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Optimal carbon pricing with fluctuating energy prices — Emission targeting vs. price targeting*

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ABSTRACT

Prices of primary energy commodities display marked fluctuations over time. Market-based climate policy instruments (e.g., emissions pricing) create incentives to reduce energy consumption by increasing the user cost of fossil energy. This raises the question of whether climate policy should respond to fluctuations in fossil energy prices? We study this question within an environmental dynamic stochastic general equilibrium (E-DSGE) model calibrated on the German economy. Our results indicate that the welfare implications of dynamic emissions pricing crucially depend on how the revenues are used. When revenues are fully absorbed, a reduction in emissions prices stabilizes the economy in response to energy price shocks. However, when revenues are at least partially recycled, a stable emissions price improves overall welfare. This result is robust to different modeling assumptions.

Keywords: energy prices, E-DSGE, climate policy, welfare
JEL Codes: E62, E64, Q43, Q52

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1 Introduction

Despite having a long-term focus, climate policy has to consider economic conditions in the short-term. As emissions are highly pro-cyclical (Doda (2014)) , costs and benefits of environmental regulation could vary over the business cycle. This aspect is considered in the design of real-world environmental policies. The European Emission Trading System (EU ETS) includes a Market Stability Reserve that aims to protect the system from business cycle shocks (Perino et al. (2021)). In the past decade, a large literature emerged that studied how climate policy should be designed in light of business cycles (see Annicchiarico et al. (2021) for a review). A key lesson from this literature is that the policy implications depend on the source of the business cycle, namely the type of shock that triggers fluctuations.

Recently, prices of various energy commodities have increased at record levels (see Fig. 1). While the price increase in 2021 was first driven by growing demand from a recovering global economy after the pandemic, recent geopolitical developments related to the Russian-Ukrainian conflict led to further price hikes (IEA 2022). From the literature on energy price dynamics, it is well known, that energy price fluctuations are closely linked to business cycle dynamics (cf. Kim and Loungani (1992)) and could even induce recessions (cf. Kilian and Vigfusson (2017)). Thus, high energy prices could lead to a trade-off between long-term climate policy and short-term stability and affordability of energy. In this paper, we examine this nexus by providing a welfare economic analysis in a stylized dynamic stochastic general equilibrium (DSGE) setting.

In our model, we disregard the benefits of carbon pricing in terms of reduced climate damages as these benefits occur globally and in the long-term. Rather, we take the European climate policy perspective of achieving a certain emissions target. In this setting, pricing carbon constitutes a distortion and, hence, a welfare loss. Thus, a reduction of the carbon price generates welfare gains in the first place. As carbon prices are introduced with the explicit intention to reduce carbon emissions, a reduction of carbon prices in the light of rising energy prices must be — if policy aims at achieving emissions goals at least in the medium run — accompanied by higher carbon prices in the future. The idea to compensate households for rising energy prices by reducing carbon taxes or carbon prices therefore constitutes a policy approach where carbon prices fluctuate countercyclical relative to energy prices to stabilize net energy prices for consumers.

We show in a simple analytical model that the welfare implications of such a counter-cyclical pricing approach crucially depend on the way the revenues from pricing carbon are used by the government. If these revenues are to a certain extent reimbursed to households in a non-distortionary way, a counter-cyclical pricing policy is not optimal. Only if the revenues from pricing carbon represent a complete loss of resources on the side of the households (i.e. if these revenues are used to build 'pacific islands'), a policy which tries to compensate for fluctuating energy prices by countercyclical adjustments in carbon prices turns out to be optimal.

Using a numerical DSGE model calibrated for the German economy, we quantify welfare implications of different policy approaches. The key insights also hold for a number

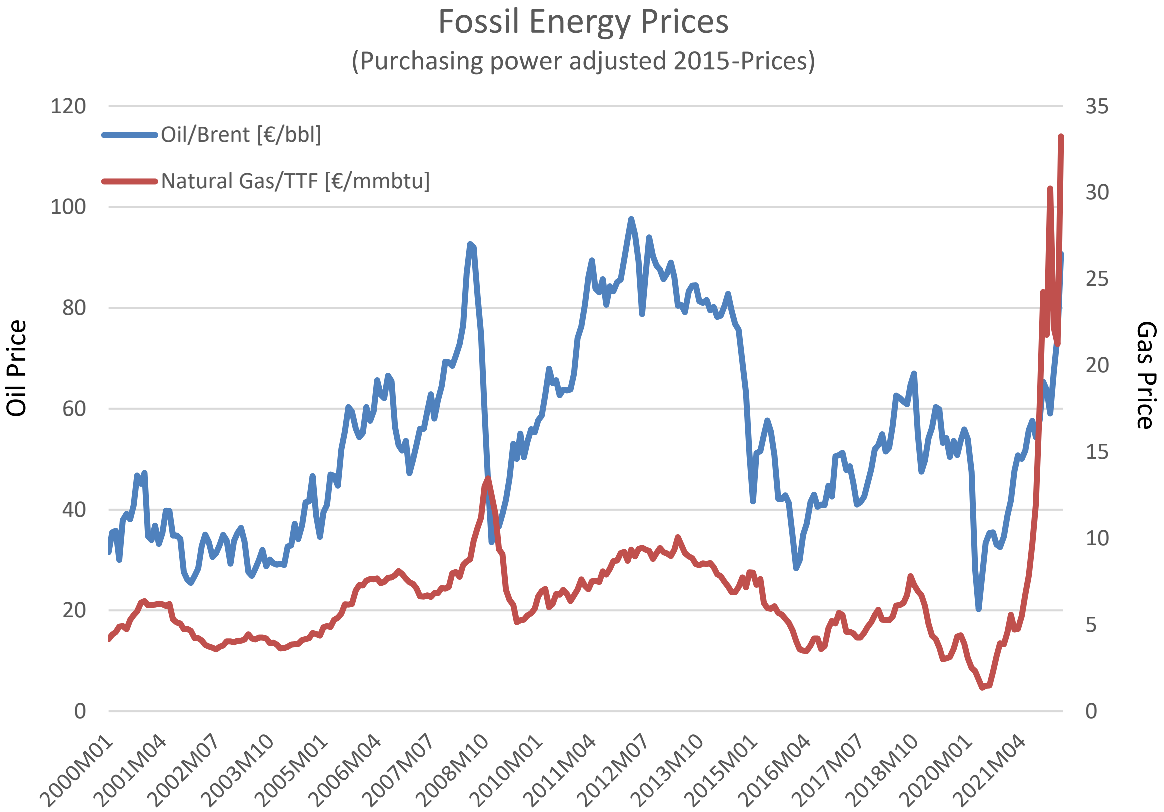

Figure 1: International fossil energy prices (nominal). Source: World Bank Pink Sheet.

of model extensions and other revenue recycling schemes.

2 Emissions targeting vs. price targeting

In this section, we motivate two different policy rules: emissions and price targeting. Let us first consider an economy where the carbon price emerges from an emissions trading scheme. The demand for emissions permits can be derived from the decisions of agents to use fossil energy (either firms or households) and might fluctuate over time due to exogenous fluctuations in energy prices on world markets. The demand for permits is declining in the carbon price. As an increasing energy price reduces the demand and the use of fossil energy, it simultaneously reduces the demand for emissions permits.

In such a setting, achieving a certain climate target is equivalent to set an emissions target which determines the supply of permits (cf. the inelastic supply curve at E^* in figure 2). In this case — which we refer to as *emissions targeting* — the price of permits is endogenous and fluctuates according to changes in the demand for permits that are caused by fluctuating energy prices (cf. the demand functions $E(\tau + p_a)$ and $E(\tau + p_b)$ in figure 2 that result if the energy price deviates from its steady state value p^* and the corresponding carbon prices τ_a and τ_b.).

As an alternative to *emissions targeting*, we consider a *price targeting* approach, where

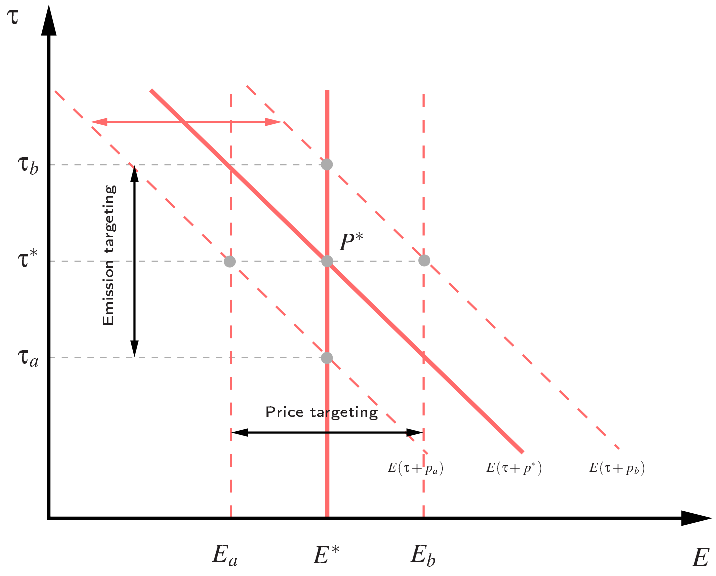

Figure 2: *Price- vs. emission targeting.*

the supply of permits is set such that a pre-determined permit price emerges (cf. τ^* in figure 2). Figure 2 shows, that in order to keep the carbon price at τ^*, the supply of permits must be increased in case of declining energy prices which shift the demand for permits to the right (cf. the supply curve at E_b) and vice versa in case of rising energy prices (cf. the supply curve at E_a). Note that a pure *price targeting* approach can also be implemented as an open-end permit supply at a fixed price τ^* or as a carbon tax at the rate τ^* (rather than an emissions trading scheme).

Under *price targeting*, a pre-determined climate (emissions) goal cannot be met in every period and thus emissions E fluctuate. In contrast, under *emissions targeting* the pre-determined climate goal is met in every period and the carbon price τ^* fluctuates. Both approaches are environmentally equivalent when expected emissions under *price targeting* equal the emissions goal in the *emissions targeting* approach. However,the revenues $\tau\, E$ from pricing carbon will fluctuate due to either fluctuating prices or permit quantities. Whether or not the fluctuations of the revenues from pricing carbon matter for the agents in the economy depends on whether or not these revenues are reimbursed to the agents and therefore result in transfer payments flowing to the households. Thus the welfare effects of both strategies crucially depend on to what extent the revenues from pricing carbon are reimbursed to the households.

3 Model

The analysis is based on a simple DSGE–Model following Fischer and Springborn (2011). In the production of a final good, which is used for consumption and investment (cf. (1-a)), firms use capital K_t and energy E_t .[1] The use of energy is accompanied by emissions that have to be covered by emission permits. For simplicity, we assume in a one–to–one relationship between emissions and energy use. Thus, the cost of energy use consist of the price p_t for energy itself as well as the carbon price τ_t and this results — given the assumed Cobb–Douglas production function — in the energy demand function (1-d). Equation (1-b) is the usual Euler equation describing optimal intertemporal consumption choice and (1-e) states that the logarithm of the energy price p_t follows an AR(1)–process and fluctuates randomly around a mean value $\ln \bar{p}$.

$$
\begin{aligned}
Y_t &= A\, K_t^{\alpha}\, E_t^{\gamma} && \text{(1-a)}\\
C_t^{-\theta} &= \beta\, \mathbb{E}_t\, \left(R_{t+1}\, C_{t+1}^{-\theta}\right) && \text{(1-b)}\\
Y_t &= C_t + p_t\, E_t + (1-\mu)\, \tau_t\, E_t + K_{t+1} - (1-\delta)\, K_t && \text{(1-c)}\\
p_t + \tau_t &= \gamma\, Y_t / E_t && \text{(1-d)}\\
p_t &= \bar{p}^{1-\rho}\, p_{t-1}^{\rho}\, \exp(\epsilon_t) && \text{(1-e)}\\
\left(\frac{\tau_t}{\tau^*}\right)^{\lambda} &= \left(\frac{E_t}{E^*}\right)^{1-\lambda} && \text{(1-g)}
\end{aligned}
$$

Equation (1-g) specifies climate policy against the background of the above made distinction between emission targeting and price targeting. We assume that the ultimate goal of climate policy is to implement a an emissions target E^* and that τ^* is the carbon price that results from the market for permits in case of an energy price p^* with permit supply E^*. Thus, $\lambda = 0$ implements (pure) emission targeting as in every period the level of emissions equals the emission target E^*. Contrary, $\lambda = 1$ represents a (pure) price targeting as the carbon price is held constant while expected emissions equal E^*.[2] Hybrid forms of both regimes can be analyzed by allowing for $\lambda \in (0, 1)$. Finally, (1-c) is the resource constraint of the economy. Here the parameter μ governs, to what extent the revenues from pricing carbon $\tau_t\, E_t$ are recycled to households via transfers. With $\mu = 0$ no reimbursement takes place, while $\mu = 1$ implies that all revenues flow back to the households via transfer payments.

A quantitative analysis requires a numerical specification of the model. To this end, the model is calibrated to match some empirically observed moments of the German economy (cf. Table 1 for the respective parameter values). For the calibration of the energy price, we rely on data on primary energy prices and on the utilization of fossil fuels in Germany over the period 1996Q1–2021Q2 and construct a composite energy price

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[1] In order to provide a clear intuition on the underlying mechanisms that drive our results and to simplify the exposition of the model, we abstract from nominal rigidities and use a simple RBC model in our main analysis. As a robustness check, we replicate the analysis, taking endogenous labor supply, price rigidities as in Calvo (1983) and investment adjustment costs as in Christiano et al. (2005) into account. While these modifications of the baseline model affect the quantitative results of our analysis, the findings are not affected qualitatively.

[2] The present formalization of climate policies can also be interpreted as a dynamic policy rule, comparable to a Taylor rule, as explained by Roach (2021).

Parameter	Value	Description
α	0.3	Capital share in national income
β	0.998	Discount factor — annual real rate of 0.8%
θ	2	Inverse elasticity of intertemporal substitution
γ	0.03	Fossil energy share in GDP
δ	0.025	Depreciation rate
ρ	0.76	Estimated from data on energy prices
σ_ϵ	0.111	dto.
τ^*	$0.238\,\bar{p}$	20% reduction of s.s. emissions compared to a situation with $\tau = 0^{1)}$

1) An energy price $p_1 = k^{\frac{\gamma+\alpha-1}{1-\alpha}}\, p_0$ implies that $e(p_1) = k\, e(p_0)$. Thus, $\tau^* = \left(0.8^{\frac{\gamma+\alpha-1}{1-\alpha}} - 1\right)\bar{p}$.

Table 1: Calibrated Parameters

index.[3] To account for nominal price changes we deflate the quarterly series using the harmonized consumer price index and finally filter the resulting series using the HP–filter. The estimation of the process according to (1-e) then results in an estimate of the autocorrelation coefficient of $\rho = 0.76$ and an estimate of the standard deviation of the shock of $\sigma_\epsilon = 0.111$.[4]

4 Dynamic reactions to shocks to energy prices and welfare effects

4.1 Impulse responses

Impulse responses of macroeconomic variables to shocks to energy prices under emission targeting and price targeting depend on the extent to which the revenues from pricing carbon are reimbursed to the households. Figure 3 shows the impulse responses of emissions, the carbon price and consumption to a serially correlated shock to energy prices under emission targeting and price targeting if revenues from pricing carbon represent a pure loss resources, i.e. in case of no reimbursement ($\mu = 0$). We consider an energy price shock of one standard deviation, which amounts to a price increase of roughly 11 percent. [5]

Without reimbursement, emission targeting shields the economy completely from the effects of fluctuating energy prices. As the carbon price τ_t simply offsets any change

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[3] Data on primary energy utilization and fossil fuel prices is obtained from BMWI (2021) where an aggregate price index is constructed using import prices on oil, natural gas and hard coal, weighted by their energy consumption shares in Joule. Data on the consumer price index is taken from Bundesbank (2022), series BBDP1.M.DE.Y.VPI.C.A00000.I15.A (seasonally adjusted consumer price index)

[4] Many papers that analyze energy price fluctuations in the context of DSGE models follow Kim and Loungani (1992) and assume an ARMA(1,1) process for energy prices. The results presented here, however, are not sensitive to this alternative modelling choice.

[5] Figure 3 and 4 each show the responses (i.e. deviations from the respective steady states) to a one standard deviation shock to energy prices.

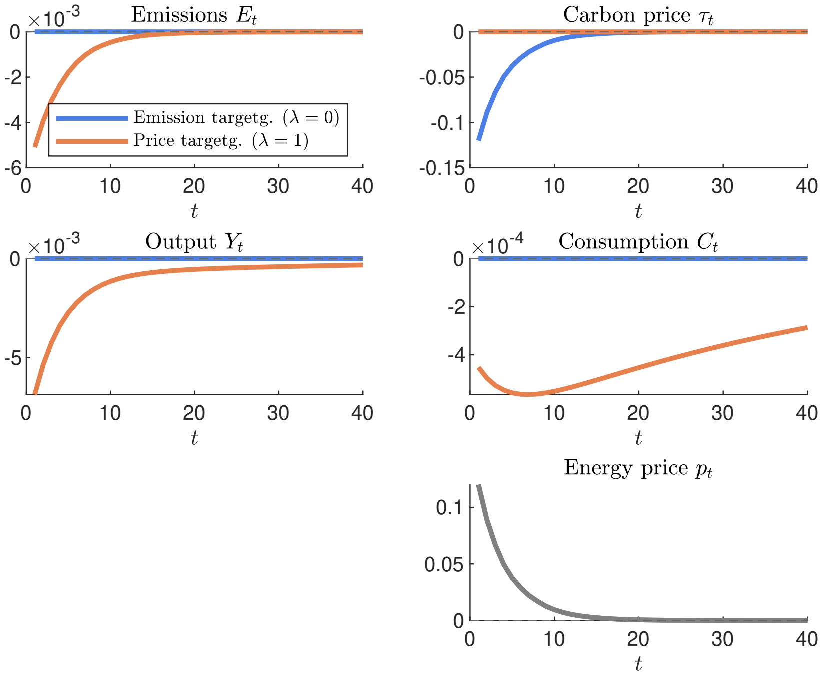

Figure 3: *Quarterly impulse response of an energy price shock of 11% – without any recycling of revenues* ($\mu = 0$)*.*

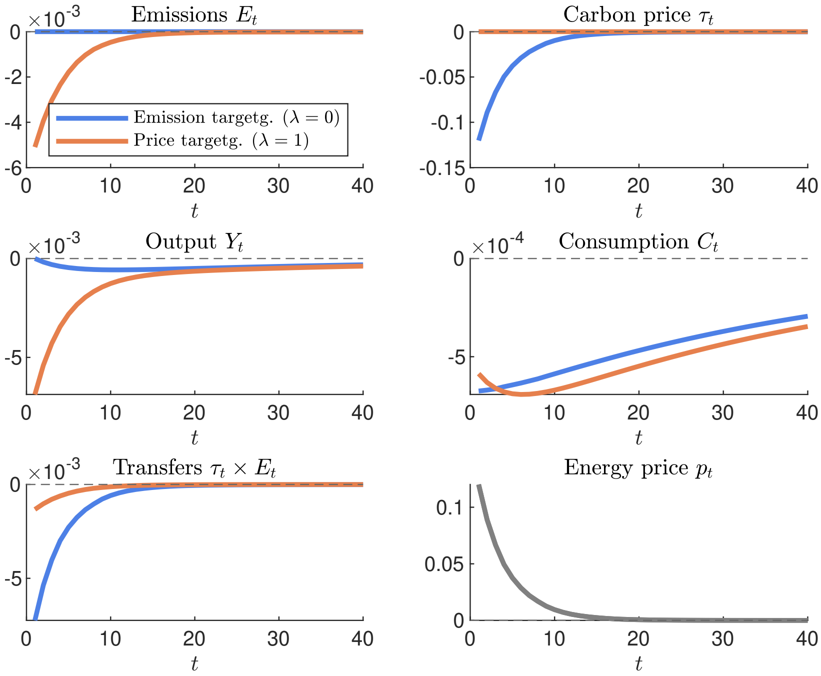

Figure 4: *Quarterly impulse response of an energy price shock of 11% – with recycling of revenues* ($\mu = 1$)*.*

in energy prices, fluctuating energy prices do not cause any fluctuations in energy use and therefore also no fluctuations in other macroeconomic variables (cf. the blue impulse responses in figure 3). In contrast, in case of price targeting (cf. the red impulse responses in figure 3) fluctuations in energy prices directly translate into fluctuations of energy use and other macroeconomic variables. Consequently, without reimbursement of revenues ($\mu = 0$) emission targeting is the optimal strategy.

This stabilizing effect of emission targeting, however, disappears if the revenues from pricing carbon are reimbursed to the households. Figure 4 depicts the respective impulse responses of emissions, the carbon price and consumption to a serially correlated shock to energy prices if all revenues from pricing carbon are reimbursed to the households via transfer payments. Even if emission targeting results in a stabilization of energy use, the fact that the carbon price declines in reaction to an increase in energy prices results in a reduction of transfer payments to the households. In reaction to this, households reduce consumption and investment which cause fluctuations in macroeconomic variables (cf. the blue impulse responses in figure 4).

A first result is that for the macroeconomic impact of energy price shocks it matters whether or not the revenues from pricing carbon are reimbursed to the households, because the above described shielding effect in case of emission targeting disappears in case of such a reimbursement. As another result one might notice that only because of this shielding effect emission targeting is obviously the welfare maximizing policy if there is no reimbursement.

Matters are not that clear if the revenues from pricing carbon are reimbursed to the households as the impulse responses depicted in figure 4 do not answer the question which regime — emission targeting or price targeting — performs better with respect to welfare. Next, we perform an explicit welfare analysis to answer this question.

4.2 Welfare effects

For our welfare analysis, we take emission targeting as the baseline scenario and calculate the percentage change Δ in consumption of the representative household that makes her indifferent to a scenario with price targeting. Hence, we use equivalent variations in expected welfare as we take the stochastic process driving energy prices as given.[6]

Figure 5 plots the respective welfare effects Δ for different values of λ — thus allowing for hybrid forms of emission and/or price targeting — and three different values of μ representing no revenue recycling, partial revenue recycling and complete recycling of the revenues from pricing carbon. The respective values for Δ resulting in case of pure price targeting are listed in table 2.

As can bee seen in case $\mu = 0$, i.e. without any revenue recycling, any form of price targeting causes welfare losses. The reason for this is the above described shielding effect of emission targeting which is not present in case of price targeting. If, however, the

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[6] As described above, the stochastic process for the energy price implies that emissions fluctuate whenever there is no strict emission targeting (i.e. $\lambda \neq 0$) such that mean emissions differ from the level of emissions occurring in a deterministic steady state. Therefore, in order to perform a meaningful welfare analysis, the carbon price target τ^* in (1-g) is adjusted endogenously to achieve independently of λ a constant level of mean emissions. Table 3 shows the respective first and second moments of model variables for the cases of (pure) emission targeting and (pure) price targeting. As can be seen, price targeting requires a higher mean carbon price — and thus a higher carbon price target p^* — in order to keep mean emissions constant.

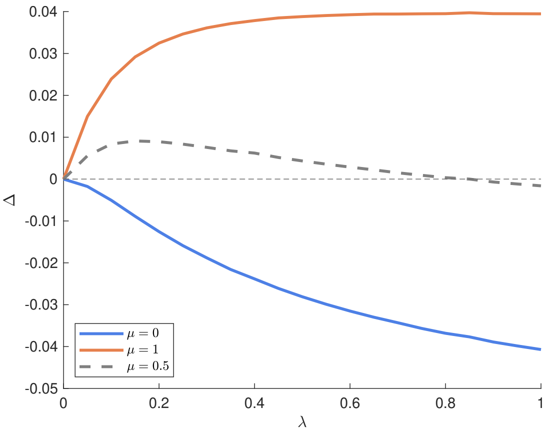

Figure 5: *Welfare gain* Δ *over a continuum of pure emissions targeting* ($\lambda = 0$) *to pure price targeting* ($\lambda = 1$) *depending on the share of carbon pricing revenues redistributed to households,* μ.

Recycling of revenues		
complete ($\mu = 1$)	partial ($\mu = 0.5$)	none ($\mu = 0$)
0.0395	-0.0004	-0.0406

Table 2: *Welfare gain* Δ *in case of pure price targeting compared to pure emission targeting.*

revenues are reimbursed price targeting can be a superior strategy. With $\mu = 1$ price targeting is superior to emission targeting under welfare aspects, even if a hybrid strategy results in larger welfare gains than pure price targeting with $\lambda = 1$. A similar result applies if there is only partial reimbursement of revenues from pricing carbon: If the fraction of revenues flowing back to the households is sufficiently large, price targeting — again with some kind of hybrid strategy being optimal — turns out to be superior to emission targeting.

The observed welfare differences between price targeting and emissions targeting are directly related to the different dynamics under the two regimes. In detail, price targeting leads to larger output fluctuations in response to energy price shocks (figure 3), but relatively smaller fluctuations in revenues ($\tau_t \times E_t$). The stabilization of transfers under price targeting helps to reduce the volatility of private consumption, which is favorable from a welfare perspective. To confirm this reasoning, table 3 summarizes the moments of key variables with complete recycling and without recycling for both instruments. Without recycling, emissions targeting fully stabilizes emissions, output and consumption. In this case, we also observe that expected aggregate consumption is a magnitude larger compared to price targeting. This pattern changes in case of complete revenue recycling. While the volatility of output and consumption is still smaller under emissions targeting, expected aggregate consumption is a magnitude larger under price targeting. The reason behind these differences is that without revenue recycling, variations in revenues are completely unrelated to other variables. In contrast, when revenues are recycled, the higher expected value and the smaller variance of revenues under price targeting matters. Revenue recycling can thus be viewed as an insurance against energy price fluctuations, such that the larger and less volatile share of revenues in aggregate consumption under price targeting allows for larger expected aggregate consumption.

	With complete recycling $\mu = 1$			
	emission targeting		price targeting	
	$\mathbb{E}[x]$	σ_x	$\mathbb{E}[x]$	σ_x
τ_t	0.238	0.169	0.261	0
E_t	0.060	0	0.060	0.008
$\tau_t\, E_t$	0.014	0.010	0.016	0.002
Y_t	2.488	0.003	2.487	0.012
C_t	1.737	0.003	1.738	0.004
	Without recycling $\mu = 0$			
τ_t	0.238	0.168	0.261	0
E_t	0.060	0	0.060	0.008
$\tau_t\, E_t$	0.014	0.010	0.016	0.002
Y_t	2.488	0	2.487	0.012
C_t	1.723	0	1.722	0.003

Table 3: *First and second moments*

As can be seen from figure 5 and table 2, the welfare effects are quantitatively rather small. This is in line with other studies that analyze welfare effects associated with stabilization policies and that usually find that the resulting welfare effects are rather small. Based on private consumption expenditures per capita in Germany in 2020 (≈ 20.600€) a consumption change of 0.04% as stated in table 2 amounts to approximately 8.23€ per capita and year, which is in fact a manageable amount (≈ 680€ million per year at the aggregate level).The finding that price targeting that allows for pro cyclical emissions dynamics is superior from a welfare perspective is consistent with findings in other studies. Heutel (2012) uses a similar framework to examine climate policies in light of TFP fluctuations. He reports a potential welfare gain from a pro cyclical emissions policy of around 950$ million per year for the US economy.

5 Robustness

The present analyis is based on a simplified setup for the sake of clarity and to focus on the underlying economic arguments. However, the main results are robust to more elaborate models that account for features usually considered in DSGE models. In the following, we briefly illustrate the implications of specific model extensions.

Since energy price shocks induce fluctuations in relative factor prices, aggregate dynamics crucially hinge upon the functional form of the production function. In the main analysis we assume a unit elasticity of substitution between physical capital and fossil energy inputs. However, assuming that the production function is of the CES type and allowing for complementary between capital and energy does not qualitatively alter the presented results.[7]

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[7] Results for the CES specification are avialable upon request.

Another potentially important simplification of the framework is the assumption of an inelastic labor supply. Furthermore, Annicchiarico and Di Dio (2015) point out that the presence of real and nominal frictions can affect the evaluation of climate policy instruments. To take these aspects into account, we introduce nominal rigidities as in Calvo (1983) and allow for endogenous labor supply of households. In addition, we incorporate convex investment adjustment costs as in Christiano et al. (2005). These extensions require the specification of additional parameters which we set in accordance with the relevant literature, as summarized in table 4.

Parameter	Value	Description
χ	1.5	Inverse Frisch elasticity
ψ	20.5	Disutility of labor — average hours of 0.33
ϵ	6	Elasticity of substitution for intermediate goods
θ_p	0.75	Calvo Parameter
κ	3.9	Adjustment costs Parameter
γ_Π	1.47	Taylor rule coefficient inflation
γ_R	0.91	Taylor rule coefficient persistence

Table 4: Additional Parameters (Frictions).

As one would expect, endogenous labor supply and the presence of frictions alter aggregate dynamics. While the responses to energy price shocks are qualitatively similar to the dynamics observed in the baseline model, the overall adjustments are sluggish and take longer. Consequently, we also observe quantitative differences in the welfare comparison between price targeting and emissions targeting compared to the baseline model. The corresponding welfare effects are reported in table 5.

	Recycling of revenues		
	complete ($\mu = 1$)	partial ($\mu = 0.5$)	none ($\mu = 0$)
Baseline	0.040	-0.002	-0.041
dto. with $\sigma_{K,E} = 0.5$	0.017	-0.008	-0.032
dto. with $\theta = 8$	0.039	-0.001	-0.041
Frictions & end. labor	0.010	-0.011	-0.032

Table 5: *Welfare gain Δ in case of price targeting compared to emission targeting for different model extensions.*

Compared to the previous results the welfare effects show no qualitative differences. Again, we find that in terms of welfare, emissions targeting is favorable without revenue recycling but price targeting is superior with revenue recycling. However, the welfare effects tend to be smaller in the extended model. While the welfare costs of price targeting without revenue recycling reduce only slightly to 0.03%, the welfare gains with revenue recycling reduce to about 0.01% of consumption.

6 Conclusion

The present paper picks up the ongoing discussion to what extent climate policies should respond to fluctuations in fossil energy prices. Since market-based climate policy instruments increase the costs of fossil energy, temporary downward adjustments of emissions targets or emissions price targets appear as suitable measures to stabilize the economy in response to energy price shocks. However, reductions of carbon prices do not only stabilize the utilization of fossil energy but also affect aggregate macroeconomic dynamics and the revenues generated from climate policies. Against this background, whether or not climate policy should be dynamically adjusted in response to fossil fuel price fluctuations is an open question.

We assess this question from a macroeconomic perspective. In the first part of the analysis, we illustrate the underlying mechanisms and key arguments using a simple analytical model. The second part of our analysis is based on an RBC model where emissions result from the utilization of fossil energy. We calibrate the model to match the German economy and introduce energy price shocks in accordance with data on a fossil energy price index. This framework allows to quantitatively assess the differences between price targeting and emissions targeting with regards to aggregate dynamics and welfare.

This analysis offers various insights. We find that if revenues from climate policies are not recycled, reducing carbon prices can fully stabilize aggregate output and consumption in response to energy price fluctuations. However, if revenues are at least partially recycled, this stabilizing effect vanishes. Our welfare computations show, that in this case, a price targeting policy, which keeps emissions prices constant and allows for cyclical adjustments in the utilization of energy can be welfare improving. Admittedly, the welfare gains from such a policy are rather moderate and amount to roughly 8€ per capita and year if revenues are fully recycled. Nevertheless, these results suggest that welfare oriented climate policies should not be adjusted to counteract fluctuations in fossil energy prices.

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