CARBON PRICING AND INFLATION VOLATILITY

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Abstract

Carbon pricing initiatives, designed to increase the relative prices of greenhouse gas-intensive goods and services, could not only push up CPI inflation but also affect its volatility. Existing empirical literature has only found that carbon pricing schemes are generally associated to a transitory effect on the level of inflation. This paper assesses empirically the effects of carbon pricing on inflation volatility for both carbon tax and cap-and-trade schemes (also known as emission trading systems). Our work finds strong evidence that cap-and-trade schemes are associated with larger volatility in CPI headline inflation, while no significant effect is found in the case of carbon taxes. This effect seems to feed only through the energy component, and does not seem to affect the volatility of core inflation. In addition, we find that under cap-and-trade schemes, both the increase in the underlying price of emissions and the expansion in the activities covered by these initiatives are associated with greater inflation volatility. These findings have important policy implications, given that inflation volatility could complicate the conduct of monetary policy. Since the ambition to mitigate climate change in the years to come is expected to be implemented through broader coverage of carbon pricing, central banks should monitor those developments closely.

Keywords: carbon pricing, emission trading systems, carbon tax, inflation, inflation volatility.

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

Resumen

Las iniciativas de fijación de precios del carbono, diseñadas para incrementar los precios relativos de los bienes y servicios intensivos en gases de efecto invernadero, no solo podrían incidir en la inflación del IPC, sino también en su volatilidad. La literatura empírica ha encontrado, de manera general, que estas medidas incrementan transitoriamente el nivel de inflación. Este trabajo analiza empíricamente los efectos de las iniciativas de fijación de precios del carbono sobre la volatilidad de la inflación, tanto de los mercados de derechos de emisión como de los impuestos sobre el carbono. Encontramos abundante evidencia de que los mercados de derechos de emisión conducen a una mayor volatilidad de la inflación. El aumento de la volatilidad provendría del componente energético, mientras que no se aprecia un efecto significativo en el caso de la inflación subyacente. Además, los incrementos del precio efectivo de las emisiones y de las actividades cubiertas por estas iniciativas inducen una mayor volatilidad de la inflación. Por todo ello, y dada la creciente ambición para mitigar el cambio climático, estos resultados cobran cada vez más relevancia en términos de política económica, ya que una mayor volatilidad de la inflación puede complicar la gestión y comunicación de la política monetaria.

Palabras clave: precios del carbono, mercados de derechos de emisión, impuesto sobre el carbono, inflación, volatilidad.

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

1 Introduction

Not only climate change but also its mitigation policies may affect business cycle and inflation dynamics. The scientific consensus, as reflected in the findings of the International Panel on Climate Change, points to an increasing concern that, absent a significant reduction in greenhouse gases (GHG) emissions, the process of global warming will lead to devastating and potentially irreversible consequences for the planet (IPCC, 2022). In light of this evidence, many governments have implemented significant mitigation policies and committed to expand their ambition, fundamentally with regard to the reduction of GHG emissions. 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 affecting the 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.

Monetary policy has been no exception. Both climate change and the transition to a low-carbon economy could affect the delivery of central bank's price stability mandates and the conduct of monetary policy through various channels. That is, 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), they may hinder the transmission of monetary policy. Indeed, in the context of its new monetary policy strategy, the ECB has recently committed to incorporate climate change considerations into the design of monetary policy for these reasons (ECB, 2021). Also, in several recent speeches ECB Executive Board Member Schnabel (2021, 2022) further emphasized the importance of both physical and transition risks as a threat to price and macroeconomic stability and, hence, to the conduct of monetary policy.

Among the policy measures to mitigate climate change, carbon pricing is commonly seen as the most efficient economic instrument for reducing emissions (Hepburn *et al.*, 2020), since it allows internalizing the external costs derived from the production and consumption of GHG-intensive goods, by bringing the implicit cost of emissions closer to their social cost (Pigou,

[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, without ruling out 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.

1932). In fact, the presence of carbon pricing initiatives has increased sharply in the last years, not only regarding the number of initiatives implemented but also in geographical terms and in relation to the emissions covered by those systems (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 GHG emissions, pushing up (at least temporarily) inflation. However, the incentives from carbon pricing to increase energy efficiency and foster innovation in low-carbon sources of energy, especially in the electricity sector, combined to the diminishing weight of fossil fuels in the consumption basket act in the opposite direction.[2] 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 inflationary and disinflationary underlying forces and, in some cases, on the persistence of inflation (Konradt and Weder di Mauro, 2021; Mckibbin *et al.*, 2021; Känzig, 2021; Moessner, 2022). These studies show that carbon pricing initiatives generally produce a transitory effect on the level of headline inflation. However, to our knowledge no previous work has dealt with the effect of carbon pricing schemes on the volatility of inflation.

Nevertheless, carbon pricing initiatives could be expected to affect the inflation process differently depending on the design of those initiatives. Indeed, several works and reports have already suggested a relation between some types of carbon pricing systems and price volatility (see, for example, Metcalf (2021) or ECB (2021)). That is because the presuming impact on inflation volatility of the two main carbon pricing initiatives, cap-and-trade schemes (also known as emissions trading schemes (ETS)) and carbon taxes[3], are different. Under ETS, a cap is first set on pollution, issuing afterwards a volume of emission allowances compatible with that cap and allowing companies to trade with them and determine a market clearing price, which could be potentially rather volatile. Conversely, under carbon taxes schemes, policy makers set a price on GHG emissions, letting the market determine the amount of pollution consistent with that price. Therefore, carbon prices tend to be relatively stable as long as their tax rates and tax base do not change so often. All in all, while a carbon tax is expected to lead to relatively stable carbon prices, cap-and-trade systems have been found to lead to substantial price volatility (Goulder and Schein, 2013; Metcalf, 2021). This volatility could be translated into producer

[2]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 substitute them may need some longer time. Therefore, inflationary pressures may be more persistent.

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

and consumer prices, especially of those goods and services related to the sectors under the coverage of ETS. This way, 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 assessing empirically the effects on inflation volatility of the two main types of carbon pricing initiatives, that is to say, carbon taxes and ETS systems. Moreover, we consider the impact not only on the volatility of headline CPI, but also of the energy and the core subcomponents. We also analyse the role played by the level of carbon prices and the share of GHG emissions covered by those carbon pricing initiatives. We find that carbon pricing initiatives in the form of ETS are associated with larger CPI headline inflation volatility, an effect that is not found in the case of schemes of the carbon tax type. Our results also suggest that ETS affect the volatility of inflation through the energy component, since energy related goods are the ones that are targeted directly or indirectly by carbon pricing initiatives, while it does not seem to affect core inflation volatility. Finally, we find that, under ETS, expanding the coverage of those initiatives and increasing the underlying price of emissions leads to greater inflation volatility.

As summarised above, climate change mitigation policies could have a wide-ranging impact on the nominal side of the economy, reflected mainly in the inflation level, their volatility and on asset markets prices, which are likely to affect the implementation and transmission of monetary policy (NGFS, 2021; ECB, 2021). 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. But if the carbon pricing schemes are also found to affect inflation volatility, those relative price shocks complicate the communication and the conduct of the monetary policy. Since the ambition to mitigate climate change in the years to come is expected to be partly instrumented through broader coverage of carbon pricing initiatives, a better understanding of its implications for the inflation process becomes crucial.

The rest of the paper is structured as follows. Section 2 reviews the literature. Section 3 explains the database built including its descriptive statistics. Section 4 deals with the empirical model and the econometric approach considered. 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. Regarding the ex-post (estimated) economic impact of carbon pricing, a growing body of research has recently addressed the study of their effects on economic growth (Metcalf and Stock, 2020), industrial and business performance, competitiveness and innovation (Shapiro and Metcalf, 2021; Venmans *et al.*, 2020; Martin *et al.*, 2014, 2016), employment (Martin *et al.*, 2014; Yamazaki, 2017), international trade (Mundaca *et al.*, 2021) and the inequality of income distribution (Elkins and Baker, 2001; Känzig, 2021).

With respect to inflation, although the field is gaining momentum, evidence is still rather limited. In 2014, McKibbin *et al.* (2014) derived model-based evaluations of the introduction of a carbon tax in the US, pointing to sizable positive and temporary effects on inflation.[4] Regarding ex-post analysis of the impacts on inflation, a recent study by Konradt and Weder di Mauro (2021) conclude 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 lead to increases in the price of the broader basket of goods and services. Focusing on the euro area, Mckibbin *et al.* (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 impacting 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 (2021) also derive 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. Finally, Moessner (2022) analyses 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 ETS. She finds that an increase in the price of ETS 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

[4] Model-based evaluations of a carbon tax in Spain (Estrada and Santabárbara, 2021) show similar results: the introduction of a carbon tax translates into a temporary increase in inflation. However, they find that what governments would do with carbon tax revenues will shape the response of the economy to the energy transition.

effects on the rest of components.

To date, this emerging body of research has focused on assessing the impact of carbon pricing on the level of inflation. However, to our knowledge the effects of carbon pricing schemes on the volatility of inflation remain largely unexplored. The impact of carbon pricing on inflation volatility should be expected to depend on several factors. First, carbon pricing systems can take the form of both carbon taxes and cap-and-trade systems, with presumed differing impacts on the volatility of inflation. For cap-and-trade schemes, a cap is first set on pollution, issuing afterwards a volume of emission allowances compatible with that cap and allowing companies to determine a market clearing price by selling and buying allowances. On the contrary, under a carbon tax, policy makers directly set a price on CO_2 emissions, letting the market determine the amount of pollution consistent with that price. Therefore, while a carbon tax is expected to lead to more stable carbon prices, cap and trade systems show substantial price volatility (Goulder and Schein, 2013; Metcalf, 2021). This volatility could be translated into producer and consumer prices, especially of those goods and services related to those sectors under the coverage of carbon pricing. However, 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 inflation volatility.

The economic impact of carbon pricing has also proved to be dependent 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, 2020). The effect of carbon pricing on inflation should also be dependent on the effective price of the initiative (Metcalf and Stock, 2020; Konradt and Weder di Mauro, 2021). 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 (Konradt and Weder di Mauro, 2021; Mckibbin *et al.*, 2021; Känzig, 2021; Moessner, 2022), which could translate to differential impacts on the volatility of that inflation. Finally, the effects of carbon pricing systems on inflation may depend on some other factors, such as the production structure, and particularly whether the country specializes in high-polluting industries and sectors. That is because these sectors tend to be under the coverage of carbon pricing systems.

Regarding the control variables, the literature has identified a number of domestic and global factors as affecting inflation volatility. First, with respect to the 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). Central bank independence and monetary policy

1997; Neely and Rapach, 2011; Parker, 2018). Central bank independence and monetary policy frameworks have also been associated to the capacity of the monetary authority to achieve price stabilization (Cukierman *et al.*, 1992; Bernanke and Gertler, 2001; Klomp and de Haan, 2010). 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 also are commonly associated to inflation volatility. For example, trade, its role as commodity exporter, or the *de iure* and *de facto* of capital account liberalization of each economy are all of them related to the reaction of domestic prices to swings in external economic conditions (Romer, 1993; Lane, 1997; Bowdler and Malik, 2017; Aghion *et al.*, 2004). In the same vein, the choice of the exchange rate regime is commonly seen as a mechanism related to how external shocks affect inflation dynamics (Bleaney and Fielding, 2002; Alfaro, 2005; Kamber and Wong, 2020). Third, a strain 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 *et al.*, 2017; Parker, 2018; Kamber and Wong, 2020).

3 Data

Our sample starts in 2000, after the introduction of the euro[5] and just before the adhesion of China to the World Trade Organization[6], two major events affecting the inflation process in advanced economies. We focus our analysis on OECD countries, since inflation in advanced economies has behaved differently than in emerging market economies (Blanchard *et al.*, 2015; Ha *et al.*, 2019). This results in an unbalanced panel of 36 countries for the period 2000-2020. To match the measure of inflation volatility, the resulting panel has biennial frequency.

Our dependent variable on inflation volatility is built from CPI data for headline, core and energy inflation that is 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.[7] Also, for robustness checks we construct some alternative measures of inflation volatility. First, in order to avoid unduly overweighting extreme data points following a common approach in the literature inflation volatility is computed as

[5] 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 in inflation patterns in those countries (Balatti, 2020; Bowdler and Malik, 2005).

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

[7] 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 is available. Figure A1 in the Appendix depicts the evolution of this measure of inflation volatility.

the log of one plus the standard deviation of inflation (Bowdler and Malik, 2017).[8] Second, both inflation volatility measures are built using different time windows, 12 and 36 months, respectively.

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 regional (supranational) carbon pricing initiatives.[9] By processing the information contained in the database, we build some variables of interest for this work. First, in order to capture which jurisdictions have introduced carbon pricing initiatives, we construct 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 ('*Carbon pricing, any*'). Second, we distinguish between initiatives of the cap-and-trade (or ETS) and carbon tax types, incorporating two dummy variables: '*ETS, any*' and '*Carbon tax, any*', that reflect whether the country has implemented any type of ETS or carbon tax, respectively, in a given year. Third, since the effect of carbon pricing on inflation is expected to depend on the underlying carbon price, we compute the weighted average of the real carbon price in each jurisdiction for each year ('Price'), weighing the carbon price of each initiative within the same country by the share of emissions covered by each initiative. 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 expressed in dollar terms and, thus, are deflated by the US CPI. Fourth, the effect of carbon pricing should also be related to the amount of GHG covered by the initiatives in that country. Unluckily the Carbon Pricing Dashboard only offers coverage within the jurisdiction for the last available year, which would significantly reduce the variability and accuracy of the information employed in the analysis. However, the data on global emissions coverage, that is, the percentage of global emissions covered by a given initiative, is offered for each year. Therefore, we are able to compute a proxy of the percentage of emissions covered in each jurisdiction by multiplying global emissions coverage by global emissions themselves –to get total emissions covered by each initiative for a given year– and dividing it by each country's emissions levels that same year.[10] One additional difficulty stems from the fact that,

[8] This allows to down-weight very large readings of inflation that may occur during hyperinflation episodes as well as inflation records close to zero.

[9] See `https://carbonpricingdashboard.worldbank.org`

[10] For the years 2019 and 2020, World Bank does not offer information on GHG emissions, so we assume that the percentage of emissions covered by each carbon pricing initiative in each jurisdiction remains constant after 2018. Although most of the GHG emissions data required are now available for one extra year, 2019, using different sources (such as Climate Analysis Indicator Tool, Potsdam Institute for Climate Impact Research or United Nations Framework Convention on Climate Change), we have opted for preserving the consistence within the World Bank dataset.

for some countries, there may be coexisting national, regional and subnational initiatives that can overlap for a given year in terms of the emissions they cover. Since we cannot rely on accurate information on overlapping emissions for each initiative on an annual basis, we decided to compute two different measures of coverage. The first one considers that the initiatives at different administrative levels are fully overlapping, and it is therefore linked to the initiative with maximum coverage by jurisdiction ('*Coverage-fully overlapping*'). On the contrary, the second measure assumes that the initiatives are not overlapping at all and is obtained by adding up the coverage of each initiative within the country/jurisdiction ('*Coverage-not overlapping*')[11].

We also consider some other factors that may affect the relationship between carbon pricing and inflation volatility. In order to account for the production structure, and particularly whether the country specializes in high-polluting industries and sectors, we include the share in value added in each economy of the 20% highest polluting sectors worldwide ('*VA share polluting sectors (20%)*'). Moreover, countries with carbon pricing initiatives may also rely on more stringent environmental norms, that may impose some implicit abatement costs beside the explicit price for carbon. To control for this fact, the role of those other climate change mitigation policies is captured from the OECD's Environmental Stringency Index[12], which aims at measuring 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 include an additional dummy variable ('*Post-2015*').

Regarding the usual control variables identified in the literature, we gathered information from different sources. Population, GDP per capita and Trade openness are directly drawn from World Bank's World Development Indicators. For *de iure* central bank independence, we employed the Garriga (2016) dataset[13]. Our proxy for capital flows and financial openness is built as the sum of the absolute value of inflows and outflows in percentage of each country GDP based on IMF International Financial Statistics data. Using data on merchandise exports from World Bank, a country is considered as a primary exporter if exports of food, fuels, and ores and metals imply more than 20% of total merchandise exports. Exchange rate regime classification

[11]It should be noted that for few countries, such as Finland, Sweden or Norway, and some years may count on coexisting carbon tax and ETS initiatives with relevant coverage. The last measure of coverage may result in levels of higher than 100% for some years. As shown in Section 5.4, our results are robust to the use of the two measures.

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

[13]Garriga (2016) uses Cukierman *et al.* (1992) to classify central banks according to several criteria related to the characteristics of the chief executive officer of the bank, policy formulation attributions, objectives, and limitations on lending to the public sector. The resulting index ranges from 0 (lowest) to 1 (highest independence).

follows Reinhart and Rogoff (2004) and Ilzetzki *et al.* (2019).[14] Following Fernández *et al.* (2017) and Kamber and Wong (2020), real commodity prices are accounted through the growth rate in Agricultural, Metal and Minerals, and Energy Commodity Price Indices, deflated by the US CPI, obtained from World Bank's Pinksheet on Commodity Prices.

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

With respect to carbon pricing, Figure 1 panel (a) 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% of global emissions, by 2020 the coverage of global emissions from OECD carbon pricing initiatives reached 11%. As shown in Figure 1 panel (b), 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 an overall coverage of 15% of emissions. It is also worth noting that OECD countries involve a substantial proportion of all the initiatives implemented globally; by considering OECD countries we are accounting for a 78% of initiatives and a 73% 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 2000-2020. As it can be observed, our sample shows substantial variability both in geographical terms and across time, with initiatives of different types –ETS and carbon taxes– implemented in a number of countries and at different points in time. Those initiatives are also heterogeneous in terms of their coverage and price for carbon.

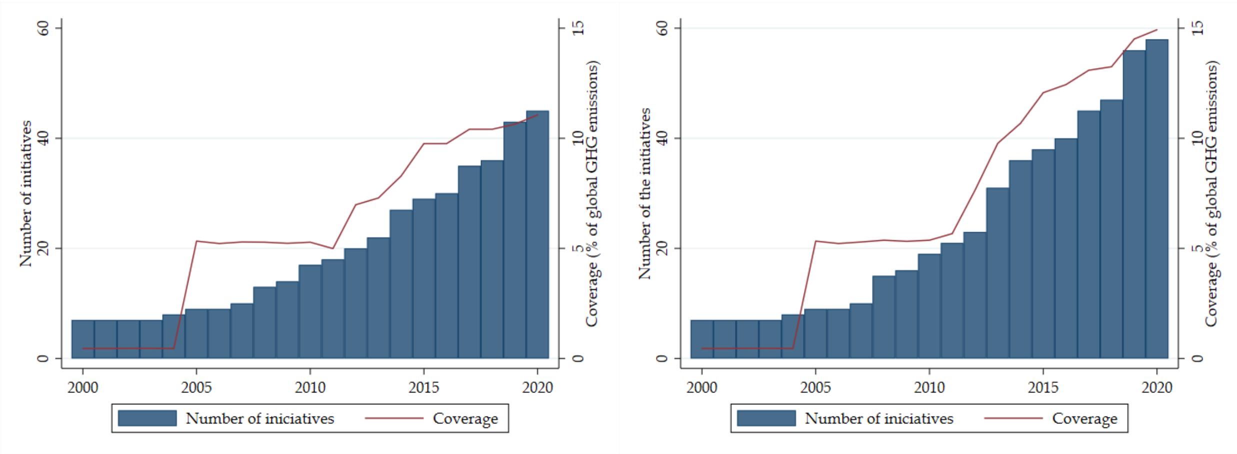
[14] They classify exchange rate regimes ranging from 1 to 6, ranging from no separate legal tender to free falling systems or dual markets. The data and a more thorough description can be accessed here: https://carmenreinhart.com/exchange-rate/.

Table 1: Descriptive statistics

		N	Mean	SD	Min	Max
Inflation volatility	Headline infl. standard deviation (percentage points)	396	0.999	1.214	0.182	15.40
	Energy infl. standard deviation (percentage points)	396	5.529	3.729	1.048	34.57
	Core infl. standard deviation (percentage points)	374	0.618	0.583	0.101	4.311
Carbon pricing	Carbon pricing, any	396	0.672	0.455	0	1
	ETS, any	396	0.595	0.474	0	1
	Carbon Tax, any	396	0.359	0.478	0	1
	Coverage (not overlapping) (%)	396	34.88	31.88	0	130.8
	Coverage ETS (not overlapping) (%)	396	24.73	21.70	0	48.88
	Coverage Carbon Tax (not overlapping) (%)	396	10.57	20.45	0	82.03
	Coverage (fully overlapping) (%)	396	27.97	23.05	0	82.03
	Coverage ETS (fully overlapping) (%)	396	23.48	21.42	0	48.73
	Coverage Carbon Tax (fully overlapping) (%)	396	10.39	20.30	0	82.03
	Price (US$/t$CO_2$e)	396	4.016	9.214	0	83.41
	Price (ETS) (US$/t$CO_2$e)	396	3.896	4.474	0	14.69
	Price (Carbon Tax) (US$/t$CO_2$e)	396	3.899	12.63	0	100.8
	Environmental Stringency, 0 (not stringent) to 6 (highest degree)	352	2.546	1.005	0	4.890
	Value-added share of polluting sectors (%)	360	0.141	0.0494	0.0468	0.356
	Post-2015, dummy	396	0.273	0.446	0	1
Control variables	GDP per capita (in thousands)	395	39.94	18.24	9.047	113.8
	Population (in thousands)	396	35.17	56.66	0.283	329.5
	Trade openness (% of GDP)	394	96.45	57.90	19.81	400.6
	Primary exporter (dummy)	396	0.448	0.491	0	1
	Capital flows (% of GDP)	389	87.74	352.4	3.543	3,365
	Commodity prices: Energy inflation (%)	396	4.843	18.85	-31.97	30.43
	Commodity prices: Agriculture inflation (%)	396	1.286	7.575	-9.476	14.45
	Commodity prices: Metals & Minerals inf. (%)	396	4.738	16.32	-15.83	31.85
	ExR_Reg No separate legal tender, preannounced peg/band (dummy)	324	0.472	0.498	0	1
	ExR_Reg: Crawling peg/band narrower than ±2% (dummy)	324	0.119	0.318	0	1
	ExR_Reg: Crawling peg/band wider than ±2% (dummy)	324	0.336	0.467	0	1
	ExR_Reg: Free floating (dummy)	324	0.069	0.253	0	1
	Central Bank Independence 0 (lowest) to 1 (highest independence)	252	0.690	0.158	0.179	0.861
	CPI inflation (%)	396	2.503	4.191	-4.990	68.53

N: # of observations; SD: standard deviation

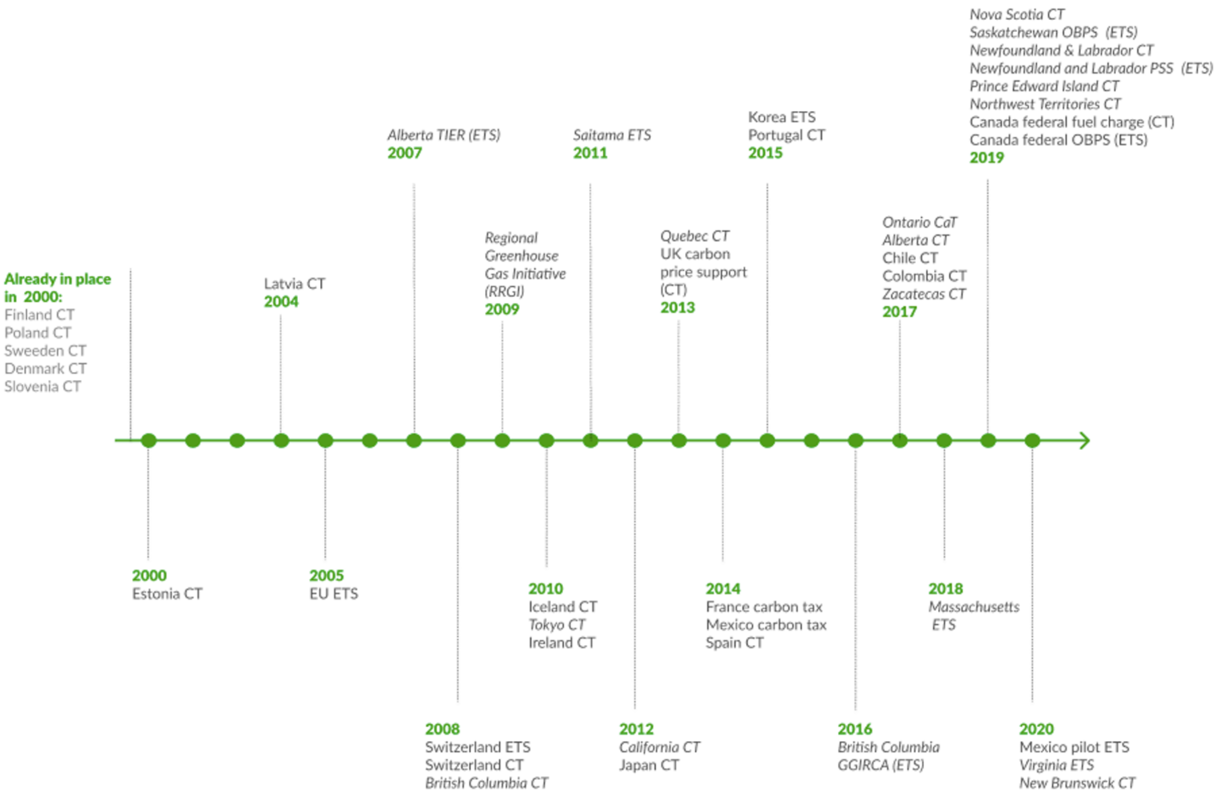
Figure 1: Number of carbon pricing initiatives and coverage



(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

4 Empirical model and estimation strategy

Against the background described above, the econometric model to be estimated can be outlined as follows:

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

where $\sigma(\pi)_{i,t}$ is the dependent variable measured, for a country i and for each biennial[15] period t, as the standard deviation of monthly year-on-year inflation computed in windows of 24 months.[16] We considered that inflation volatility could be influenced by its own lag $\sigma(\pi)_{i,t-1}$, showing certain degree of persistence. $Carbon\, pricing_{i,t}$ includes the set of variables that depict the existence and different features of carbon pricing systems, representing our variables of interest (*'Carbon pricing, any', 'ETS, any', 'Carbon tax, any', 'Coverage-fully overlapping', 'Coverage-not overlapping'* and *'Price'*). $X_{i,t}$ includes the relevant controls described in the previous section. 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. α, β, γ, are the coefficients associated with the lag of the dependent variable, and with objective and control variables, respectively. Note that when this past realisation of the dependent variable is also a function of the individual effect, μ_i, the dynamic component is by construction correlated with the error term. To tackle this issue, we employed the System-GMM estimator by Arellano and Bover (1995) and Blundell and Bond (1998).[17]

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

$$\sigma(\pi)_{i,t} = \beta Carbon\, pricing_{i,t} + \gamma X_{i,t} + \mu_i + \epsilon_{i,t} \tag{2}$$

which could be estimated through the fixed effects or random effects estimators. In the presence

[15] Given that our measure of inflation volatility is computed in windows of 24 months, we opted to collapse the rest of the dataset to biennial data (taking averages for both years) to be able to isolate the contemporaneous impact of the objective and control variables. If we had opted for an annual panel, the dependent variable, the 24-month inflation volatility, has been also affected by the previous year evolution of the regressors. As a robustness, we estimated analogous models at annual frequency including contemporaneous and the lagged values of interest and control variables with similar results, which are available upon request.

[16] Alternative time windows and additional measures of volatility (see Section 3 for a more thorough description) will be considered as robustness tests in Section 5.5.

[17] This estimator incorporates the lagged levels and differences of the dependent variable as instruments. We opt for the two-step GMM alternative, which performs a first-step estimation to retrieve the optimal weighting matrix of instruments that is then used in a second step, using the finite-sample correction derived by Windmeijer (2005) to achieve more efficient estimates.

of correlation between the individual effect and the explanatory variables, the fixed effect estimator should be employed, as the random effect estimator is expected to yield biased and inconsistent estimates of the regression parameters. The Hausman test is usually employed to opt for the fixed or the random effect estimator.[18]

5 Results

5.1 Dynamic vs static panel

We first estimated the dynamic panel, considering the potential effect of the persistence of inflation volatility. Table A1 in the Appendix shows the estimates of the System-GMM estimator differentiating by type of carbon pricing systems. In none of the specifications considered, the lag of inflation volatility is significant.[19] [20] Therefore, we opt to choose a static panel as our baseline specification.

5.2 Baseline results

Our baseline results are presented in Tables 2 and 3. They correspond to the fixed effect estimator which in this case, after conducting a Hausman test[21], is preferred over the random effects one to tackle time-invariant unobserved heterogeneity.[22]

Table 2 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 to 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). Afterwards, trade openness (column 2), controls for exposure to commodity prices and capital

[18]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.

[19]Although we do not find persistence of inflation volatility at biennial frequency, it does not imply that inflation volatility show persistence at higher frequencies.

[20]For consistent estimation, in the context of dynamic models the error must be serially uncorrelated. For this purpose, Arellano and Bover (1995) propose a test for the hypothesis of no second order serial correlation of the disturbance. The results of those tests, as well as a Hansen test of over-identifying restrictions reported at the bottom of the table, fail to reject the hypotheses of no serial correlation of order two, and validity of the instruments, respectively. We also report the instrument count.

[21]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.

[22]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.

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.[23] Table 3 presents the same structure as Table 2, but in this case carbon pricing systems are further disaggregated as to consider the ETS and carbon tax types separately.

Table 2: Baseline results: Carbon pricing

Standard deviation of the headline CPI inflation	(1)	(2)	(3)	(4)	(5)
Carbon pricing, any	0.610***	0.665***	0.681***	0.696***	0.619***
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
GDP per capita	-0.064***	-0.056***	-0.070***	-0.056***	-0.048***
	(0.000)	(0.001)	(0.000)	(0.001)	(0.003)
Population	-0.042**	-0.049***	-0.050***	-0.042**	-0.029*
	(0.014)	(0.008)	(0.008)	(0.018)	(0.079)
Trade openness		-0.004	-0.005	0.000	0.000
		(0.350)	(0.331)	(0.997)	(0.921)
Primary exporter			0.224	0.234	0.179
			(0.287)	(0.256)	(0.354)
Capital flows			-0.000	-0.000	-0.000
			(0.438)	(0.900)	(0.853)
Commodity prices: Energy inflation				0.013***	0.010***
				(0.001)	(0.008)
Commodity prices: Agriculture inflation				0.059***	0.065***
				(0.000)	(0.000)
Commodity prices: Metals & Minerals inf.				-0.037***	-0.041***
				(0.000)	(0.000)
CPI inflation					0.101***
					(0.000)
Constant	4.611***	4.892***	5.426***	4.144***	3.193***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	395	394	387	387	387
R-squared	0.071	0.075	0.086	0.217	0.314
Number of countries	36	36	36	36	36
Hausman test p-value	0.000	0.000	0.000	0.000	0.000

Notes: * (**) [***] denotes statistical significance at 10% (5%) [1%]. Robust p-values in parentheses. See main text of the paper for the definition of the variables.

Overall, the existence of a carbon pricing systems is related to increased volatility of inflation (Table 2), which seems to be solely driven by ETS schemes (Table 3). Carbon pricing systems in the form of a carbon tax do not seem to have a significant impact on the volatility of inflation in any of the specifications (Table 3). Regarding the variables of control, higher country size and level of development is related to lower levels of volatility, as expected. Trade openness do not seem to have a significant effect in our sample. On the contrary, being a primary exporter

[23]We do not include time fixed effects because they are collinear with some of the control variables, namely, the ones related to global factors. However, in Section 5.5, we show that our results are robust to the inclusion of time fixed effects.

seems to lead to increased volatility of inflation. Global factors, captured by the changes in the different commodity price indices, and also domestic CPI inflation, are significant in all specifications, reflecting their relevance in line with previous findings (Bleaney and Fielding, 2002; Fernández *et al.*, 2017; Parker, 2018; Kamber and Wong, 2020).

Table 3: Baseline results. ETS and carbon taxes

Standard deviation of the headline CPI inflation	(1)	(2)	(3)	(4)	(5)
ETS, any	0.705***	0.768***	0.827***	0.756***	0.710***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Carbon Tax, any	-0.040	-0.024	-0.051	0.115	0.055
	(0.849)	(0.909)	(0.813)	(0.576)	(0.778)
GDP per capita	-0.075***	-0.067***	-0.082***	-0.067***	-0.058***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Population	-0.033**	-0.038**	-0.036*	-0.030*	-0.018
	(0.048)	(0.032)	(0.050)	(0.084)	(0.266)
Trade openness		-0.006	-0.006	-0.001	-0.001
		(0.236)	(0.212)	(0.776)	(0.823)
Primary exporter			0.051	0.096	0.047
			(0.812)	(0.646)	(0.811)
Capital flows			-0.000	-0.000	-0.000
			(0.388)	(0.864)	(0.798)
Commodity prices: Energy inflation				0.014***	0.010***
				(0.001)	(0.006)
Commodity prices: Agriculture inflation				0.057***	0.062***
				(0.000)	(0.000)
Commodity prices: Metals & Minerals inf.				-0.037***	-0.041***
				(0.000)	(0.000)
CPI inflation					0.101***
					(0.000)
Constant	4.758***	5.067***	5.584***	4.310***	3.369***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	395	394	387	387	387
R-squared	0.081	0.086	0.098	0.223	0.321
Number of countries	36	36	36	36	36
Hausman tests	0.000	0.000	0.000	0.000	0.000

Notes: * (**) [***] denotes statistical significance at 10% (5%) [1%]. Robust p-values in parentheses. See main text of the paper for the definition of the variables.

Table 4 includes additional institutional control variables related to exchange rate regimes and central bank independence. It should be noted that the inclusion of these variables would significantly reduce the sample, since they are available only until 2016 in the case of exchange rate regimes and 2012 for central bank independence. Hence, for the rest of the paper we remain with the specification in which no data is sacrificed and main controls are included (column 5 in Tables 2 and 3). However, we should stress that our main results are robust to the inclusion of those additional controls.

Table 4: Robustness to the introduction of other control variables

Standard deviation of the headline CPI inflation	(1)	(2)	(3)	(4)
Carbon pricing, any	0.492***	0.656**		
	(0.001)	(0.022)		
ETS, any			0.479***	0.854***
			(0.002)	(0.004)
Carbon Tax, any			0.145	-0.193
			(0.393)	(0.645)
GDP per capita	-0.003	-0.052	-0.012	-0.082*
	(0.848)	(0.201)	(0.467)	(0.058)
Population	0.000	-0.094***	0.010	-0.086**
	(0.984)	(0.008)	(0.487)	(0.014)
Trade openness	-0.002	-0.003	-0.002	-0.005
	(0.549)	(0.703)	(0.506)	(0.569)
Primary exporter	0.214	0.806**	0.081	0.715*
	(0.240)	(0.027)	(0.669)	(0.051)
Capital flows	0.000	0.000	0.000	0.000
	(0.979)	(0.645)	(0.923)	(0.631)
Commodity prices: Energy inflation	0.014***	0.008	0.015***	0.010
	(0.000)	(0.444)	(0.000)	(0.338)
Commodity prices: Agriculture inflation	0.058***	0.069***	0.056***	0.066***
	(0.000)	(0.000)	(0.000)	(0.000)
Commodity prices: Metals & Minerals inf.	-0.033***	-0.042***	-0.033***	-0.043***
	(0.000)	(0.000)	(0.000)	(0.000)
CPI inflation	-0.059***	0.096***	-0.059***	0.097***
	(0.000)	(0.000)	(0.000)	(0.000)
ExR_Reg No separate legal tender, preannounced peg/band	-27.838***		-27.830***	
	(0.000)		(0.000)	
ExR_Reg: Crawling peg/band narrower than ±2%	-26.938***		-26.905***	
	(0.000)		(0.000)	
ExR_Reg: Crawling peg/band wider than ±2%	-26.769***		-26.794***	
	(0.000)		(0.000)	
ExR_Reg: Free floating	-26.686***		-26.417***	
	(0.000)		(0.000)	
Central Bank Independence		-0.132		0.417
		(0.954)		(0.856)
Observations	318	246	318	246
R-squared	0.718	0.321	0.719	0.332
Number of countries	36	36	36	36

Notes: * (**) [***] denotes statistical significance at 10% (5%) [1%]. Robust p-values in parentheses. See main text of the paper for the definition of the variables.

5.3 Channels. Effects on the volatility of energy and core inflation

In second place, we investigate the channels by which carbon pricing systems affect inflation volatility, analysing the differential impact on the energy CPI component and the degree of pass-through to the volatility of core inflation. For this purpose, in Table 5 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 ETS 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 the Tables 2 and 3.

The estimates reveal that carbon pricing systems show the highest impact on the volatility

Table 5: Energy and core inflation

	(1) Sd.Headline	(2) Sd.Energy	(3) Sd.Core	(4) Sd.Headline	(5) Sd.Energy	(6) Sd.Core
Carbon pricing, any	0.619***	1.014*	-0.040			
	(0.001)	(0.067)	(0.686)			
ETS, any				0.710***	1.122*	-0.058
				(0.000)	(0.052)	(0.571)
Carbon Tax, any				0.055	0.599	-0.096
				(0.778)	(0.314)	(0.375)
Observations	387	387	367	387	387	367
R-squared	0.314	0.360	0.161	0.321	0.365	0.164
Number of countries	36	36	34	36	36	34
Control variables included	YES	YES	YES	YES	YES	YES

Notes: * (**) [***] denotes statistical significance at 10% (5%) [1%]. 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 & Minerals inflation, CPI inflation. See main text of the paper for the definition of the variables.

of inflation 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. On the contrary, we do not find a significant impact of carbon pricing initiatives on the volatility of core inflation. These results are in line with previous findings that the introduction of carbon pricing schemes seems to impact inflation through the energy component, and do not tend to affect core inflation, which seems consistent with the fact that by increasing energy prices, carbon pricing change relative prices, but do not necessarily lead to increases in the price of the rest of the basket of goods and services (Konradt and Weder di Mauro, 2021; Mckibbin *et al.*, 2021; Moessner, 2022). There is also some evidence that the indirect effects derived from the increase in the cost of producing goods and services due to higher costs of energy and intermediate inputs, and its pass-through to prices, may be not significant. In fact, Álvarez *et al.* (2011) find, for Spain and the euro area, that the indirect effect of a shock in oil prices tend to transmit at a substantially lower speed to consumer prices, and that those effects tend indeed to be limited as opposed to the direct effects. Consistent with those results, the effect on the volatility of core inflation is found insignificant, at least at the carbon price levels and coverage from our sample.

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, but only for headline and energy inflation volatility (columns 5 and 6), while core inflation does not seem to be affected. The effect of ETS on the volatility of energy inflation is also larger than the one on headline inflation (columns 4 and 5). We cannot find a significant effect on carbon taxes on the volatility of any constituent of the CPI.

5.4 GHG emissions coverage and effective carbon price

As we mentioned in Section 2, the effect of carbon pricing systems on inflation volatility may depend on the amount of the GHG emissions covered by the carbon pricing initiatives in each country and the effective carbon price paid in this jurisdiction. Table 6 summarises the effect of coverage and the level of carbon prices on inflation volatility. These specifications also considered the full set of controls although they are not reported for convenience.

Table 6: Results by GHG emissions coverage and effective carbon price

Standard deviation of the headline CPI inflation						
	GHG coverage				Effective carbon price	
	(1)	(2)	(3)	(4)	(5)	(6)
Coverage (not overlapping)	0.013***					
	(0.000)					
Coverage ETS (not overlapping)		0.017***				
		(0.000)				
Coverage Carbon Tax (not overlapping)		0.008				
		(0.138)				
Coverage (fully overlapping)			0.015***			
			(0.002)			
Coverage ETS (fully overlapping)				0.016***		
				(0.001)		
Coverage Carbon Tax (fully overlapping)				0.007		
				(0.212)		
Price					0.010	
					(0.466)	
Price (ETS)						0.045*
						(0.026)
Price (Carbon Tax)						0.001
						(0.891)
Observations	387	387	387	387	387	387
R-squared	0.319	0.322	0.313	0.322	0.291	0.296
Number of countries	36	36	36	36	36	36
Controls included	YES	YES	YES	YES	YES	YES

Notes: * (**) [***] denotes statistical significance at 10% (5%) [1%]. 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 & Minerals inflation, CPI inflation. See main text of the paper for the definition of the variables.

As shown in columns 1 to 4 of Table 6, the GHG emissions coverage of the carbon pricing initiatives significantly affects the volatility of inflation. That is, the higher the level of coverage, the higher the volatility of headline inflation. In addition, the result is robust to the use of the two alternative measures of coverage ('*Coverage-not overlapping*' and '*Coverage-fully overlapping*') described in Section 3. When considering the effect of the coverage disaggregating by type of carbon price systems, once again, the effect appears to be driven by the ETS schemes, being not significant in the case of carbon taxes (columns 2 and 4). Regarding the effective carbon price level, our results point to higher carbon prices increasing the volatility of headline inflation (column 5), an effect again explained by the ETS (column 6).

5.5 Additional 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.

First, Table A2 in the appendix tests our hypotheses described in Section 2 that the effect on carbon pricing systems on inflation could depend on a country's level of specialization in high polluting-sectors and industries, and the existence of a structural break after the renewed surge in environmental policies following the Paris Agreement in 2015, finding no evidence of any of the two. Also, our results are proved 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 countries environmental stringency not necessarily related. A more stringent environmental regulation does not seem nevertheless to affect the volatility of inflation.

Second, we test our specification against the use of different time windows for the computation of volatility and alternative measures, as described in Section 2. As shown in Tables A3 and A4, our main results are robust to the use of windows of 12 and 36 months (Table A3), and the log of one plus the standard deviation of inflation (Table A4).

Third, given that the classification of advanced economies differs among organizations, we restrict our sample to those countries that are considered as advanced economies according to the International Monetary Fund, using the classification of its World Economic Outlook. As depicted in Table A5, in this restricted subsample, carbon pricing systems keep showing a significant positive effect on inflation volatility, driven by the systems of the ETS type.

Finally, we add a specification in which time dummies are included, at the expense of removing those variables collinear with them, the global factors captured by the international commodity prices, showing that main results hold under this alternative modelling choice (Table A6).

5.6 Robustness to the use of local projections

One of the studies on the impact of carbon pricing initiatives on the level of inflation (Konradt and Weder di Mauro, 2021)[24] has also considered the dynamic responses by using panel local projections following Jordà (2005). In this section, we apply this methodology to inflation volatility to check to what extent our previous results are robust to alternative empirical approaches.

We choose the following specification to estimate the dynamic response of the volatility of CPI inflation at horizon h to a carbon price shock.

$$\sigma(\pi)_{i,t+h} = \Theta^h Carbonprice_{i,t} + \beta^h(L) Carbonprice_{i,t-1} + \delta^h(L)\sigma(\pi)_{i,t-1} + \gamma^h X_{i,t} + \mu_i^h + \epsilon_{i,t+h} \quad (3)$$

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 the associated to any carbon pricing initiative, to ETS and to carbon taxes. $X_{i,t}$ includes all the relevant controls incorporated in the baseline specifications, which described in the section 3. μ_i^h is a country fixed effect and $\epsilon_{i,t+h}$ represents an error term. Under the identifying assumption that a component of the effective carbon price is not predictable by past macroeconomic controls, 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. Finally, $\beta^h(L)$ 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.

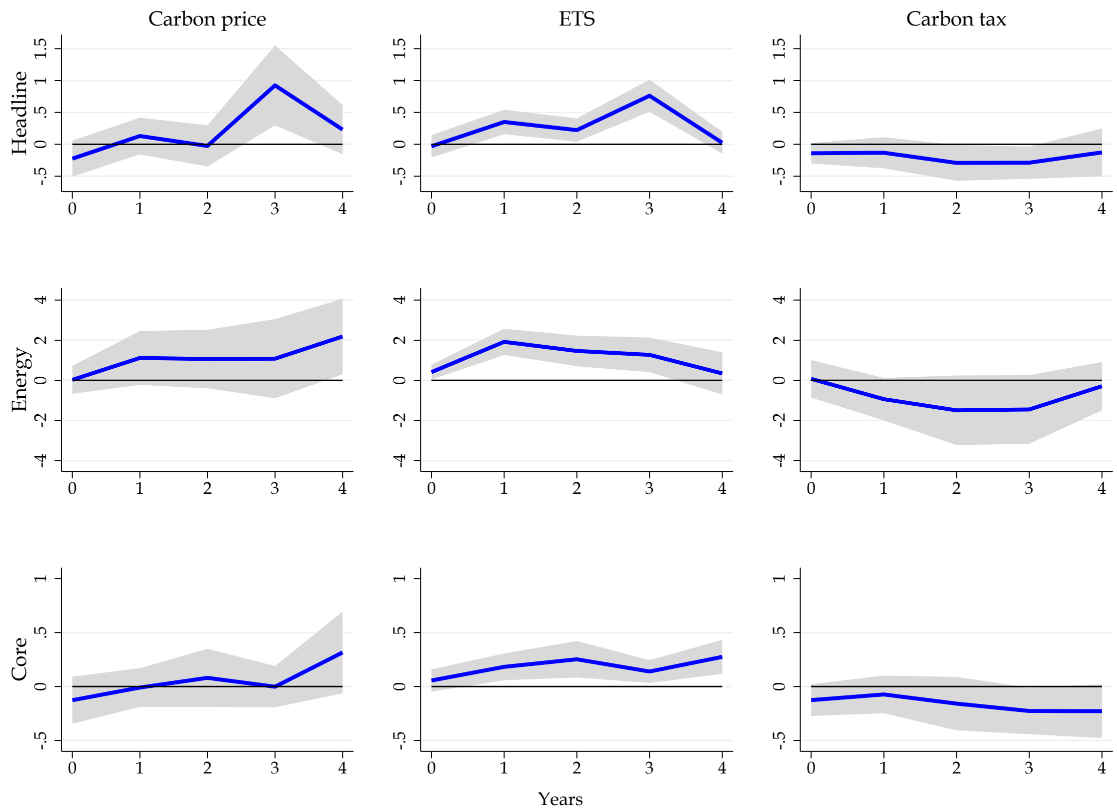
The annual impulse responses shown in Figure 3 are constructed based on the fixed effects estimates of Θ^h coefficients at each horizon. Following Metcalf and Stock (2020) and Konradt and Weder di Mauro (2021), the shock consists in a one-time permanent increase in the effective carbon price by 40 USD applied to 30% of each economy's GHG emissions, equivalent to an increase of the effective carbon price of 12 USD. The 95% confidence bands reported rely on the respective estimated standard errors clustered by country and heteroskedasticity robust.

The main conclusions extracted from this analysis could be summarized as follows. First, a rise in effective carbon prices is associated to an increase of the volatility of headline inflation. This is specially clear for ETS effective prices whereas the impact of carbon taxes rates is only

[24]Konradt and Weder di Mauro (2021) adapt the specification employed by Metcalf and Stock (2020) to assess the impact of carbon taxes on economic growth.

found to marginally reduce volatility for one of the years. Second, only ETS effective prices push up the volatility of energy inflation since the dynamic impact of carbon tax rates is not significant in the horizon. Third, the volatility of core inflation is found to be affected with some delay by effective carbon prices of those jurisdictions with ETS, which is a novel result of this exercise providing evidence of lagged indirect effects of ETS schemes on inflation. All in all, the baseline results based on a static panel data analysis hold roughly robust to the dynamic local projections approach.

Figure 3: Impulse responses of headline, energy and core inflation volatility to shocks in carbon prices, ETS prices and carbon tax rates



Notes: The blue solid lines describe the dynamic impulse responses to a 40 USD carbon tax with 30% emission coverage. The grey area delimits 95% confidence bands. All responses are calculated 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 & Minerals inflation, and CPI inflation. Standard errors are heteroskedasticity robust and clustered by country.

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 policy makers, including central banks, to understand their economic consequences.

Carbon pricing initiatives, aimed at increasing the relative prices of GHG intensive good and services, could not only push up inflation but also affect the volatility of headline inflation. This paper assesses empirically the effects of carbon pricing on inflation volatility disaggregating by the two main types of initiatives: ETS and carbon taxes. To our knowledge, while some other works have dealt with their impact on the level of inflation, this is the first paper that addresses the effects on carbon pricing schemes on the volatility of that inflation.

Our main findings could be summarised as follows. First, this work finds strong evidence that carbon pricing schemes are associated with larger CPI headline inflation volatility. Importantly, this effect is found to be driven only by systems of the ETS type, while no impact is found for the case of carbon taxes. Second, we find that inflation volatility seems to be fed through the energy component. That is to say, the effect of carbon pricing on the volatility of inflation stemming from ETS systems seems mainly circumscribed to energy inflation, and no significant impact is found for the volatility of the core inflation. Third, only for ETS systems, both the increase in the underlying price of emissions and the expansion of the activities covered by carbon pricing initiatives are associated with greater inflation volatility. Finally, our results hold robust to the inclusion of multiple variables of control, different empirical specifications and subsamples of countries.

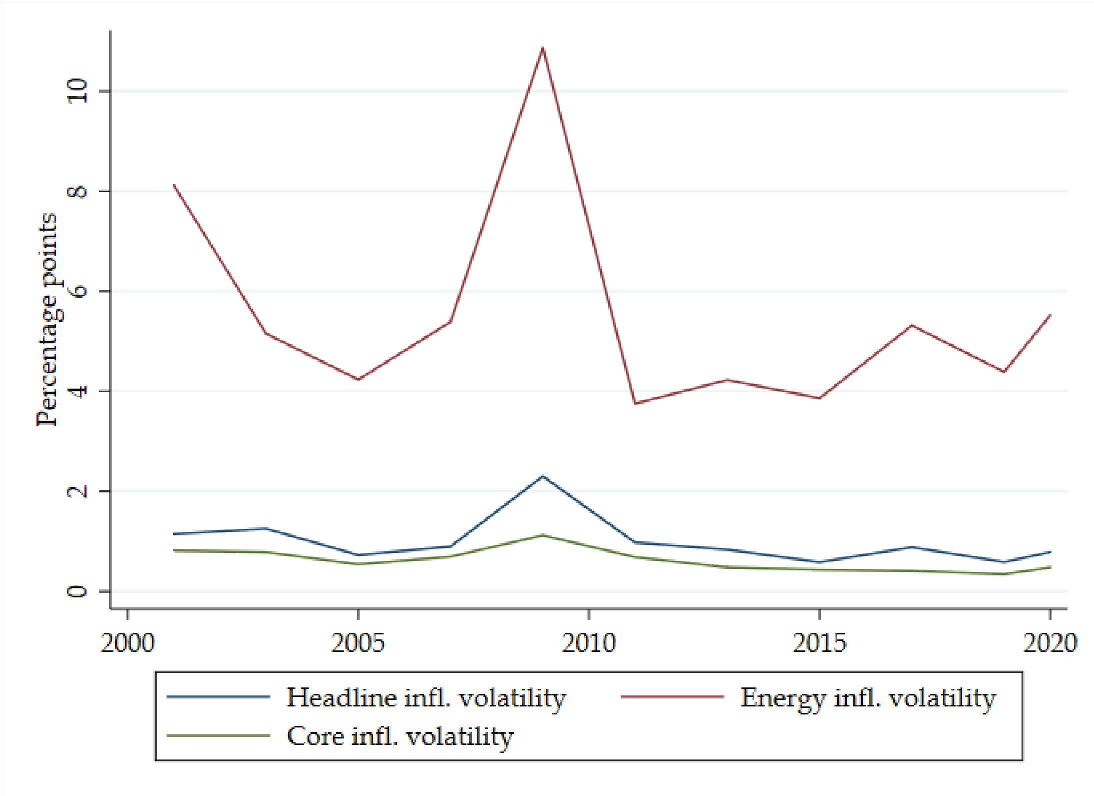
Altogether, our results seem consistent with the fact that carbon pricing initiatives of the ETS type tend to lead to more volatile carbon prices (and carbon price inflation) than the more stable carbon taxes, and that volatility is fed into consumer prices, particularly through the energy component. It also confirms the results of previous studies that carbon pricing initiatives, by changing relative prices and increasing the price of fossil fuels, led to a direct effect on inflation by affecting the energy component, but the evidence of indirect effects in the goods and services part of the core CPI is scarce at least at the carbon price levels and coverage from our sample. Our results find additional evidence that those effects also ultimately translate to higher volatility of the headline inflation mainly through the energy component.

These results have also important implications for monetary policy. Since existing empirical literature has only found that carbon pricing schemes are generally associated to a transitory effect on the level of inflation, credible monetary policy authorities will generally 'look through' this effect as it shares the features of a negative supply-side shock. However, as ETS is found to affect inflation volatility, those relative price shocks further complicate the conduct of monetary policy. Since both the coverage of carbon pricing schemes and the price for carbon should increase in order to achieve the ambitious climate goals of the Paris Agreement, larger inflation volatility could be expected, especially in those jurisdictions in which ETS play a leading role as a mitigation policy. This could affect the communication and the conduct of the monetary policy, and should therefore be monitored closely by central banks. In addition, our results also point to the need to consider the introduction of corrective mechanisms to reduce the volatility of those systems.

Finally, further research is needed to better understand how mitigation policies affect other relevant dimensions of the inflation process, beyond its level and volatility. Particularly for the conduct of monetary policy, it seems of great interest to address the implications of carbon pricing initiatives on inflation persistence, inflation expectations or inflation forecast errors.

Appendix. Figures and Tables

Figure A1: Standard deviation of CPI inflation



Source: Authors' own elaboration based on OECD Data

Table A1: System-GMM estimates of the dynamic panel

	(1) Any carbon pricing	(2) ETS and carbon taxes
L. inflation volatility	0.032	0.032
	(0.671)	(0.648)
Carbon pricing, any	-0.338	
	(0.478)	
ETS, any		-0.276
		(0.507)
Carbon Tax, any		0.095
		(0.809)
GDP per capita	0.003	-0.000
	(0.694)	(0.997)
Population	0.002	0.002
	(0.194)	(0.244)
Trade openness	0.007**	0.007**
	(0.020)	(0.037)
Primary exporter	0.194	0.156
	(0.254)	(0.324)
Capital flows	-0.001**	-0.001***
	(0.021)	(0.008)
Commodity prices: Energy inflation	0.011***	0.010***
	(0.005)	(0.004)
Commodity prices: Agriculture inflation	0.074***	0.076***
	(0.000)	(0.000)
Commodity prices: Metals & Minerals inf.	-0.049***	-0.050***
	(0.000)	(0.000)
CPI inflation	0.160***	0.158***
	(0.000)	(0.000)
Observations	355	355
Number of countries	36	36
Hansen test p-value	0.215	0.197
Arellano-Bond test AR(1) p-value	0.00571	0.00382
Arellano-Bond test AR(2) p-value	0.504	0.461
Instrument count	34	34

Notes: * (**) [***] denotes statistical significance at 10% (5%) [1%]. Robust p-values in parentheses. See main text of the paper for the definition of the variables.

Table A2: Results considering period post Paris Agreement, the share in value added of polluting sectors and environmental stringency

Standard deviation of the headline CPI inflation	(1)	(2)	(3)	(4)	(5)	(6)
Carbon pricing, any	0.619***		1.396**		0.583***	
	(0.001)		(0.016)		(0.004)	
ETS, any		0.777***		1.069**		0.837***
		(0.000)		(0.030)		(0.000)
Carbon Tax, any		-0.058		-0.015		-0.021
		(0.797)		(0.981)		(0.9160)
Post-2015, dummy	0.345	0.490*				
	(0.364)	(0.099)				
Carbon pricing, any * Post-2015, dummy	-0.246					
	(0.525)					
ETS, any * Post-2015, dummy		-0.360				
		(0.233)				
Carbon Tax, any * Post-2015, dummy		-0.005				
		(0.985)				
Value-added share of polluting sectors (20%)			3.597	0.457		
			(0.453)	(0.923)		
Carbon pricing, any *Value-added share polluting sectors			-5.425			
			(0.178)			
ETS, any * Value-added share polluting sectors				-2.556		
				(0.432)		
Carbon tax, any * Value-added share polluting sectors				0.865		
				(0.851)		
Environmental Stringency					-0.040	-0.167
					(0.729)	(0.186)
Observations	387	387	354	354	343	343
R-squared	0.316	0.327	0.323	0.325	0.335	0.349
Number of countries	36	36	36	36	32	32
Control variables included	YES	YES	YES	YES	YES	YES

Notes: * (**) [***] denotes statistical significance at 10% (5%) [1%]. Robust p-values in parentheses. Control variables: GDP per capita, Population, Trade openness, Prima exporter, Capital flows, Commodity prices: Energy inflation, agriculture inflation and Metals & Minerals inflation, CPI inflation. See main text of the paper for the definit of the variables.

Table A3: Robustness checks. Time windows

Standard deviation of the headline CPI inflation						
	(1) 12 months	(2) 24 months	(3) 36 months	(4) 12 months	(5) 24 months	(6) 36 months
Carbon pricing, any	0.239***	0.619***	0.573***			
	(0.000	(0.001)	(0.006)			
ETS, any				0.305***	0.710***	0.618***
				(0.000)	(0.000)	(0.009)
Carbon Tax, any				-0.021	0.055	0.304
				(0.764)	(0.778)	(0.159)
Observations	716	387	249	716	387	249
R-squared	0.456	0.314	0.414	0.464	0.321	0.421
Number of countries	36	36	36	36	36	36
Control variables included	YES	YES	YES	YES	YES	YES

Notes: * (**) [***] denotes statistical significance at 10% (5%) [1%]. 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 & Minerals inflation, CPI inflation. See main text of the paper for the definition of the variables.

Table A4: Robustness checks. Volatility measure in logarithms

Log(1+standard deviation headline CPI inflation)		
	(1)	(2)
Carbon pricing, any	0.187***	
	(0.000)	
ETS, any		0.229***
		(0.000)
Carbon Tax, any		-0.008
		(0.886)
Observations	387	387
R-squared	0.361	0.372
Number of countries	36	36
Controls included	YES	YES

Notes: * (**) [***] denotes statistical significance at 10% (5%) [1%]. 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 & Minerals inflation, CPI inflation. See main text of the paper for the definition of the variables.

Table A5: Robustness checks. Alternative advanced economies grouping

Standard deviation of the headline CPI inflation		
	(1)	(2)
Carbon pricing, any	0.524***	
	(0.000)	
ETS, any		0.640***
		(0.000)
Carbon Tax, any		0.009
		(0.946)
Observations	299	299
R-squared	0.411	0.431
Number of countries	28	28
Control variables included	YES	YES

Notes: * (**) [***] denotes statistical significance at 10% (5%) [1%]. 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 & Minerals inflation, CPI inflation. See main text of the paper for the definition of the variables.

Table A6: Robustness checks. Inclusion of time dummies

Standard deviation of the headline CPI inflation						
	Baseline results		GHG coverage		Effective carbon price	
	(1)	(2)	(3)	(4)	(5)	(6)
Carbon pricing, any	0.507**					
	(0.014)					
ETS, any		0.694***				
		(0.005)				
Carbon Tax, any		0.058				
		(0.774)				
Coverage (fully overlapping)			0.011*			
			(0.055)			
Coverage ETS (fully overlapping)				0.014**		
				(0.026)		
Coverage Carbon Tax (fully overlapping)				0.008		
				(0.197)		
Price					0.005	
					(0.743)	
Price (ETS)						0.060**
						(0.024)
Price (Carbon tax)						-0.002
						(0.866)
Observations	387	387	387	387	387	387
R-squared	0.340	0.344	0.337	0.344	0.328	0.335
Number of countries	36	36	36	36	36	36
Control variables included	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES

Notes: * (**) [***] denotes statistical significance at 10% (5%) [1%]. 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 & Minerals inflation, CPI inflation. Biennial time fixed effects included. Results including coverage non-overlapping are qualitatively similar and available upon request. See main text of the paper for the definition of the variables.

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