business performance, competitiveness and innovation (Martin et al. 2014; Martin, Muûls, and Wagner 2016; Venmans, Ellis, and Nachtigall 2020; Shapiro and Metcalf 2021), employment (Martin et al. 2014; Yamazaki 2017), international trade (Mundaca, Strand, and Young 2021), and inequality of income distribution (Elkins and Baker 2001; Känzig 2023).

With respect to inflation, in recent years the field has gained some momentum. In 2014, McKibbin, Morris, and Wilcoxen (2014) derived model-based evaluations of the introduction of a carbon tax in the U.S., pointing to sizable positive and temporary effects on inflation. Some recent work has also looked at inflationary effects of carbon pricing using New Keynesian frameworks (see, for example, Annicchiarico and Di Dio 2017; Economides and Xepapadeas 2018; Del Negro, di Giovanni, and Dogra 2023), generally finding that transition policies may induce temporary effects on inflation. The effects of carbon taxes on inflation volatility have also been addressed by means of environmental DSGE models, suggesting that disorderly scenarios in which climate policies are delayed may generate an increase in inflation volatility (Diluiso et al. 2021).

Regarding ex post analysis of the impacts on inflation, a recent study by Konradt and Weder di Mauro (2021) concludes that carbon taxes in Europe and Canada have not been inflationary, and they may even have been deflationary. They stress that the observed inflationary pressures seem restricted to the headline component and do not affect core inflation, which can be attributed to the fact that carbon taxes alter relative prices—by increasing the price of energy—but do not necessarily lead to increases in the price of the broader basket of goods and services. Focusing on the euro area, McKibbin, Konradt, and Weder di Mauro (2021) further explore this relationship, finding a positive effect of carbon taxes on inflation, particularly in the first years following the introduction of the carbon tax. The effect is nevertheless found to fade in the medium to long term. Moreover, the impact on core inflation tends to be negative, also pointing to carbon taxes affecting inflation through the change in relative prices instead of affecting overall price levels. By exploiting high-frequency data and some institutional features of the European carbon market, Känzig (2023) also derives a positive impact of carbon pricing on energy and consumer prices. Indeed, carbon policy shocks are found to account for around one-third of the variations in energy prices in the context of the EU ETS. In a similar fashion, Moessner (2022) analyzes the effects of carbon pricing on the level of headline, food, energy, and core inflation for OECD countries, focusing not only on carbon taxes but also on the prices of ETSs. She finds that an increase in the price of ETSs is indeed inflationary but its effects are circumscribed to energy CPI inflation and fade away in two years. Surprisingly, an increase in carbon taxes is found to push up food CPI inflation only, and it shows no significant effects on the rest of components.

To date, this body of research has focused on exploring the ex post impact of carbon pricing on the level of inflation. By empirically assessing the effects of carbon pricing on inflation volatility, our paper speaks to several strands of the literature. First, we aim to contribute to the long-lived debate on prices versus quantities (Weitzman 1974) and the ongoing discussion on the choice of the optimal carbon pricing instrument (see Parry, Black, and Zhunussova 2022 for a review). Carbon pricing systems can take the form of both carbon taxes and cap-and-trade systems, with presumed differing impacts on inflation volatility. As outlined in the introduction, carbon taxes tend to deliver relatively stable carbon prices, while ETSs have been found to lead to substantial carbon price volatility (Goulder and Schein 2013; Metcalf 2021). Higher volatility of carbon prices could be transmitted to producer and consumer prices—especially of those goods and services related to those sectors under the coverage of carbon pricing—and thus increase inflation volatility.[6] Second, we contribute to the existing literature on the impact of transition policies on the business cycle (Annicchiarico et al. 2021; Carattini, Heutel, and Melkadze 2021; Diluiso et al. 2021). Our work adds to this discussion by identifying another potential source of macroeconomic volatility. Finally, our paper is connected to the emerging body of research on how climate change and mitigation policies might influence central banks' operations and the ability of monetary policy to pursue price stability. Noteworthy contributions in this area include those by Carattini, Heutel, and Melkadze (2021); Diluiso et al. (2021); Ferrari and Nispi Landi (2023); Kaldorf and Giovanardi (2023); and Nakov and Thomas (2023).

3. Data

Our sample starts in 2000, after the introduction of the euro[7] and just before the accession of China to the World Trade Organization,[8] two major events affecting the inflation process in advanced economies. We focus our analysis on OECD countries, as inflation in advanced economies has behaved differently than in emerging market economies (Blanchard, Cerutti, and Summers 2015; Ha, Kose, and Ohnsorge 2019). This results in an unbalanced panel of 36 countries for the period 2000–20.

[6] Nevertheless, it should also be noted that the introduction of carbon price initiatives could also reduce the weight of fossil fuels in the CPI consumption basket (Andersson 2019), which has historically been a source of volatility of inflation.

[7] That is because a substantial proportion of OECD countries are part of the euro area. The creation of the European Monetary Union in 1999 led to structural changes in monetary policy and inflation patterns in those countries (Bowdler and Malik 2005; Balatti 2020).

[8] China's accession to World Trade Organization in 2001 is often seen a milestone in globalization. The globalization of inflation hypothesis argues that the factors influencing inflation dynamics are becoming increasingly global (Forbes 2019).

Our dependent variable for inflation volatility is constructed from CPI data for headline, core, and energy inflation, which are retrieved from the OECD Data Portal with monthly frequency. Inflation volatility for these three indices is computed as the standard deviation of year-on-year inflation for each country in windows of 24 months.[9] Also, as a robustness test, in order to avoid unduly overweighting extreme data points, following a common approach in the literature, inflation volatility is computed as the log of one plus the standard deviation of inflation (Bowdler and Malik 2017).[10] There is also evidence that carbon pricing leads to differing impacts according to the component of inflation considered, i.e., headline, energy, or core inflation (McKibbin, Konradt, and Weder di Mauro 2021; Moessner 2022; Känzig 2023; Konradt and Weder di Mauro 2023), which could translate to differential impacts on the volatility of that inflation. Therefore, we compute these measures for headline, energy, and core inflation separately.

Information on carbon pricing comes from the Carbon Pricing Dashboard, a comprehensive database with global geographical coverage elaborated by the World Bank, that includes data on either national, subnational, and supranational carbon pricing initiatives.[11] By processing the information contained in the database, we build some variables of interest for this work. First, the economic impact of carbon pricing has proved to depend on the level of coverage of the initiatives, on the basis that the pass-through to consumer prices is expected to be higher if the initiative covers a greater proportion of emissions within its jurisdiction (Metcalf and Stock 2023). The effect of carbon pricing on inflation should also depend on the price of the initiative (Konradt and Weder di Mauro 2021, 2023; Metcalf and Stock 2023). Therefore, following Konradt and Weder di Mauro (2023) and Metcalf and Stock (2023), we compute the real effective

[9]The choice of the frequency was motivated by the need to compute inflation volatility relying on a sufficient number of observations. However, it should be noted that it led to the exclusion of Australia and New Zealand, for which only quarterly data are available. Figure A.1 in Appendix A depicts the evolution of this measure of inflation volatility.

[10]This allows to downweight very large readings of inflation that may occur during hyperinflation episodes as well as inflation records close to zero.

[11]See https://carbonpricingdashboard.worldbank.org.

carbon price in each jurisdiction for each year (*Price*), weighting the carbon price of each initiative within the same country by the share of emissions covered by each initiative.[12]

Additionally, the effects of carbon pricing systems on inflation may depend on some other factors, which we control for. Carbon pricing initiatives may coexist with more stringent environmental norms, which may impose some implicit abatement costs alongside the explicit price for carbon. The role of those other climate change mitigation policies is captured from the OECD's Environmental Stringency Index,[13] which aims to measure environmental policy stringency internationally over a relatively long time horizon. Finally, to consider the possibility of a structural change after the surge in environmental policies following the Paris Agreement in 2015, we create an additional dummy variable (*Post-2015*). Additional potential mechanisms through which carbon pricing may affect inflation are explored in Section 5.3.

Regarding control variables, the literature has identified a number of domestic and global factors that affect inflation volatility. First, with respect to domestic factors, the size of the country and its level of development are usually considered as drivers of inflation volatility (Lane 1997; Neely and Rapach 2011; Parker 2018). In addition, the domestic level of CPI inflation has also been identified as a factor affecting its volatility (Bleaney and Fielding 2002). Second, some domestic factors related to the sensitivity of the economy to external conditions are also commonly associated with inflation volatility. For example, trade, its role as commodity exporter, or the de iure and de facto capital account liberalization of each economy are all related to the reaction of domestic prices to swings in external economic conditions (Romer 1993; Lane 1997; Aghion, Bacchetta, and Banerjee 2004; Bowdler and Malik 2017). Third, a strand of the literature has found that inflation dynamics are increasingly explained by global factors, and particularly international commodity prices, rather than by domestic conditions (Fernández,

[12]Emissions not covered by any initiative are supposed to have a price of zero; therefore, the variable *Price* could be understood as a sort of real effective price of CO_2 in each country. Carbon prices are deflated by the national CPI and expressed in 2018 dollar terms.

[13]The correlation between having carbon pricing initiatives and environmental stringency is indeed not as high as could be expected, yielding a value of 0.56.

Schmitt-Grohé, and Uribe 2017; Parker 2018; Kamber and Wong 2020).

In order to account for those factors, we gathered information from different sources. Population, GDP per capita, and trade openness are directly drawn from the World Bank's World Development Indicators. Our proxy for capital flows and financial openness is built as the sum of the absolute value of inflows and outflows as a percentage of each country's GDP based on the International Monetary Fund's International Financial Statistics data. Using data on merchandise exports from the World Bank, a country is considered a primary exporter if exports of food, fuels, ores, and metals constitute more than 20 percent of total merchandise exports. Following Fernández, Schmitt-Grohé, and Uribe (2017) and Kamber and Wong (2020), real commodity prices are accounted for through the growth rate in Agricultural, Metal and Minerals, and Energy Commodity Price Indices, deflated by the U.S. CPI, obtained from the World Bank Pink Sheet on commodity prices.

Table 1 shows the main descriptive statistics of our annual panel for all relevant variables.

With respect to carbon pricing, Figure 1A shows that the number of initiatives implemented in OECD countries has grown sharply in the last decades, going from only 7 initiatives in 2000 to 45 initiatives in 2020. Coverage has also risen steadily. While in 2000 existing OECD initiatives covered together only 0.45 percent of global emissions, by 2020 the coverage of global emissions from OECD carbon pricing initiatives reached 11 percent. As shown in Figure 1B, on a global scale, the evolution of the number of initiatives and coverage followed a similar pattern during the period, with 58 initiatives already implemented worldwide by 2020 and a global coverage of 15 percent of emissions. It is also worth noting that OECD countries involve a substantial proportion of all initiatives implemented globally; by considering OECD countries, we are accounting for 78 percent of initiatives and 73 percent of total emissions covered by those initiatives.

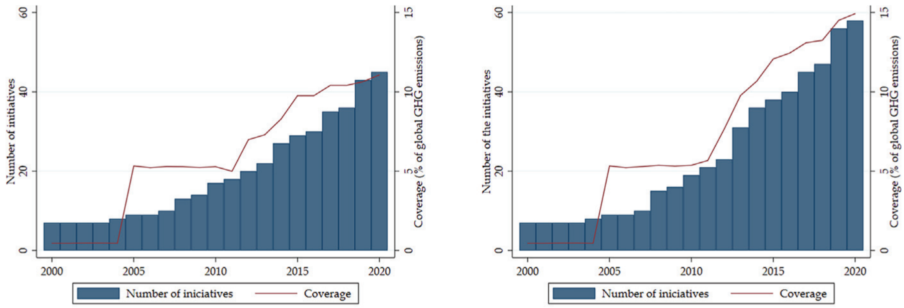
Figure 2 further depicts a timeline of the introduction of carbon pricing in OECD countries for the period 2000–20. As can be observed, our sample shows substantial variability both in geographical terms and across time, with initiatives of different types—ETSs and carbon taxes—implemented in a number of countries and at

Table 1. Descriptive Statistics

		N	Mean	SD	Min.	Max.
Inflation Volatility	Headline Infl. Standard Deviation (Percentage Points)	756	0.981	1.173	0.159	15.40
	Energy Infl. Standard Deviation (Percentage Points)	756	5.331	3.765	0.709	38.70
	Core Infl. Standard Deviation (Percentage Points)	756	0.741	1.023	0.104	12.91
Carbon Pricing	Real Price (2018 US$/t$CO_2$e)	756	4.641	10.15	0	89.07
	Real Price (ETS) (2018 US$/t$CO_2$e)	756	4.086	5.366	0	20.33
	Real Price (Carbon Tax) (2018 US$/t$CO_2$e)	756	4.067	12.88	0	103.3
	Environmental Stringency, 0 (Not Stringent) to 6 (Highest Degree)	672	2.516	1.009	0	4.890
	Post-2015, Dummy	756	0.238	0.426	0	1
Control Variables	GDP per capita (in Thousands)	756	39.94	18.24	9.047	113.8
	Population (in Millions)	756	35.07	56.45	0.281	329.5
	Trade Openness (% of GDP)	754	96.06	57.54	19.80	408.4
	Primary Exporter (Dummy)	756	0.431	0.496	0	1
	Capital Flows (% of GDP)	718	88.04	365.9	2.670	3,607
	Commodity Prices: Energy Inflation (%)	756	6.596	25.49	–45.13	58.32
	Commodity Prices: Agriculture Inflation (%)	756	1.190	9.741	–13.82	22.98
	Commodity Prices: Metals and Minerals Infl. (%)	756	4.962	19.73	–22.85	48.47
	CPI Inflation (%)	756	2.699	3.910	–4.990	68.53

Note: N: number of observations; SD: standard deviation.

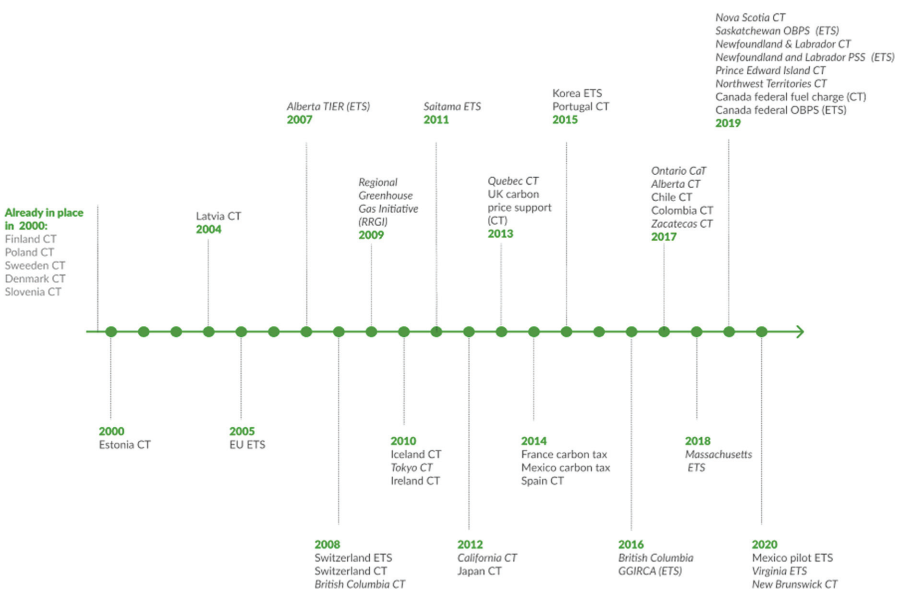
Figure 1. Number of Carbon Pricing Initiatives and Coverage



(a) OECD countries (b) World

Source: Authors' own elaboration based on World Bank Carbon Pricing Dashboard.

Figure 2. Timeline for Initiatives of Carbon Pricing in OECD Countries



Source: Authors' own elaboration based on World Bank Carbon Pricing Dashboard.

different points in time. Those initiatives are also heterogeneous in terms of their coverage and price for carbon.

4. Empirical Strategy

In our analysis, we employ a widely utilized empirical framework from the literature to assess the economic impacts of carbon taxes, which has been employed by previous studies (Konradt and Weder di Mauro 2021; Metcalf and Stock 2023). Specifically, we use panel local projections (Jordà 2005) as our central specification.[14]

To estimate the dynamic response of CPI inflation volatility at horizon h to a carbon price shock, we adapt the specifications introduced by Konradt and Weder di Mauro (2023) and Metcalf and Stock (2023):

$$\begin{aligned}\sigma(\pi)_{i,t+h} &= \Theta^h \, Carbon\,price_{i,t} + \beta^h(L)\, Carbon\,price_{i,t-1} \\ &\quad + \delta^h(L)\sigma(\pi)_{i,t-1} + \gamma^h X_{i,t-1} + \mu_i^h + \epsilon_{i,t+h}, \qquad (1)\end{aligned}$$

where $\sigma(\pi)_{i,t}$ is the standard deviation of monthly year-on-year inflation for a country i and for the year t, computed in windows of 24 months. We consider the standard deviation of headline, energy, and core inflation. $Carbon\,price_{i,t}$ is the real effective carbon price, for which we distinguish among those associated with any carbon pricing initiative, to ETSs and to carbon taxes. Θ^h can be interpreted as the effect of an unexpected change in the carbon price in year t on inflation volatility in h years, under the identifying assumption that a component of the effective carbon price is not predictable by past macroeconomic controls. $X_{i,t-1}$ includes all the relevant control variables described in Section 3.[15,16] μ_i^h are country fixed

[14]Please note that an alternative approach, utilizing panel data models, was followed in a previous working paper version of this study. For details on this alternative approach, please refer to Appendix B.

[15]In our setting, some of the controls may be contemporaneously affected by the carbon tax. For instance, commodity prices are both an outcome and a channel through which carbon prices affect inflation, and contemporaneous GDP could be affected by carbon taxes. Therefore, we include lagged control variables. However, in Section 5.4 we show that the results are robust to the inclusion of contemporaneous control variables.

[16]We do not include time fixed effects because, as noted by Känzig and Konradt (2023), when examining supranational carbon pricing initiatives such as the

effects and $\epsilon_{i,t+h}$ represents the error term. $\beta^h(L)$ and $\delta^h(L)$ represent lag polynomials, reflecting the use of the four latest lags to control for persistence of the carbon pricing and inflation volatility, respectively.

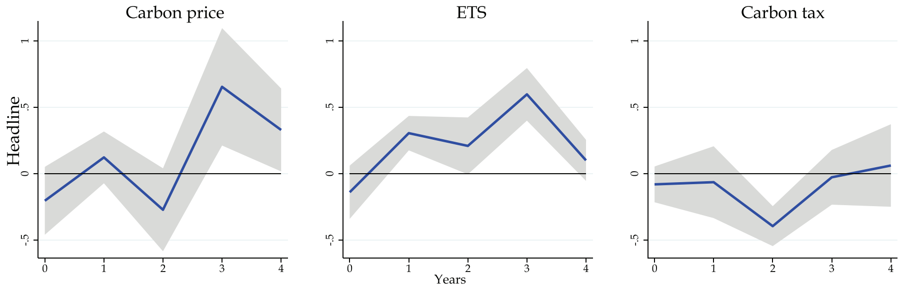
Our identification approach thus hinges on several strategies. First, as in Metcalf and Stock (2020) and Konradt and Weder di Mauro (2021, 2023), we rely on time-series identification. That is, by using an extensive set of controls, as well as past values of inflation volatility and carbon pricing, we can identify the impact of changes in carbon prices that are not predicted by past economic conditions, or unobserved historical factors that could simultaneously affect inflation volatility and carbon prices. The remaining variation can thus be assumed to be unexpected. Second, although we should not expect endogeneity issues within this framework, in Section 5.5 we test the robustness of our results to an instrumental variables (IV) approach using panel local projections IV (LP-IV) along the lines of Jordà, Schularick, and Taylor (2015), using a series of carbon policy surprises developed by Känzig (2023) as our primary instrument for carbon prices.

The impulse responses are constructed based on the fixed effects estimates of Θ^h coefficients at each horizon. As in Konradt and Weder di Mauro (2021, 2023) and Metcalf and Stock (2023), the shock consists in a one-time permanent increase in the effective carbon price by USD 40 applied to 30 percent of each economy's GHG emissions, equivalent to an increase of the effective carbon price of USD 12.[17] The reported 95 percent confidence bands are based on

European carbon market, it becomes impractical to include time fixed effects. This is because the policy variation of interest primarily occurs at the supranational level, and including time fixed effects would absorb the majority of this relevant variation. Moreover, time fixed effects are collinear with some of the control variables, namely, the ones related to global factors: energy commodity prices inflation, agriculture commodity prices inflation, and metals and minerals commodity prices inflation. Nevertheless, a robustness test to the inclusion of time fixed effects is included in Section 5.4.

[17]As we mentioned, the effect of carbon pricing systems on inflation volatility may depend on the amount of GHG emissions covered by carbon pricing initiatives in each country and the carbon price paid in this jurisdiction.

Figure 3. Impulse Responses of Headline Inflation Volatility to Shocks in Carbon Prices



Note: The solid blue lines describe the dynamic impulse responses to an increase in the effective carbon price by USD 40 with 30 percent emission coverage. The gray area delimits 95 percent confidence bands. All responses are estimated by local projections including country fixed effects and controlling for GDP per capita; population; trade openness; primary exporter; capital flows; commodity prices: energy inflation, agriculture inflation, and metals and minerals inflation; and CPI inflation. Standard errors are heteroskedasticity robust and clustered by country.

the respective estimated standard errors clustered by country and are heteroskedasticity robust.

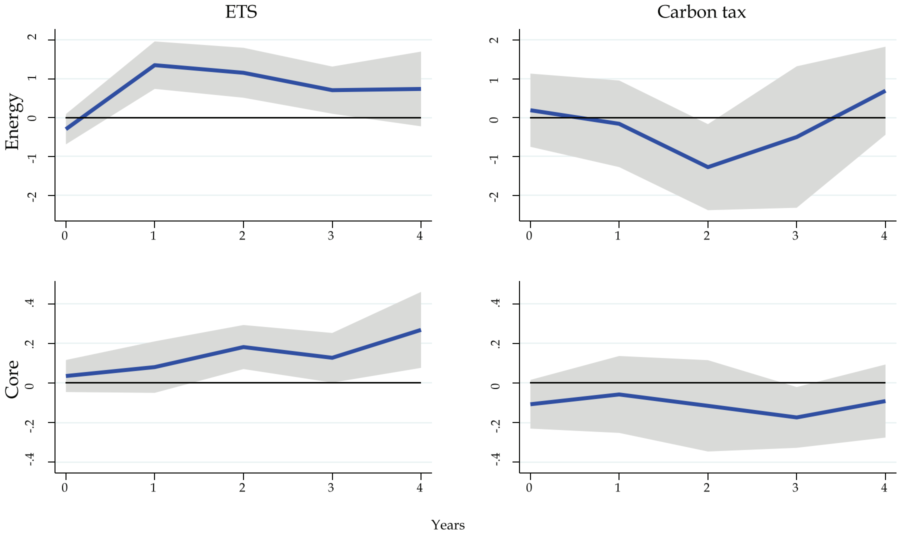
5. The Impact of Carbon Pricing on Inflation Volatility

5.1 Baseline Results

Our baseline results presented in Figure 3 depict, respectively, the effects of a rise in effective carbon prices on headline inflation volatility without further differentiating by types (left-hand-side chart), and considering the ETS and carbon tax types separately (center and right-hand-side charts).

Overall, a preliminary analysis suggests that the presence of a carbon pricing system is associated with increased inflation volatility, although the pattern is not entirely clear. However, when differentiating between ETS schemes and carbon taxes, distinct patterns emerge. An increase in ETS effective prices is linked to a rise in the volatility of headline inflation, whereas carbon tax rates do not have a significant impact and are only found to marginally reduce volatility in one of the years.

Figure 4. Impulse Responses of Energy and Core Inflation Volatility to Shocks in ETS Prices and Carbon Tax Rates



Note: The solid blue lines describe the dynamic impulse responses to an increase in the effective carbon price by USD 40 with 30 percent emission coverage. The gray area delimits 95 percent confidence bands. All responses are estimated by local projections including country fixed effects and controlling for GDP per capita; population; trade openness; primary exporter; capital flows; commodity prices: energy inflation, agriculture inflation, and metals and minerals inflation; and CPI inflation. Standard errors are heteroskedasticity robust and clustered by country.

5.2 *Channels: Effects on the Volatility of Energy and Core Inflation*

In a second step, we investigate the channels by which carbon pricing systems affect inflation volatility, analyzing the differential impact on the energy CPI component and the degree of pass-through to the volatility of core inflation. For this purpose, in Figure 4 the dependent variables are energy and core inflation volatility, respectively, and the effects of ETSs and carbon taxes are considered separately. Control variables from the baseline specification are also included.

The estimates reveal that only schemes of the ETS type push up the volatility of the energy and core components of inflation, while overall such impact is not found in the case of carbon taxes.[18] ETS schemes show a significant impact on inflation volatility for the case of the energy component, which should be expected given that energy-related goods are the ones that are targeted directly or indirectly by carbon pricing initiatives. The volatility of core inflation is found to be affected with some delay, after two years, in those jurisdictions with ETSs, which suggests lagged indirect effects of ETS schemes on core inflation volatility.

These results align with prior research indicating that the implementation of carbon pricing schemes affects inflation primarily through the energy component (Konradt and Weder di Mauro 2021; McKibbin, Konradt, and Weder di Mauro 2021; Moessner 2022). It is also in line with evidence on the indirect effects of other cost-push shocks, such as rising energy prices, which may lead to increased production costs and subsequent pass-through to consumer prices. In fact, Kilian and Zhou (2023) found that energy price shocks affect overall U.S. inflation through the energy component of the consumer basket, but also exhibit effects on core inflation. For the euro area, López, Párraga Rodríguez, and Santabárbara (2022) and Adolfsen et al. (2024) show a significant transmission of gas prices (due to their role in electricity pricing) to all inflation components, including core inflation, albeit with some lag.

5.3 Mechanisms: Sectoral Coverage, Production Structure, Volatility of ETSs, and ETS Free Allowances

In this section, we investigate potential mechanisms driving the effects of carbon pricing on inflation volatility, such as the sectoral coverage of carbon pricing initiatives, the differences in countries' production structure, the volatility of ETS prices, or the amount of ETS pollution rights allocated freely. These factors collectively

[18] In fact, carbon taxes not only fail to increase inflation volatility, but they are actually found to slightly reduce it for one of the years. This reduction can be attributed to two main factors. Firstly, the implementation of carbon pricing can lead to a reduction in the relative weight of fossil fuels in the CPI consumption basket, historically a significant source of inflation volatility (Andersson 2019). Secondly, an increase in the carbon tax implies a larger share of the fixed component of the energy price, potentially mitigating the volatility of energy consumer prices in response to fluctuations in energy input prices.

contribute to explaining the diverse effects observed in carbon pricing initiatives. To capture these effects, we adapt the local projection baseline specification by including an interaction term that considers each of these mentioned mechanisms.

$$\begin{aligned}\sigma(\pi)_{i,t+h} = {} & \Theta^h \, Carbon\ price_{i,t} + \alpha^h \, Carbon\ price_{i,t} \\ & \times mechanism_{i,t} + \beta^h(L) \, Carbon\ price_{i,t-1} \\ & + \delta^h(L)\sigma(\pi)_{i,t-1} + \gamma^h X_{i,t-1} + \mu_i^h + \epsilon_{i,t+h},\end{aligned} \tag{2}$$

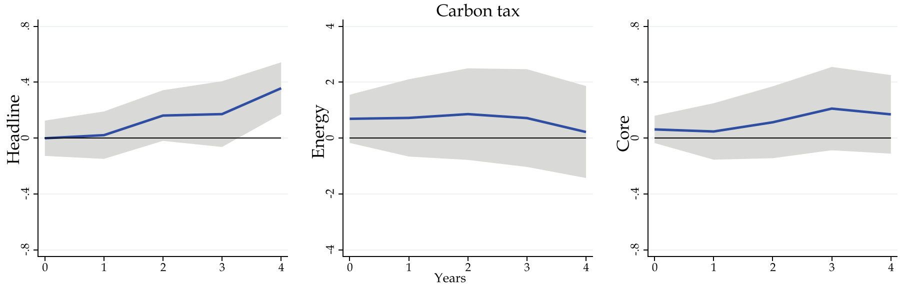
where α^h captures the differential impact of carbon prices according to the mechanism considered. As in Känzig and Konradt (2023), variables that capture these mechanisms are standardized so coefficients can be interpreted as the impact of changes corresponding to one standard deviation compared to the average country.

5.3.1 Carbon Pricing Sectoral Coverage

The finding that ETS schemes are associated with larger inflation volatility could potentially stem from two plausible explanations. Firstly, a contributing factor could be the divergent coverage of cap-and-trade systems and carbon taxes. For instance, electricity producers tend to be encompassed within ETSs, while in the case of taxes, they more frequently exclude the electricity generation sector. These distinct coverage scopes may influence the impact on inflation volatility. Second, ETS prices, being market driven, inherently display higher levels of volatility compared to carbon taxes, which are set at less frequent intervals. This increased volatility in cap-and-trade prices could potentially translate into higher overall inflation volatility. By further examining these factors, we can gain deeper insights into the mechanisms driving the differential effects of cap-and-trade schemes and carbon taxes on inflation volatility.

Starting with the divergent coverage of ETSs and carbon taxes, one potential approach to explore this hypothesis is to examine whether differences between ETS prices and carbon taxes persist when analyzing regimes with similar coverage, particularly those that include the electricity generation sector. By narrowing the focus to these specific regimes, we can gain insights into whether the observed differences in price dynamics between cap-and-trade and

Figure 5. Effects of Carbon Pricing Depending on Electricity-Sector Coverage (only national carbon taxes)



Note: Impulse responses to an increase in effective carbon taxes of USD 40 with 30 percent emission coverage interacted to a variable indicating whether electricity sector is covered by the system. The gray area delimits 95 percent confidence bands. All responses are estimated by local projections including country fixed effects and controlling for GDP per capita; population; trade openness; primary exporter; capital flows; commodity prices: energy inflation, agriculture inflation, and metals and minerals inflation; and CPI inflation. Standard errors are heteroskedasticity robust and clustered by country.

carbon taxes are primarily driven by variations in sectoral coverage. Unfortunately, all national and supranational ETSs within our sample cover the electricity sector, with the notable exception of Canada's federal ETS, which was only introduced in 2019. Therefore, we cannot compare across ETSs including and excluding the electricity sector. Nevertheless, regarding carbon taxes, our analysis incorporates a significant number of carbon taxes both with and without the inclusion of the electricity sector (see Table A.4), which allows us to test this hypothesis.

As shown in Figure 5, no significant differences in volatility are encountered for carbon taxes that include and exclude the electricity sector. This supports the hypothesis that the coverage of the electricity sector may not be the primary driver of the observed disparities in inflation volatility between ETSs and carbon taxes.

5.3.2 Volatility in ETS Prices

In a subsequent step, we extend our analysis to investigate the implications of their differing level of carbon price volatility in the cap-and-trade regimes, as discussed earlier. This approach allows us to gain a deeper understanding of the role of differences in carbon price volatility as a mechanism driving the divergent impact of ETSs and carbon taxes on inflation volatility. To accomplish this, we obtained the price for the major national and supranational cap-and-trade regimes included in our sample and calculated their respective volatility.[19]

The results indicate that headline inflation, energy inflation, and core inflation exhibit higher levels of volatility in response to increased volatility in ETS prices (see Figure 6).[20] That is, ETS schemes tend to have a more significant impact on inflation volatility across components, as their prices are indeed more volatile. These findings therefore provide suggestive evidence that carbon price volatility may be a key mechanism driving the observed effects, and that the inherent volatility within the cap-and-trade framework plays a crucial role in shaping the relationship between carbon pricing and inflation.

5.3.3 Specialization in High-Polluting Sectors

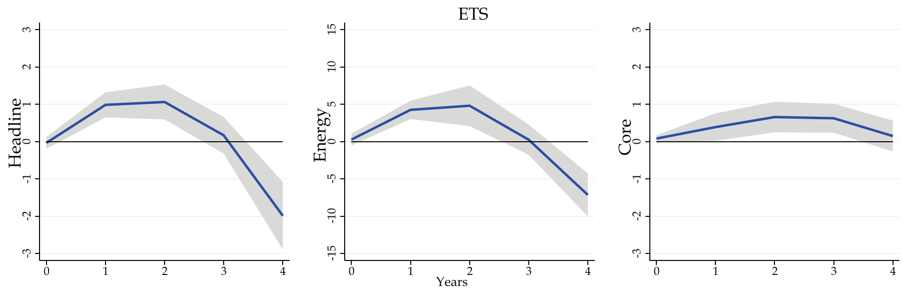
The impact of carbon pricing can also vary depending on a country's productive structure. A given shock is expected to have a more intense effect on inflation depending on the country specialization in high-polluting industries and sectors, which we measure by the share of value-added in each economy generated by the top 20 percent most polluting sectors worldwide using OECD data.

As shown in Figure 7, both ETS and carbon tax shocks indeed appear to have a comparatively higher impact when a larger share of value-added can be attributed to high-polluting sectors, with the effect primarily observed in the energy CPI volatility.

[19]Those include the EU ETS, as well as the Switzerland, Mexico, and Korea ETSs. We compute the coefficient of variation to build a measure of volatility comparable across ETS regimes. The ETS prices used in the analysis are sourced from the International Carbon Action Partnership.

[20]However, it is important to note that an exception arises in the fourth year. This deviation may be attributed to enhanced incentives within more volatile regimes to replace fossil fuels as a means to mitigate the higher impact of carbon pricing on such regimes, which may reduce the effects on inflation volatility over the medium term.

Figure 6. Effects of ETS Price Volatility



Note: Impulse responses to an increase in effective ETS prices of USD 40 with 30 percent emission coverage interacted to the volatility of carbon price within ETS regimes. The gray area delimits 95 percent confidence bands. All responses are estimated by local projections including country fixed effects and controlling for GDP per capita; population; trade openness; primary exporter; capital flows; commodity prices: energy inflation, agriculture inflation, and metals and minerals inflation; and CPI inflation. Standard errors are heteroskedasticity robust and clustered by country. The ETS prices used in the analysis are sourced from the International Carbon Action Partnership. Volatility is measured using the coefficient of variation due to the substantial dispersion of prices within the included regimes.

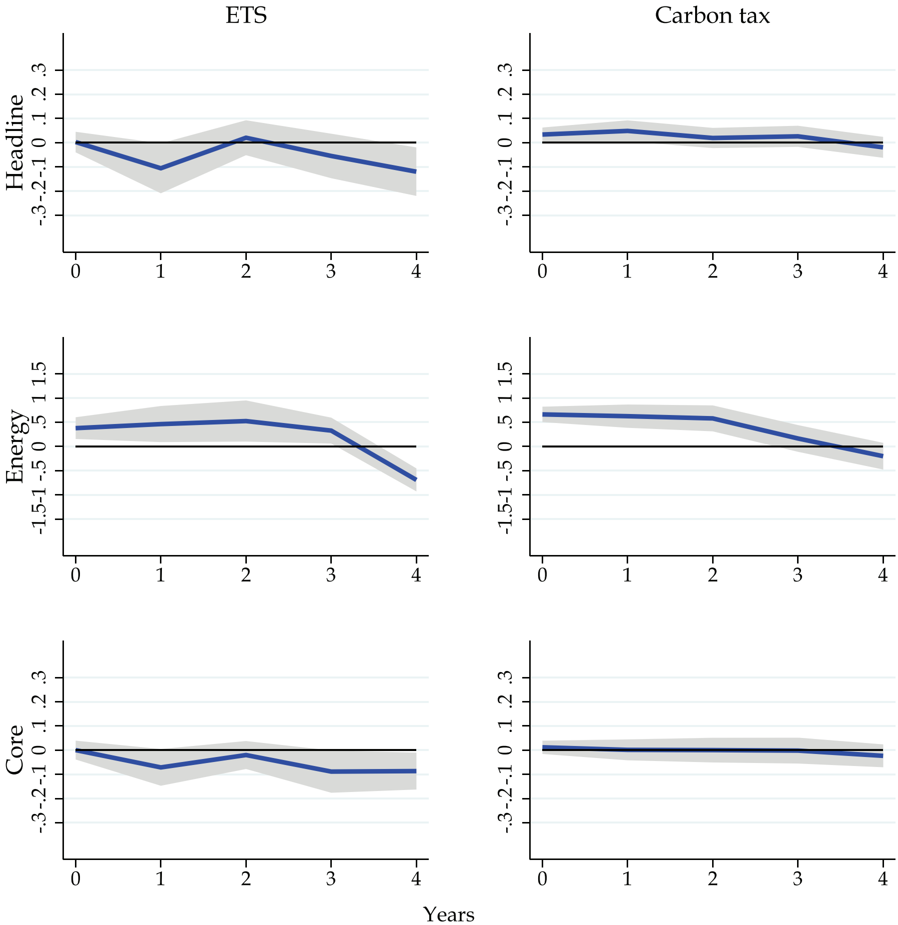
5.3.4 ETS Free Allowances

Finally, another potential avenue to explore the mechanisms behind the effects of carbon pricing on inflation volatility is the allocation of free allowances within cap-and-trade schemes, which has shown substantial variation across EU countries and time. We focus our analysis on the EU ETS, for which we have available data.[21]

The allocation of free allowances has been seen as a strategic policy choice aimed at addressing concerns such as potential loss of competitiveness and carbon leakage. By providing free allowances to certain industries or sectors, policymakers aimed at alleviating the immediate burden of carbon pricing on these entities. This allocation mechanism effectively reduces the costs they would otherwise incur from purchasing allowances, thereby lowering the effective carbon price they bear.

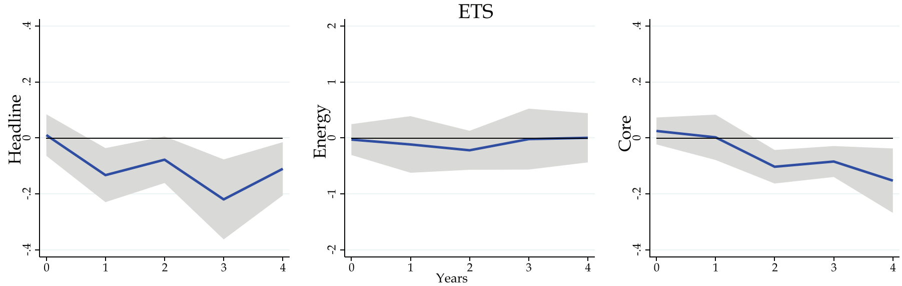
[21] Data on free allowances are taken from the EU Transaction Log, being available from 2005, the year of the establishment of the EU ETS.

Figure 7. Effects of Carbon Pricing by Value-Added Generated by Polluting Sectors



Note: Impulse responses to an increase in effective carbon prices of USD 40 with 30 percent emission coverage interacted to the value-added generated by polluting sectors. The gray area delimits 95 percent confidence bands. All responses are estimated by local projections including country fixed effects and controlling for GDP per capita; population; trade openness; primary exporter; capital flows; commodity prices: energy inflation, agriculture inflation, and metals and minerals inflation; and CPI inflation. Standard errors are heteroskedasticity robust and clustered by country.

Figure 8. Effects of Carbon Pricing by Share of Free Allowances in the EU ETS Market



Note: Impulse responses to an increase in effective EU ETS prices of USD 40 with 30 percent emission coverage interacted to the share of free allowances. The gray area delimits 95 percent confidence bands. Standard errors are heteroskedasticity robust and clustered by country. Data on free allowances sourced from EU Transaction Log.

Interestingly, our findings show that a higher share of free allowances is associated with lower effects of ETS prices on inflation volatility, with the exception of the energy component, where no significant effect was found (see Figure 8). This supports the hypothesis that higher allocation of free allowances may help prevent price volatility. This outcome is not surprising when considering the historical functioning of the EU ETS. At the start of the current trading period, manufacturing industries received 80 percent of their allowances for free, while the electricity sector—the one directly related to the energy component—has not received any free allowances since 2013.[22]

5.4 Robustness Tests

Finally, in this section we present further evidence of our results being robust to the use of different specifications, subsamples, and additional controls.

[22]See https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/free-allocation_en#documentation for more detailed information on the functioning of the allocation of free allowances across industries and sectors.

First, as described in Section 3, we could expect that the existence of a structural break after the renewed surge in environmental policies following the Paris Agreement in 2015 could be driving the results. Tables A.1 and A.2 in Appendix A show results restricting the sample to the years before the Paris Agreement, finding no evidence of those affecting the results. Also, our findings prove robust to the inclusion of the OECD index of environmental stringency, in an attempt to control for the fact that our variables of carbon pricing could be capturing the effects of changes in each country's environmental stringency not necessarily related (see again Tables A.1 and A.2 in Appendix A). Second, we add a specification in which time dummies are included, at the expense of removing those variables collinear with them, showing that main results hold under this alternative modeling choice (Tables A.1 and A.2 in Appendix A). Third, we test our specification against the use of the log of one plus the standard deviation of inflation, as described in Section 3. As shown in Figure A.2 in Appendix A, our main results are robust. Fourth, we show that the results are robust to the inclusion of contemporaneous (instead of lagged) control variables (see Figure A.3).

5.5 IV Approach: Local Projections IV

While carbon pricing should not be expected subject to endogeneity in our baseline empirical framework, this section examines the robustness of our findings to an IV approach.

For that purpose, we employ panel local projections IV (LP-IV) along the lines of Jordà, Schularick, and Taylor (2015). Dynamic causal effects are estimated from the same set of equations as in (2), where $Carbon\,price_{i,t}$ is the possible endogenous regressor and z_t acts as an instrument for $Carbon\,price_{i,t}$. As in the baseline specification, we also include all relevant lagged controls, four lags of carbon pricing and inflation volatility, and country fixed effects. Errors are heteroskedasticity robust and clustered by country.

5.5.1 Instrumental Variable: Carbon Policy Surprises

As our primary instrument, we rely on a set of EU ETS carbon policy surprises developed by Känzig (2023). However, this approach requires us to reduce our sample to the countries covered by the EU

ETS. This study builds upon the existing body of literature on high-frequency identification techniques, which identify policy surprises by analyzing the movements of asset prices following significant policy events. While commonly applied in the context of monetary policy (Kuttner 2001; Gürkaynak, Sack, and Swanson 2005; Gertler and Karadi 2015; Nakamura and Steinsson 2018) or global oil markets (Känzig 2021), Känzig (2023) adapts this approach to the domain of carbon pricing by applying it specifically to the EU ETS market.

To construct a series of carbon policy surprises, Känzig (2023) compiles a comprehensive list of regulatory events related to changes in the supply of emission allowances within the EU ETS.[23] This list encompasses various events related to, among others, decisions made by the European Commission, votes conducted by the European Parliament, and judgments rendered by European courts. In total, 126 such events are identified, covering the period from 2005 to 2019. Carbon policy surprises are then computed as the change in the EU emission allowances' futures prices on the day of the regulatory event compared to the last trading day before the event, in percentage terms or measured relative to the prevailing wholesale electricity price on the day before. The monthly series is constructed by aggregating the daily surprises, adding them up over each month. In cases where no regulatory events take place during a particular month, the series is assigned a value of 0. Yearly series are constructed by adding up monthly series.

$$CPSurprise_{t,d} = \frac{F_{carbon,t,d} - F_{carbon,t,d-1}}{F_{carbon,t,d-1}} \cdot 100 \qquad (3)$$

We take the monthly surprises in percentage of ETS prices and aggregate them yearly to match our specification.

As highlighted by Stock and Watson (2018), variables based on high-frequency surprises such as the ones we use in this section are susceptible to measurement error, since they may not capture all relevant events. While they may still serve as valid external instruments, employing them directly can yield biased estimates of the

[23]That allows us to address concerns that the events are capturing other information pertaining economic activity or broader factors affecting the demand of emission allowances.

Table 2. First-Stage Regressions of ETS Effective Carbon Price on the Instrument

	(1) Headline	(2) Energy	(3) Core
Carbon Policy Surprises	0.27***	0.24***	0.26***
	(0.01)	(0.01)	(0.01)
F-statistic	2576.45***	2331***	3033***
Observations	586	585	584

Note: *p < 0.10, **p < 0.05, ***p < 0.01. First-stage regressions include country fixed effects and controls for GDP per capita; population; trade openness; primary exporter; capital flows; commodity prices: energy inflation, agriculture inflation, and metals and minerals inflation; and CPI Inflation—as well as four lags of inflation volatility (headline, energy, or core depending on the equation) and effective ETS carbon prices. Country-cluster robust standard errors are reported in parentheses.

dynamic causal effects. Thus, we use them as instruments using LP-IV rather than as a direct measure of the specific shock of interest. Unfortunately, carbon policy surprises are only provided for the EU ETS market, so we will only provide LP-IV results pertaining to shocks in ETS prices.

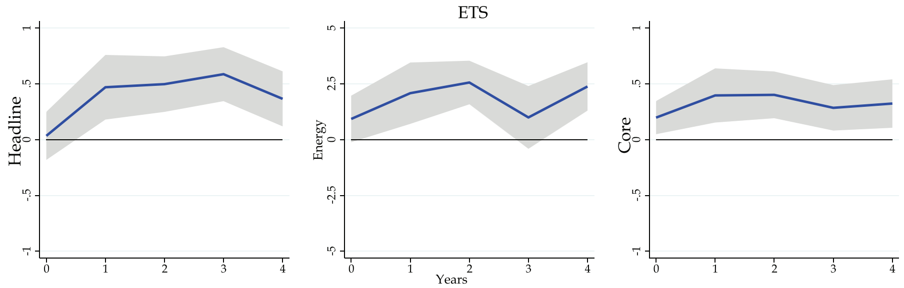
5.5.2 Results of LP-IV

Table 2 presents the results of first-stage IV regressions. As expected, carbon policy surprises are positive and significantly correlated with carbon prices. High values for the F-statistic provide additional evidence of the significance of the instrument in the first-stage regression at the 1 percent level. The instrument's relevance is further confirmed by the Kleibergen and Paap (2006) tests of weak instruments, which are reported in Table A.3 in Appendix A for each variable and horizon.

Exogeneity conditions[24] cannot directly be tested in our framework. Nevertheless, the high-frequency identification strategy should be able to isolate the exogenous component of ETS carbon price shocks. Also, as discussed in Känzig (2023), the series of surprises

[24]In an LP-IV framework, both contemporaneous and lead-lag exogeneity must hold for validity.

Figure 9. LP-IV Impulse Responses of Headline, Energy, and Core Inflation Volatility to Shocks in ETS Prices



Note: Impulse responses to an increase in effective ETS prices of USD 40 with 30 percent emission coverage. The gray area delimits 95 percent confidence bands. All responses are estimated by local projections IV using ETS carbon pricing surprises from Känzig (2023) as instrumental variable, and including country fixed effects and controlling for GDP per capita; population; trade openness; primary exporter; capital flows; commodity prices: energy inflation, agriculture inflation, and metals and minerals inflation; and CPI inflation. Standard errors are heteroskedasticity robust and clustered by country.

used as instruments are not autocorrelated or forecastable by past macroeconomic and financial variables or other structural shock measures such as oil demand, uncertainty, financial, fiscal, and monetary policy shocks (see Appendix B.1 in Känzig 2023). Moreover, in our setting lagged macroeconomic variables should be able to control for main past macroeconomic shocks affecting inflation volatility (Stock and Watson 2018).

Figure 9 reports LP-IV impulse responses of headline, energy, and core inflation volatilities to shocks in ETS prices. As shown, our main results seem robust to the use of an IV approach. The effects of ETS effective carbon prices on energy and headline inflation volatilities are found to be qualitatively similar and of comparable magnitude, although with somewhat smoother impulse responses. Notably, the indirect effects on core inflation volatility seem to manifest with shorter delays, becoming evident as early as the first year.

6. Conclusions

In the following years, climate change and related mitigation policies are expected to affect potential growth, business cycle, and inflation dynamics. This may reshape the formulation of economic policy, and has prompted the urge from policymakers, including central banks, to understand their economic consequences. Carbon pricing initiatives, aimed at increasing the relative prices of GHG-intensive goods and services, could not only push up inflation, but also affect inflation volatility. This paper empirically assesses the effects of carbon pricing on inflation volatility, disaggregating by the two main types of initiatives: ETSs and carbon taxes.

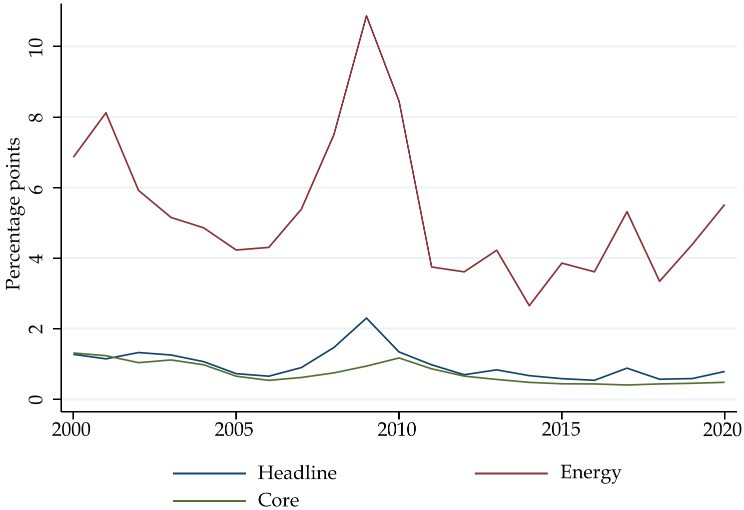
Our main findings could be summarized as follows. First, this work finds evidence of ETS schemes inducing greater volatility in consumer price inflation, while no significant impact is found in the case of carbon taxes. Second, this effect feeds through the energy component, which tends to be more closely related to carbon pricing initiatives, while it affects core inflation with some delay, suggesting lagged indirect effects of ETSs on inflation. Altogether, these results seem consistent with the fact that carbon pricing initiatives of the ETS type tend to lead to more volatile carbon prices (and carbon price inflation) than the more stable carbon taxes, and that volatility is fed into consumer prices, particularly through the energy component. It also confirms the results of previous studies that carbon pricing initiatives, by changing relative prices and increasing the price of fossil fuels, lead to a direct effect on inflation by affecting the energy component, and provide new evidence of indirect effects in the rest of goods and services included in core CPI.

Moreover, we explore several mechanisms that could drive the differences between ETSs and carbon taxes. Our findings indicate that the increased volatility observed in ETS schemes is primarily due to higher fluctuations in carbon prices, rather than to differences in the sectoral coverage compared to carbon taxes. Furthermore, we identify several factors that contribute to the heterogeneous impacts of carbon pricing initiatives across jurisdictions. For example, countries with higher weight in high-polluting sectors experience more volatile energy CPI inflation. Moreover, under the ETS, a higher share of free emission allowances allocated to each country tends to reduce inflation volatility, possibly by lowering the effective costs incurred by producers and, thus, their incentives to adjust prices. Finally, our results hold robust to the inclusion of multiple variables of control, alternative identification strategies, different empirical specifications, and subsamples of countries.

These results also have important implications for monetary policy. Given that existing literature has predominantly shown that carbon pricing initiatives tend to have a transitory impact on inflation levels, central banks with credible monetary policies typically overlook this effect, viewing it akin to a negative supply-side shock. However, the fact that ETS schemes could influence inflation volatility introduces a layer of complexity to monetary policy. As jurisdictions seek to expand both the scope and pricing of carbon mechanisms to meet the ambitious climate objectives outlined in the Paris Agreement, regions heavily reliant on ETS schemes may have to deal with heightened inflation volatility. This scenario could complicate the communication and the conduct of monetary policy, presenting central banks with a more intricate signal-extraction challenge. Furthermore, if, as suggested in prior studies (Arndt and Enders 2024), inflation volatility magnifies the transmission of supply shocks to consumer prices, central banks may find it necessary to adapt their strategies to accommodate these additional pressures. Therefore, central banks should closely monitor these effects. Finally, our results contribute to the ongoing debate on the choice of the optimal carbon pricing instrument by shedding light on novel side effects associated with ETS initiatives compared to carbon taxes.

Appendix A. Additional Figures and Tables

Figure A.1. Standard Deviation of CPI Inflation



Source: Authors' own elaboration based on OECD data.

Table A.1. LP: Robustness Tests. Impulse Responses of Headline, Energy, and Core Inflation Volatility for Shocks in Effective ETS Prices

	$h = 0$	$h = 1$	$h = 2$	$h = 3$	$h = 4$
	Headline Inflation				
Baseline Estimates	–0.14	0.30	0.21	0.60	0.10
	(0.20)	(0.13)	(0.21)	(0.20)	(0.15)
Baseline Period Pre-Paris Agreement	–0.14	0.25	0.21	0.63	0.26
	(0.25)	(0.14)	(0.20)	(0.34)	(0.26)
Baseline + OECD Stringency	–0.08	0.29	0.16	0.50	0.08
	(0.19)	(0.14)	(0.23)	(0.16)	(0.16)
Baseline + Time FE	–0.12	0.13	0.14	0.69	0.07
	(0.22)	(0.12)	(0.21)	(0.24)	(0.16)
	Energy Inflation				
Baseline Estimates	–0.30	1.35	1.15	0.71	0.74
	(0.39)	(0.61)	(0.64)	(0.61)	(0.96)
Baseline Period Pre-Paris Agreement	0.12	1.30	1.57	0.74	0.78
	(0.57)	(0.83)	(0.62)	(0.89)	(1.21)
Baseline + OECD Stringency	–0.31	1.46	1.16	0.60	0.99
	(0.45)	(0.70)	(0.71)	(0.59)	(1.06)
Baseline + Time FE	0.17	0.83	0.71	1.08	0.85
	(0.36)	(0.57)	(0.60)	(0.65)	(0.96)
	Core Inflation				
Baseline Estimates	0.04	0.08	0.18	0.13	0.27
	(0.08)	(0.13)	(0.11)	(0.13)	(0.19)
Baseline Period Pre-Paris Agreement	0.08	0.06	0.15	0.09	0.27
	(0.09)	(0.14)	(0.15)	(0.14)	(0.25)
Baseline + OECD Stringency	0.05	0.15	0.12	0.11	0.19
	(0.09)	(0.11)	(0.09)	(0.14)	(0.17)
Baseline + Time FE	0.02	0.10	0.22	0.19	0.34
	(0.08)	(0.11)	(0.14)	(0.14)	(0.19)

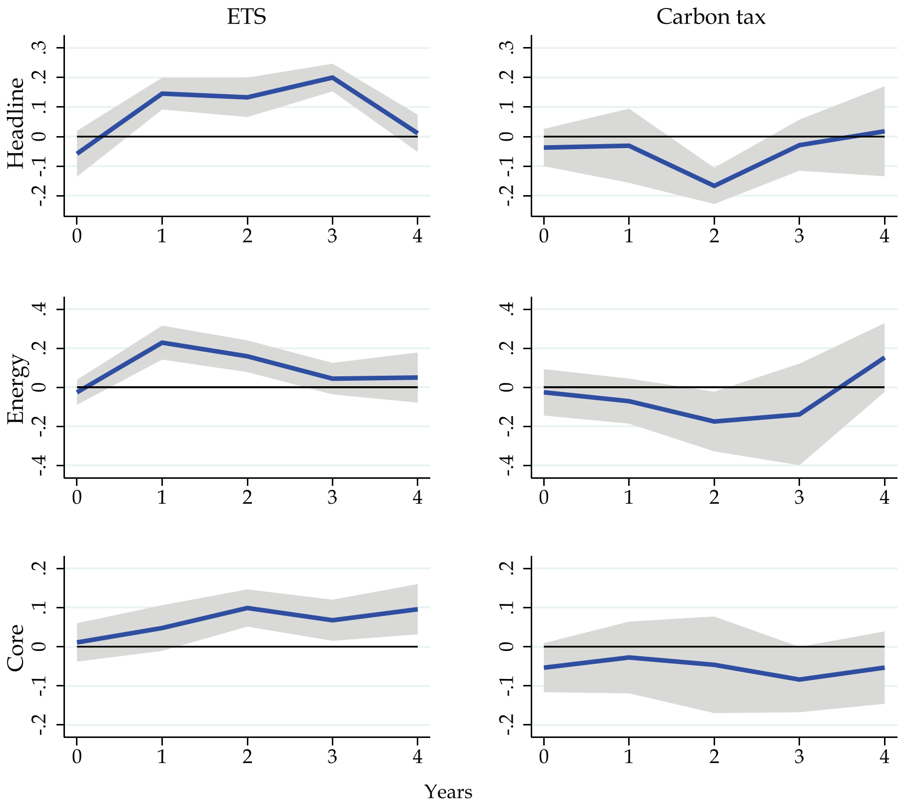
Note: Impulse responses to an increase in the effective carbon price by USD 40 with 30 percent emission coverage. Difference between point estimates and symmetric 95 percent confidence bands reported in parentheses. All responses are estimated by means of local projections. Baseline estimates include country fixed effects and controlling for GDP per capita; population; trade openness; primary exporter; capital flows; commodity prices: energy inflation, agriculture inflation, and metals and minerals inflation; and CPI inflation. When considering time fixed effects, commodity prices variables are not included. Standard errors are heteroskedasticity robust and clustered by country.

Table A.2. LP: Robustness Tests. Impulse Responses of Headline, Energy, and Core Inflation Volatility for Shocks in Effective Carbon Tax Rates

	$h = 0$	$h = 1$	$h = 2$	$h = 3$	$h = 4$
	Headline Inflation				
Baseline Estimates	–0.08	–0.06	–0.39	–0.03	0.06
	(0.13)	(0.27)	(0.15)	(0.21)	(0.31)
Baseline Period Pre-Paris Agreement	–0.07	0.12	–0.53	–0.14	–0.07
	(0.39)	(0.26)	(0.16)	(0.30)	(0.51)
Baseline + OECD Stringency	–0.08	–0.02	–0.37	–0.06	0.04
	(0.13)	(0.26)	(0.17)	(0.16)	(0.33)
Baseline + Time FE	–0.13	0.07	–0.18	–0.09	0.04
	(0.18)	(0.28)	(0.26)	(0.12)	(0.32)
	Energy Inflation				
Baseline Estimates	0.19	–0.16	–1.27	–0.50	0.69
	(0.94)	(1.11)	(1.11)	(1.82)	(1.13)
Baseline Period Pre-Paris Agreement	0.67	–0.74	–2.58	–2.22	1.07
	(1.83)	(1.28)	(1.41)	(1.69)	(1.56)
Baseline + OECD Stringency	0.26	0.06	–1.12	–0.39	0.86
	(0.90)	(1.05)	(0.94)	(1.63)	(1.04)
Baseline + Time FE	–0.04	0.22	–0.22	–0.77	0.21
	(0.77)	(1.29)	(1.80)	(2.10)	(1.56)
	Core Inflation				
Baseline Estimates	–0.11	–0.06	–0.12	–0.17	–0.09
	(0.12)	(0.19)	(0.23)	(0.15)	(0.18)
Baseline Period Pre-Paris Agreement	–0.20	–0.05	–0.14	–0.23	–0.16
	(0.23)	(0.20)	(0.19)	(0.20)	(0.24)
Baseline + OECD Stringency	–0.11	–0.07	–0.10	–0.18	–0.14
	(0.12)	(0.19)	(0.21)	(0.13)	(0.15)
Baseline + Time FE	–0.11	–0.07	–0.07	–0.12	–0.10
	(0.12)	(0.21)	(0.22)	(0.14)	(0.18)

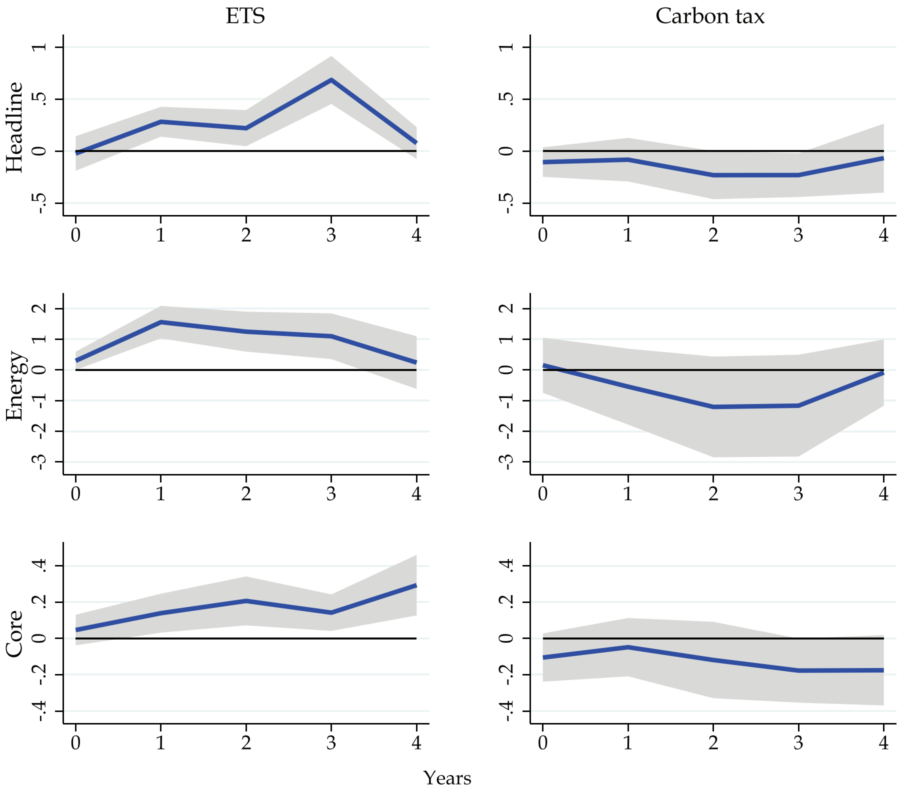
Note: Impulse responses to a USD 40 carbon tax with 30 percent emission coverage. Difference between point estimates and symmetric 95 percent confidence bands reported in parentheses. All responses are estimated by means of local projections. Baseline estimates include country fixed effects and controlling for GDP per capita; population; trade openness; primary exporter; capital flows; commodity prices: energy inflation, agriculture inflation, and metals and minerals inflation; and CPI inflation. When considering time fixed effects, commodity prices variables are not included. Standard errors are heteroskedasticity robust and clustered by country.

Figure A.2. Robustness Check: Results with Log Volatility



Note: The solid blue lines describe the dynamic impulse responses to an increase in the effective carbon price by USD 40 with 30 percent emission coverage. The gray area delimits 95 percent confidence bands. All responses are estimated by local projections including country fixed effects and controlling for GDP per capita; population; trade openness; primary exporter; capital flows; commodity prices: energy inflation, agriculture inflation, and metals and minerals inflation; and CPI inflation. Standard errors are heteroskedasticity robust and clustered by country.

Figure A.3. Robustness Check: Contemporaneous Control Variables



Note: The solid blue lines describe the dynamic impulse responses to an increase in the effective carbon price by USD 40 with 30 percent emission coverage. The gray area delimits 95 percent confidence bands. All responses are estimated by local projections including country fixed effects and controlling for contemporaneous values of GDP per capita; population; trade openness; primary exporter; capital flows; commodity prices: energy inflation, agriculture inflation, and metals and minerals inflation; and CPI inflation. Standard errors are heteroskedasticity robust and clustered by country.

Table A.3. LP-IV: Kleibergen-Paap Test for Each Horizon and Dependent Variable

	$h = 0$	$h = 1$	$h = 2$	$h = 3$	$h = 4$
	Headline Inflation				
Kleibergen and Paap p-value	27.99 (0.00)	25.93 (0.00)	25.76 (0.00)	25.48 (0.00)	25.47 (0.00)
	Energy Inflation				
Kleibergen and Paap p-value	30.38 (0.00)	28.15 (0.00)	27.74 (0.00)	27.24 (0.00)	27.57 (0.00)
	Core Inflation				
Kleibergen and Paap p-value	27.73 (0.00)	25.09 (0.00)	24.73 (0.00)	24.50 (0.00)	24.34 (0.00)

Note: The null hypothesis of the Kleibergen-Paap LM test is that the structural equation is underidentified (i.e., the rank condition fails).

Table A.4. Classification of Initiatives According to Sectoral Coverage, with Particular Regard to the Electricity Sector

National and Supranational ETSs		
System	**Includes Electricity Sector**	**Other Sectors Covered**
EU ETS	Yes	
Switzerland ETS	Yes	
Korea ETS	Yes	
Canada Federal OBPS	No	
Mexico Pilot ETS	Yes	
National Carbon Taxes		
Instrument Name	**Includes Electricity Sector**	**Other Sectors Covered**
Poland Carbon Tax		Mining and extractives, Transport, Agriculture, forestry and fishing fuel use
Norway Carbon Tax		Industry, Transport, Aviation, Buildings, Agriculture, forestry and fishing fuel use
Sweden Carbon Tax		Transport, Buildings, Agriculture, forestry and fishing fuel use
Denmark Carbon Tax	Yes	Transport, Buildings, Agriculture, forestry and fishing fuel use
Latvia Carbon Tax		
Estonia Carbon Tax	Yes	
Switzerland Carbon Tax		Industry, Buildings
Iceland Carbon Tax	Yes	Industry, Transport, Buildings, Agriculture, forestry and fishing fuel use
Japan Carbon Tax	Yes	Industry, Transport, Buildings
UK Carbon Price Support	Yes	
Mexico Carbon Tax	Yes	Industry, Aviation, Buildings
Portugal Carbon Tax	Yes	Transport, Buildings, Agriculture, forestry and fishing fuel use
Chile Carbon Tax	Yes	Industry
Colombia Carbon Tax		Industry, Transport, Aviation, Buildings, Agriculture, forestry and fishing fuel use
Canada Federal Fuel Charge		Transport, Aviation, Buildings, Agriculture, forestry and fishing fuel use

Source: Carbon Pricing Dashboard. Initiatives classified as including the electricity sector only "in principle" have been excluded from the analysis in order to ensure the accuracy and reliability of our estimations.

Appendix B. Panel Data Analysis

Empirical Specification

An alternative panel data specification can also be outlined as follows:

$$\sigma(\pi)_{i,t} = \alpha\sigma(\pi)_{i,t-1} + \beta Carbon\,pricing_{i,t} + \gamma X_{i,t-1} + \mu_i + \epsilon_{i,t}, \quad \text{(B.1)}$$

where $\sigma(\pi)_{i,t}$ is the dependent variable measured, for a country i and for each year t, as the standard deviation of monthly year-on-year inflation computed in windows of 24 months.

$Carbon\,pricing_{i,t}$ includes the set of variables that depict the existence and different features of carbon pricing systems, representing our variables of interest. *Carbon pricing, any* is a dummy variable that takes value 1 if the country has any type—national, subnational, or regional—of carbon pricing implemented for a given year, while *ETS, any* and *Carbon tax, any* reflect whether the country has implemented any type of ETS or carbon tax, respectively. *Coverage-fully overlapping* and *Coverage-not overlapping* measure the amount of GHG emissions covered by the initiatives in that country. $X_{i,t-1}$ includes the lag of the relevant controls described in Section 3. Finally, μ_i is a country-level time-invariant effect that reflects individual heterogeneity, and $\epsilon_{i,t}$ represents an idiosyncratic disturbance that is expected to be independent and identically distributed. β and γ are the coefficients associated with interest and control variables, respectively.

However, if the lag of the dependent variable is not significant the above econometric specification turns into the following static panel:

$$\sigma(\pi)_{i,t} = \beta Carbon\,pricing_{i,t} + \gamma X_{i,t-1} + \mu_i + \epsilon_{i,t}, \quad \text{(B.2)}$$

which could be estimated through the fixed-effects or random-effects estimators.[25]

[25] In the presence of correlation between the individual effect and the explanatory variables, the fixed-effects estimator should be employed, as the random-effects estimator is expected to yield biased and inconsistent estimates of the regression parameters. The Hausman test is usually employed to opt for the

Panel Data Results

Our baseline results for panel data are presented in Tables B.1 and B.2. Given that the lag of the inflation volatility is found not significant,[26] we focus on the results of the static panel.[27,28]

Table B.1 depicts a series of specifications with the objective to test the effects of the existence of any carbon pricing initiative, without further differencing by types. Columns 1–5 present some stepwise estimations in which the relevant groups of control variables are sequentially introduced in the specification of the models. In a first step, general socioeconomic variables that account for the size of the country and the level of development are included (column 1). Afterward, trade openness (column 2), controls for exposure to commodity prices and capital flows (column 3), variables reflecting common global factors, mainly commodity prices (column 4), and, finally, the domestic level of CPI inflation (column 5) are added. Table B.2 presents the same structure as Table B.1, but in this case carbon pricing systems are further disaggregated as to consider the ETS and carbon tax types separately.

Overall, the existence of a carbon pricing systems is related to increased volatility of inflation (Table B.1), which seems to be solely driven by ETS schemes (Table B.2). Carbon pricing systems in the form of a carbon tax do not seem to have a significant impact on inflation volatility in any of the specifications (Table B.2).

In a second step, we investigate the channels by which carbon pricing systems affect inflation volatility, analyzing the differential impact on the energy CPI component and the degree of pass-through

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fixed- or the random-effects estimator. The random-effects estimator is preferred under the null hypothesis (zero correlation between the individual effect and the regressors) due to higher efficiency, while under the alternative the fixed-effects estimator is at least consistent and, thus, preferred.

[26]Estimates of the System-GMM estimator differentiating by type of carbon pricing systems are available upon request. In none of the specifications considered is the lag of inflation volatility significant.

[27]For all the models, results for the Hausman test reject the null hypothesis that individual effects are uncorrelated with the regressors. Therefore, we present the results of the fixed-effects estimator.

[28]We also performed a test for normality of the error components in panel data models proposed by Alejo et al. (2015). Our post-estimation results show that the null hypothesis of joint normality of both error terms (individual effect and idiosyncratic component) cannot be rejected.

Table B.1. Baseline Results: Carbon Pricing

	(1)	(2)	(3)	(4)	(5)
Carbon Pricing, Any	0.419***	0.450***	0.464***	0.512***	0.343***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
GDP per Capita	–0.047***	–0.038***	–0.044***	–0.045***	–0.029***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.002)
Population	–0.048***	–0.050***	–0.062***	–0.060***	–0.021**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.035)
Trade Openness		–0.004	–0.005	–0.005*	–0.002
		(0.169)	(0.110)	(0.085)	(0.326)
Primary Exporter			0.279*	0.249	0.145
			(0.088)	(0.114)	(0.239)
Capital Flows			–0.000	0.000	–0.000
			(0.744)	(0.997)	(0.598)
Commodity Prices: Energy Inflation				0.003	–0.002
				(0.154)	(0.199)
Commodity Prices: Agriculture Inflation				0.024***	0.022***
				(0.000)	(0.000)
Commodity Prices: Metals and Minerals Inflation				–0.013***	–0.011***
				(0.000)	(0.000)
CPI Inflation					0.164***
					(0.000)
Constant	4.204***	4.321***	4.983***	4.959***	2.397***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	756	756	708	708	708
R-squared	0.059	0.061	0.078	0.142	0.477
Number of Countries	36	36	36	36	36
Country FE	Yes	Yes	Yes	Yes	Yes

Note: *, **, and *** denote statistical significance at 10 percent, 5 percent, and 1 percent, respectively. Robust p-values are in parentheses. See main text of the paper for the definition of the variables.

Table B.2. Baseline Results: ETSs and Carbon Taxes

	(1)	(2)	(3)	(4)	(5)
ETS, Any	0.400***	0.429***	0.426***	0.464***	0.393***
	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)
Carbon Tax, Any	0.026	0.032	0.031	0.095	0.026
	(0.850)	(0.816)	(0.829)	(0.504)	(0.813)
GDP per Capita	–0.052***	–0.044***	–0.050***	–0.051***	–0.036***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Population	–0.041***	–0.042***	–0.052***	–0.050***	–0.014
	(0.000)	(0.000)	(0.000)	(0.000)	(0.142)
Trade Openness		–0.004	–0.005	–0.005*	–0.003
		(0.169)	(0.113)	(0.081)	(0.251)
Primary Exporter			0.211	0.175	0.079
			(0.202)	(0.274)	(0.527)
Capital Flows			–0.000	0.000	–0.000
			(0.732)	(0.989)	(0.559)
Commodity Prices: Energy Inflation				0.004*	–0.001
				(0.087)	(0.398)
Commodity Prices: Agriculture Inflation				0.023***	0.021***
				(0.000)	(0.000)
Commodity Prices: Metals and Minerals Inflation				–0.013***	–0.011***
				(0.000)	(0.000)
CPI Inflation					0.165***
					(0.000)
Constant	4.197***	4.319***	4.925***	4.909***	2.449***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	756	756	708	708	708
R-squared	0.058	0.060	0.076	0.140	0.480
Number of Countries	36	36	36	36	36
Country FE	Yes	Yes	Yes	Yes	Yes

Note: *, **, and *** denote statistical significance at 10 percent, 5 percent, and 1 percent, respectively. Robust p-values are in parentheses. See main text of the paper for the definition of the variables.

Table B.3. Energy and Core Inflation

	(1) Sd. Headline	(2) Sd. Energy Infl.	(3) Sd. Core	(4) Sd. Headline	(5) Sd. Energy	(6) Sd. Core
Carbon Pricing, Any	0.343***	0.661*	0.337***			
	(0.000)	(0.063)	(0.000)			
ETS, Any				0.393***	1.258***	0.415***
				(0.000)	(0.001)	(0.000)
Carbon Tax, Any				0.026	–0.082	0.145
				(0.813)	(0.839)	(0.150)
Observations	708	708	707	708	708	707
R-squared	0.477	0.359	0.377	0.480	0.368	0.388
Number of Countries	36	36	36	36	36	36
Control Variables Included	Yes	Yes	Yes	Yes	Yes	Yes

Note: ***, **, and * denote significance at 1 percent, 5 percent, and 10 percent, respectively. Robust p-values in parentheses. Control variables: GDP per capita; population; trade openness; primary exporter; capital flows; commodity prices: energy inflation, agriculture inflation, and metals and minerals inflation; CPI inflation. See main text of the paper for the definition of the variables.

to the volatility of core inflation. For this purpose, in Table B.3 the dependent variables are headline, energy, and core inflation volatility, respectively. We consider the overall effect of having implemented any carbon pricing initiative (columns 1, 2, and 3) and the effect of ETSs and carbon taxes separately (columns 4, 5, and 6). Control variables from the baseline specification are also included, in a similar vein as in column 5 in Tables B.1 and B.2.

As in our baseline local projections specification, the estimates reveal that carbon pricing systems do significantly impact inflation volatility for the case of energy CPI, which should be expected given that energy-related goods are the ones that are targeted directly or indirectly by carbon pricing initiatives. Regarding the type of carbon pricing initiative affecting inflation volatility, again, it seems that schemes based on the ETS are the ones that spur the increased volatility pattern, affecting headline, energy, and core inflation volatility (columns 5 and 6). We cannot find a significant effect of carbon taxes on the volatility of any constituent of the CPI.

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