Is the Green Transition Inflationary?*

Marco Del Negro
NY Fed and CEPR

Julian di Giovanni
NY Fed and CEPR

Keshav Dogra
NY Fed

February 3, 2023

Abstract

We develop a two-sector New Keynesian model to analyze the inflationary effects of climate policies. Climate policies do not force a central bank to tolerate higher inflation, but may generate a tradeoff between the central bank's objectives for inflation and real activity. The presence and size of this tradeoff depends on how flexible prices are in the "dirty" and "green" sectors relative to the rest of the economy, and on whether climate policies consist of taxes or subsidies.

JEL Classifications: E12, E31, E52, Q54

Keywords: Green transition, inflation, central bank's tradeoffs

*We thank Katie Baker and Neel Lahiri for outstanding research assistance. The views expressed herein are those of the authors and not necessarily those of the Federal Reserve Banks of New York or any other person affiliated with the Federal Reserve System. E-mail (URL): marco.delnegro@ny.frb.org (https://www.newyorkfed.org/research/economists/delnegro), julian.digiovanni@gmail.com (http://julian.digiovanni.ca), Keshav.Dogra@ny.frb.org (https://www.newyorkfed.org/research/economists/dogra).

1 Introduction

Climate change will have widespread effects on the economy. One prescient concern is climate change's impact on price stability. Indeed, some policymakers have argued that we face a "new age of energy inflation" (Schnabel, 2022), whereby central banks may be forced to live with a persistently higher level of inflation as a result of both the physical effects of climate change and the transition to a low-carbon economy. While this idea may be intuitively plausible, it is not clear under what conditions climate change is inflationary. Monetary policymakers may still have the necessary levers to meet their inflation targets, though doing so may involve a tradeoff with other targets, such as the output gap.

To date, very few researchers have formally analyzed the inflationary impact of climate change and the tradeoffs faced by central banks. This paper's goal is to provide a simple framework as a first step in this direction. We develop a stylized two-sector New Keynesian model to ask how the *green transition* – policies such as carbon taxes that reduce greenhouse gas emissions in order to limit global warming – affects monetary policymakers' ability to pursue price stability. We focus on the inflationary effects of climate *policy* because the green transition is an immediate concern for central bankers as policies aimed at discouraging high emission activities and/or promoting clean energy have been already put in place in many advanced economies, and more are likely to come. We do not study the impact of the physical effects of climate change itself on inflation, partly because the implications of climate change for the economy, even if potentially large, are also very uncertain and hence more difficult to discuss.

We find that the green transition does not force monetary policymakers to tolerate higher inflation, but can potentially generate a tradeoff for policymakers. Two key factors drive this tradeoff. First, the relative *stickiness* of prices in the "dirty", "green" (clean energy), and the "other" sector (the rest of the economy) is a key determinant as to whether monetary policy is able to keep inflation at its target while also stabilizing output at its natural level. Second, the two types of climate policies analyzed in this paper – either a tax on the dirty sector or a subsidy on the green sector – have dramatically different implications for inflation and the tradeoff faced by the monetary policymaker.

We begin by studying the effects of a tax on the dirty sector. To simplify the exposition, we initially abstract from the green sector and use a two-sector New Keynesian model where the dirty sector represents high-emission activities and the other sector stands in for the rest of the economy. Each sector is monopolistically competitive and features nominal rigidities; importantly, the degree of price stickiness can vary across sectors.[1] In our baseline model, there are no input-output linkages

[1] In our baseline model, production uses only labor, and there is no capital nor investment. We suspect that a more complex economy where the green transition amounts to subsidizing/penalizing capital accumulation in the clean/dirty sector will yield very similar conclusions, although we do not explicitly consider such an economy in our

between the two sectors. Thus, "dirty goods" should be thought of as a stand-in for goods and services with relatively high greenhouse gas emissions, both direct and indirect, while "other goods" represent all other consumption.[2] In this simple framework, the green transition amounts to taxing production in the dirty sector with the goal of reducing its output (and therefore emissions). We use a similar framework to discuss the symmetric case where we have a green sector whose production the government wants to encourage via a subsidy.

The key results can be summarized as follows. First, if prices were fully flexible, the transition, when modeled as an increase in taxes on the dirty sector, would increase the relative price of dirty goods, but this adjustment in relative prices can take place under any level of overall inflation. Hence with fully flexible prices, climate policies would not pose any problem for an inflation targeting central bank. Second, even in the presence of nominal rigidities, the green transition does not compel monetary policymakers to tolerate higher inflation. A central bank committed to maintaining low inflation could do so. However, in the empirically realistic case where prices are more flexible in carbon-intensive sectors, the transition creates a tradeoff between keeping inflation low and closing the output gap.[3] Intuitively, the tradeoff arises because the central bank needs to nudge inflation in the sticky sector down so that the needed adjustment in relative prices occurs with an overall inflation level that is in line with its target. But this nudge involves cooling down the economy. If the central bank is not willing to do that, it may have to accept temporarily high inflation. Finally, if instead climate policy primarily takes the form of subsidizing a green sector with relatively flexible prices, rather than taxing a dirty sector, our conclusions are reversed: the green transition is deflationary unless monetary policy engineers a positive output gap. Impulse responses to carbon policy shocks found in the literature are broadly consistent with the predictions of the model.

Related Literature. Schnabel (2022) argues that physical and transition risks arising from climate change may be inflationary. Schnabel classifies three sources of climate-driven inflation. First, "climateflation," where climate change increases the probability of natural disasters and severe weather events, which lead to droughts, supply chain problems and other production disruptions that may put upward pressure on prices. This climateflation captures possible physical risks of climate change, which we do not study here for the reasons discussed above.[4] Second, "fossilflation,"

analysis.

[2] An extension of the model to allow for input-output linkages in production does not change the results qualitatively, and is presented in Appendix A.

[3] An additional contribution of our paper is to document empirically the relationship between the "dirtiness" of a sector, as measured by emissions per value added, and price stickiness.

[4] Faccia et al. (2021) examine how rising temperatures may impact inflation via higher food prices using a panel of cross-country data, and find that while hot summers may drive up prices in the short run, the effects are either negative or insignificant in the medium term. Ciccarelli and Marotta (2021) find evidence that physical risks work as negative demand shocks while transition policies resemble downward supply movements.

where the use of policies such as carbon taxes to discourage the use of fossil fuels and reduce emissions may place upward pressure on prices. This fossilflation is at the heart of the climate policy in our proposed analytical framework. Third, "greenflation," which arises from price increases in scarce commodities (e.g., lithium for batteries) as a result of the increased demand from the green energy sector. This mechanism is unlikely to change our qualitative result that subsidies to the green sector are, on the whole, deflationary, although it is in principle quantitatively important in attenuating this effect.

While most recent studies on the impact of transition policies have focused on their effects on output (eg, Metcalf and Stock, Forthcoming), a growing number also studied the implications for inflation. Using VAR-based evidence, Känzig (2022) finds that a carbon policy shock in Europe leads to a persistent rise in energy prices (1 percent on impact, by construction) and a decline in emissions, as one would expect.[5] The responses of headline prices are about one-fifth of the response in energy prices, while prices in the rest of the economy (core) barely respond. Industrial production declines for about two years after the shock. Importantly, the policy rate essentially does not change. All in all, these responses are consistent with the simple model outlined below, where energy prices are more flexible than core prices, and policy lets nominal energy prices do all the adjustment in relative prices. Using local projections, Konradt and Weder di Mauro (2021) find that while carbon taxes implemented in Europe and Canada impact relative prices, they have no significant impact on overall inflation.[6] However, they also find that for a subset of European countries where monetary policies are constrained, the effect on inflation is positive and significant, in line with Känzig (2022) and with related work by McKibbin et al. (2021).

Some authors, like us, have used New Keynesian frameworks to study the inflationary impact of transition policies. Bartocci et al. (2022) use a two-country model with an energy sector, calibrated to the euro area and the rest of the world, and find that an increase in carbon taxes generates recessionary effects, which are ameliorated by accommodative monetary policy. Ferrari and Nispi Landi (2022) focus instead on the role of expectations in determining whether emission taxes are inflationary or deflationary. None of the existing studies, to our knowledge, emphasizes the importance of relative price stickiness in determining the tradeoffs faced by monetary policy, as we do.

Section 2 presents the baseline model economy. Section 3 solves for the flexible-price equilibrium and compares steady states before and after the climate change policy is implemented. Section 4 solves the model with nominal rigidities and studies the transition dynamics. Section 5 concludes.

[5] Känzig (2022) uses a high-frequency identification approach based on changes in carbon future prices from the European Union Emissions Trading System immediately following regulatory events.

[6] This result is supported in recent work by Moessner (2022), who estimates the impact of emissions trading systems and carbon taxes on a broad set of price indexes using a dynamic panel model for 35 countries.

2 The Model Economy

In principle, one could study the effects of climate policy in a three sector model, distinguishing between a dirty high-emissions sector that the government wants to tax; a green sector that the government wants to subsidize, which produces low-emissions goods (such as clean energy) that are substitutes for high-emissions good; and the rest of the economy, which is neither directly taxed nor subsidized by climate policy. Since our goal is to deliver qualitative insights using the simplest possible model, however, it is more intuitive to start with a two-sector (dirty vs other) model, focusing on taxes and ignoring subsidies to a green sector. We will consider subsidies only in section 4.4. Thus, our two sector model is a relatively standard New Keynesian economy except that household consumption is an aggregate of dirty goods, which may be taxed, and other goods. The economy consists of a representative household, monopolistically competitive firms, a fiscal authority, and a central bank.

Households. The representative household solves

$$\max_{\{C_t, C_t^o, C_t^d, C_t^o(\cdot), C_t^d(\cdot), L_t\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \{\ln C_t - bL_t\}$$

$$\text{s.t.} \quad \int_0^1 P_t^d(j) C_t^d(j) dj + \int_0^1 P_t^o(j) C_t^o(j) dj + \frac{1}{1+i_t} B_{t+1} = W_t L_t + T_t + B_t$$

$$C_t = (C_t^o/\gamma)^{\gamma} (C_t^d/(1-\gamma))^{1-\gamma}$$

$$C_t^i = \left(\int_0^1 C_t^i(j)^{\frac{\varepsilon_t^i - 1}{\varepsilon_t^i}} dj \right)^{\frac{\varepsilon_t^i}{\varepsilon_t^i - 1}}, \; i = o, d,$$

where W_t denotes the nominal wage rate and T_t denotes net transfers from the government and monopolistically competitive firms. Consumption C_t is a Cobb-Douglas aggregate of consumption of other goods C_t^o and dirty goods C_t^d, each of which is in turn a CES aggregate of the varieties $C_t^o(j), C_t^d(j)$ produced by monopolistically competitive producers, with elasticities of substitution ε_t^o and ε_t^d respectively. Since the baseline model does not feature an input-output structure, dirty goods should be thought of as a stand-in for goods and services with relatively high greenhouse gas emissions, both direct and indirect, while other goods represent all other consumption.

The household's optimality conditions imply the standard relationships

$$
\begin{aligned}
C_t^o &= \gamma C_t(P_t/P_t^o) = \gamma C_t S_t^{1-\gamma}, \\
C_t^d &= (1-\gamma) C_t(P_t/P_t^d) = (1-\gamma) C_t S_t^{-\gamma}, \\
C_t^i(j) &= \left(\frac{P_t^i(j)}{P_t^i}\right)^{-\varepsilon_t^i} C_t^i, \ i = o, d, \ j \in [0,1], \\
\frac{W_t}{P_t} &= b C_t, \\
1 &= \beta \mathbb{E}_t \left[(1+i_t)\frac{C_t}{C_{t+1}}\frac{P_t}{P_{t+1}}\right],
\end{aligned}
$$

where $P_t = (P_t^o)^\gamma (P_t^d)^{1-\gamma}$ is the aggregate price level, and $S_t = \frac{P_t^d}{P_t^o}$ denotes the price of dirty goods relative to other goods.

Firms. The monopolistically competitive producer of variety $j \in [0,1]$ in sector $i = o, d$ faces a tax $\mathcal{T}_t^i$ (which may be negative, i.e. a subsidy) per unit of output produced. We will assume $\mathcal{T}_t^o \leq 0$ and $\mathcal{T}_t^d \geq 0$, i.e. other goods may be subsidized, while dirty goods may be taxed (a proxy for carbon taxes and regulations). Firms produce using a linear technology $Y_t^i(j) = A_t^i L_t^i(j)$ with labor as the only input and face quadratic costs of adjusting prices.[7] We assume these adjustment costs as "psychic" (or, equivalently, they are transfers to households) i.e. they will not appear in aggregate resource constraints. Thus, the nominal marginal cost for a firm in sector i equals $M_t^i = \frac{W_t}{A_t^i} + \mathcal{T}_t^i$.

A natural interpretation of the tax is that greenhouse gas emissions are proportional to production of dirty goods, and the government taxes these emissions. However, we do not explicitly model the emissions generated by the dirty sector, the effect of emissions on climate, or the effect of climate on welfare and economic outcomes (eg, see Golosov et al., 2014; Känzig, 2022). Our focus is on the effect of climate policy on inflation over the medium term; while a change in climate policy will affect emissions and hence climate change, the effect of policy on inflation via this channel is likely to be small over the horizon we are interested in.

The firm solves

$$
\max \ E_0 \sum_{t=0}^{\infty} Q_{t|0} \left\{ (P_t^i(j) - M_t^i) Y_t^i \left(\frac{P_t^i(j)}{P_t^i}\right)^{-\varepsilon_t^i} - \frac{\Psi^i}{2}\left(\frac{P_t^i(j)}{P_{t-1}^i(j)} - 1\right)^2 P_t^i Y_t^i \right\},
$$

where $Q_{s|t} = \beta^{s-t}\frac{P_t C_t}{P_s C_s}$ denotes the representative household's nominal stochastic discount factor (SDF). Taking the first-order conditions, assuming a symmetric equilibrium and using market

[7] Section 4.5 discusses the effect of incorporating input-output linkages, but we relegate the derivation of these results to Appendix A.2.

clearing to simplify the SDF terms yields the sectoral Phillips curves

$$\Pi_t^i(\Pi_t^i - 1) = \frac{\varepsilon_t^i}{\Psi^i}\left(\frac{M_t^i}{P_t^i} - \frac{1}{\mu_t^i}\right) + \mathbb{E}_t\left\{\beta\Pi_{t+1}^i(\Pi_{t+1}^i - 1)\right\},\ i = o, d,$$

where $\Pi_t^i = \frac{P_t^i}{P_{t-1}^i}$ denotes inflation in sector i, and we define $\mu_t^i = \frac{\varepsilon_t^i}{\varepsilon_t^i - 1}$ to be the desired (gross) markup in sector $i = o, d$. The cost of price adjustment Ψ^i may differ between sectors. In particular, prices in the dirty sector may be more flexible ($\Psi^d < \Psi^o$), or even fully flexible ($\Psi^d = 0$).

The relative price S_t evolves according to

$$S_t = \frac{\Pi_t^d}{\Pi_t^o} S_{t-1}. \tag{1}$$

CPI inflation is defined as $\Pi_t = (\Pi_t^o)^\gamma (\Pi_t^d)^{1-\gamma}$.

Monetary and fiscal policy. The monetary authority sets the nominal interest rate i_t; the fiscal authority sets taxes $\mathcal{T}_t^o, \mathcal{T}_t^d$ and adjusts the lump sum transfer to households as necessary to maintain a balanced budget. We assume government debt is in zero net supply ($B_t = 0, \forall t$) which is without loss of generality since the economy features Ricardian equivalence. Rather than specify a particular monetary policy rule, we will study outcomes under various different rules.

Market clearing. In equilibrium markets clear for goods in each sector and for labor:

$$C_t^i = Y_t^i = A_t^i L_t^i,\ i = o, d,$$
$$L_t^o + L_t^d = L_t,$$

Model solution. To solve the model, note that real marginal costs (deflated by prices in each sector) can be written as

$$\frac{M_t^i}{P_t^i} = \frac{W_t}{P_t^i A_t^i} + \frac{\mathcal{T}_t^i}{P_t^i} = \frac{W_t}{P_t A_t^i}\frac{P_t}{P_t^i} + \frac{\mathcal{T}_t^i}{P_t^i} = \frac{bY_t}{A_t^i}\frac{P_t}{P_t^i} + \frac{\mathcal{T}_t^i}{P_t^i},$$

where $\frac{P_t}{P_t^o} = S_t^{1-\gamma}$ and $\frac{P_t}{P_t^d} = S_t^{-\gamma}$. Thus, we can substitute out for marginal costs to obtain

$$\Pi_t^o(\Pi_t^o - 1) = \frac{\varepsilon_t^o}{\Psi^o}\left(bY_t\frac{S_t^{1-\gamma}}{A_t^o} + \frac{\mathcal{T}_t^o}{P_t^o} - \frac{1}{\mu_t^o}\right) + \mathbb{E}_t\left\{\beta\Pi_{t+1}^o(\Pi_{t+1}^o - 1)\right\}, \tag{2}$$

$$\Pi_t^d(\Pi_t^d - 1) = \frac{\varepsilon_t^d}{\Psi^d}\left(bY_t\frac{S_t^{-\gamma}}{A_t^d} + \frac{\mathcal{T}_t^d}{P_t^d} - \frac{1}{\mu_t^d}\right) + \mathbb{E}_t\left\{\beta\Pi_{t+1}^d(\Pi_{t+1}^d - 1)\right\}. \tag{3}$$

Taxes $\frac{\mathcal{T}_t^d}{P_t^d} > 0$ are isomorphic to a positive cost-push shock or increase in dirty firms' desired markups: they tend to increase inflation. Taking $\frac{\mathcal{T}_t^o}{P_t^o}$ and $\frac{\mathcal{T}_t^d}{P_t^d}$ as given, (2) and (3) together with (1) gives us three equations in four unknowns, $\Pi_t^o, \Pi_t^d, S_t, Y_t$. Given a specification of the monetary policy rule and the path of taxes, these equations fully characterize equilibrium.

Taxes. We wish to study the macroeconomic effects of climate policy, modeled as the effect of an increase in taxes on the dirty sector $\mathcal{T}_t^d$. Rather than working with taxes directly, however, it is convenient to define the 'virtual markup' $\widetilde{\mu}_t^i$ such that

$$\frac{1}{\widetilde{\mu}_t^i} = \frac{1}{\mu_t^i} - \frac{\mathcal{T}_t^i}{P_t^i}, \; i = o, d.$$

An increase in real taxes on dirty goods $\frac{\mathcal{T}_t^d}{P_t^d}$ is isomorphic to an increase in dirty goods producers' desired markup μ_t^d: both imply an increase in that sector's virtual markup $\widetilde{\mu}_t^d$, inducing producers to prefer lower output and higher prices.

In the experiments described below, we assume productivity is constant in each sector, and model climate policy as follows. The economy is initially in a steady state with zero CPI inflation ($\Pi_t = 1$) and real taxes (or subsidies) consistent with $\widetilde{\mu}_{-1}^o = 1$, $\widetilde{\mu}_{-1}^d = 1$. At date 0, it becomes common knowledge that the tax on dirty goods will increase such that μ_t^d converges to a higher long-run level $\widetilde{\mu}_\infty^d > \widetilde{\mu}_0^d$:

$$\ln \widetilde{\mu}_t^d - \ln \widetilde{\mu}_\infty^d = \rho^{t+1}(\ln \widetilde{\mu}_{-1}^d - \ln \widetilde{\mu}_\infty^d),$$

where ρ governs the speed with which convergence to the long-run level occurs.

3 The Long Run and the Flexible-Price Benchmark

In this section we briefly describe the steady state after the taxes on the dirty sector have been implemented and the effect of nominal rigidities has vanished. We also discuss the effect that the whole dynamic path of taxes would have in a counterfactual economy where prices were *always* perfectly flexible.

Flexible-price equilibrium. While we are ultimately interested in the effect of the green transition on inflation, which is only a meaningful topic in an economy with nominal rigidities, the flexible-price equilibrium provides a useful benchmark. In the flexible price limit ($\Psi^i = 0, i = o, d$), firms are free to set prices in each sector equal to their desired markup over marginal cost, and the Phillips curves (2) and (3) become

$$bY_t \frac{S_t^{1-\gamma}}{A_t^o} = \frac{1}{\widetilde{\mu}_t^o}, \tag{4}$$

$$bY_t \frac{S_t^{-\gamma}}{A_t^d} = \frac{1}{\widetilde{\mu}_t^d}. \tag{5}$$

Relative prices, output, and hours worked in the flexible price equilibrium are given by

$$
\begin{aligned}
S_t &= \frac{\widetilde{\mu}_t^d}{\widetilde{\mu}_t^o}\frac{A_t^o}{A_t^d}, \\
Y_t &= \frac{1}{b}\left(\frac{A_t^o}{\widetilde{\mu}_t^o}\right)^{\gamma}\left(\frac{A_t^d}{\widetilde{\mu}_t^d}\right)^{1-\gamma} := Y_t^*, \\
Y_t^i &= \frac{1}{b}\frac{A_t^i}{\widetilde{\mu}_t^i},\ i = o, d, \\
L_t &= \frac{1}{b}\left[\frac{\gamma}{\widetilde{\mu}_t^o} + \frac{1-\gamma}{\widetilde{\mu}_t^d}\right], \\
&= \left[\gamma\left(\frac{\widetilde{\mu}_t^d}{\widetilde{\mu}_t^o}\right)^{1-\gamma} + (1-\gamma)\left(\frac{\widetilde{\mu}_t^d}{\widetilde{\mu}_t^o}\right)^{-\gamma}\right]\frac{Y_t}{(A_t^o)^{\gamma}(A_t^d)^{1-\gamma}}.
\end{aligned}
$$

We refer to the flexible price level of output Y_t^* as *potential output.*

Here we note that throughout, whenever we discuss efficiency, we ignore externalities associated with higher output of dirty goods, which are not modeled here. Implicitly, these externalities are the reason that the government would want to reduce the output of the dirty sector. What we call the 'efficient' level of output features higher dirty-sector output than would be socially desirable.

Even when prices are fully flexible, the equilibrium may not be efficient owing to the distortions arising from taxes and/or monopolistic competition. In the efficient flexible price equilibrium (which maximizes the utility of the representative household), these distortions are absent and $\widetilde{\mu}_t^o = \widetilde{\mu}_t^d = 1$. As is standard in New Keynesian models, this requires subsidizing output to offset monopolistic distortions, $\frac{\mathcal{T}_t^i}{P_t^i} = -\frac{1}{\widetilde{\mu}_t^i}$. Relative prices are then purely driven by relative costs of production, $S_t = A_t^o/A_t^d$, aggregate output is $Y_t = \frac{1}{b}(A_t^o)^{\gamma}(A_t^d)^{1-\gamma}$, sectoral output is $Y_t^i = \frac{1}{b}A_t^i$, $i = o, d$, and labor supply is $L_t = \frac{1}{b}$. As mentioned above, we assume the economy starts out in the efficient steady state, $\widetilde{\mu}_{-1}^o = \widetilde{\mu}_{-1}^d = 1$.

New steady state under a higher carbon tax. We will study the effect of an increase in taxes on the dirty sector, which raises $\widetilde{\mu}_t^d > 1$. Under flexible prices, this increases the relative price of dirty goods to $S_t = \mu_t^d A_t^o/A_t^d > A_t^o/A_t^d$, and reduces dirty sector output to $\frac{1}{b}\frac{A_t^d}{\widetilde{\mu}_t^d} < \frac{1}{b}A_t^d$. Given our assumptions on household preferences, this tax neither increases nor decreases output in the other sector, and therefore it reduces aggregate potential output. Note that the proportional reduction in the output of the dirty sector, relative to the efficient level of production, equals $\frac{1}{\widetilde{\mu}_t^d}$. Thus, the policy we study can also be interpreted as a *quantity target* which reduces dirty sector output by some percentage amount relative to its efficient level.

When productivity and $\widetilde{\mu}_t^i$ are both constant, the flexible-price equilibrium is also a zero-inflation steady state of the sticky-price economy, featuring $\Pi_t^o = \Pi_t^d = \Pi_t = 1$. Given our assumptions on taxes, the economy transitions from the efficient steady state to a new steady state with higher relative prices $S_t = \widetilde{\mu}^d_\infty S_{-1}$ and lower aggregate output $Y_\infty = (\widetilde{\mu}^d_\infty)^{-(1-\gamma)} Y_{-1}$.

In this new steady state the relative price of the dirty good – relative to the price for the rest of the economy's output – is going to be higher, because taxes increase the marginal cost of producing dirty output. For this same reason, dirty output is going to be scarcer, which is the point of taxes in the first place. In the main experiment we consider, taxes on the dirty sector will not affect the flexible-price level of output in the other sector, and so the overall level of output will also be lower than before. Since we consider a gradual increase in taxes, this decline in the flexible-price level of output, Y_t^*. takes place gradually over time. More generally, whether taxes on the dirty sector affect production in the other sector would depend on whether these taxes are used to subsidize the rest of the economy or not, as well as on the degree of substitutability in consumption between dirty and non-dirty output (our baseline model assumes a unit elasticity of substitution, i.e. Cobb-Douglas preferences). Regardless, the central feature of the green transition is that it features a decline in both the absolute size and the share of the dirty sector.

To achieve such an outcome, , dirty output needs to eventually become more expensive in relative terms. Is the green transition then inflationary? Not necessarily. A change in relative prices can be achieved in many ways – by increasing the nominal price of dirty goods or lowering the price of rest-of-the-economy output. Either combination works, and the ultimate result in terms of inflation depends entirely on monetary policy. If prices are flexible, monetary policy only determines nominal variables and not real allocations. Since the choice of the central bank has no consequence for real activity, there is no reason why it would choose an inflation rate different from its objective.[8] In sum, when prices are flexible, the green transition *per se* is neither inflationary nor deflationary. Any inflationary effects of the green transition therefore must have to do with nominal rigidities.

4 The Role of Nominal Rigidities

If nominal rigidities are present, taxes on the dirty sector may present the central bank with a tradeoff between efficiently facilitating the green transition and maintaining low inflation. The nature of this tradeoff, however, depends crucially on the relative degree of nominal rigidities in the dirty sector and the rest of the economy. Indeed, the literature has often argued that shocks to the relative price of energy are inflationary precisely because prices in this sector are relatively flexible (Gordon, 1975; Aoki, 2001; Rubbo, 2022). Since the energy sector also accounts for the majority of greenhouse gas emissions, one might suspect that prices are more flexible in dirty sectors of the

[8] As shown in Woodford (2003) in a flexible price economy the central bank pins down expected (and hence average) inflation by its choice of the nominal interest rate, via the Fisher equation, given that the real interest rate in such economy always equals r^*, that is, it is independent from monetary policy.

Table 1. Mean price change frequency and CO2 emissions value added for other vs. dirty sectors in the United States

Sector	CO2/VA	Price Δ Freq.
Other	0.049	0.148
Dirty	1.326	0.205

Notes: Mean price change frequency and CO2 emissions per value added for other vs. dirty sectors in the United States. Calculations are based on averaging of underlying sectoral information for fifteen sub-sectors in Other and Dirty, respectively. See Table A1 for underlying sectoral information and Figure 1 for data sources.

economy.

To investigate this prior, we collect data on price rigidity and emissions intensity at the sector level. We source information on price rigidity from Pasten et al. (2020), who use BLS PPI data to calculate the frequency of price changes at the goods level as the ratio of the number of price changes to the number of sample months. We compute the sector average of these measures as our baseline measure of price rigidity. We collect information from the World-Input Output Database (Timmer et al., 2015) and the WIOD Environmental Accounts (European Commission and Joint Research Centre et al., 2019) to construct the sector-level emissions intensity as the ratio of CO2 emissions to value added, using 2014 data, to obtain a measure is expressed in terms of kilotons of CO2 emitted per millions of US$ value added. Finally, we create a crosswalk in order to merge the price rigidity and emissions data at the sector-level.[9]

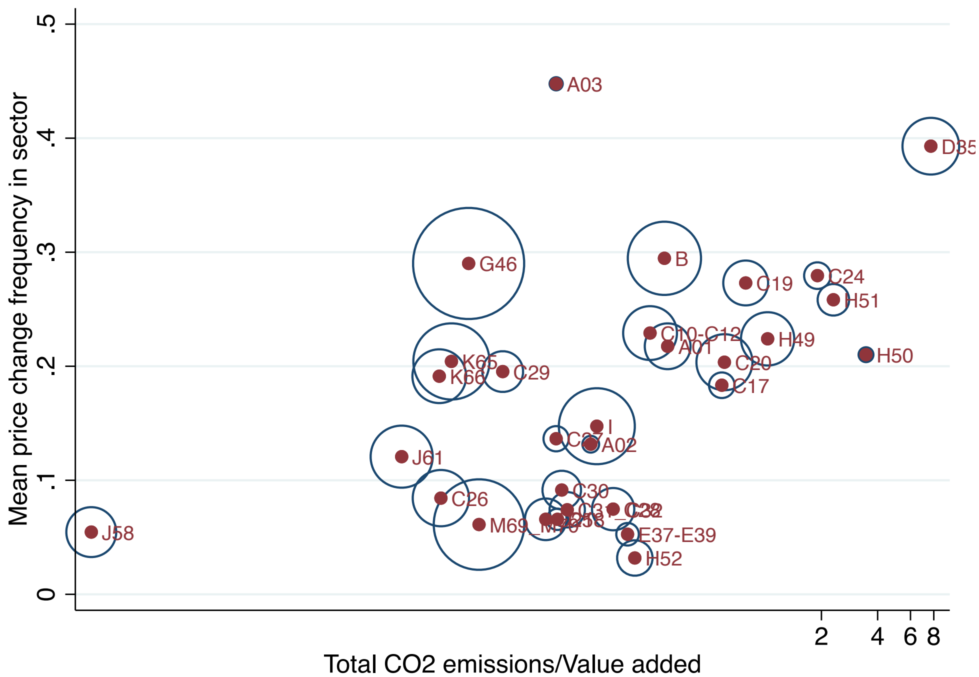
Figure 1 plots the sector-level price rigidity measure against the CO2/VA ratio for thirty U.S. sectors. Our prior is confirmed: sectors with higher CO2 emissions (relative to value added) have a higher average frequency of price change. Table 1 further presents the average frequency for a dirty group of high-emissions sectors and an other group of low-emissions sectors, where we have split the sample in two (see Table A1 for information underlying these averages). This pattern motivates us to consider scenarios where prices are more flexible (i.e. the sectoral Phillips curve is steeper) in the dirty sector.

4.1 Relative prices and Sectoral Phillips Curves

We now study the behavior of inflation during the transition to a new steady state with higher taxes on dirty goods. We loglinearize the system around the 'new' zero-inflation steady state consistent with $\widetilde{\mu}^d_\infty$. Without yet specifying a monetary policy rule, this yields four equations which can be

[9] Specifically, we assign the micro price data NAICS codes to the more aggregated sector-level ISIC code in the WIOD database and then create the mean price change frequency for the WIOD sectors.

Figure 1. Mean price change frequency of a good in a given sector vs CO2 emissions/value added across 30 sectors in the United States



Notes: This figure plots the sector-level mean price change frequency against the sector-level CO2 emissions to value added. The emissions ratio is expressed in terms of kilotons of CO2 emitted per millions of US$ value added produced and is plotted on a log scale. Circle sizes are based on sector-level value added. See Table A1 for sector names. Regressions of level on level or log-level on log-level yield a positive and significant coefficient, with and without sector D35 included.

used to understand the macroeconomic tradeoffs introduced by the green transition:

$$\pi_t^o = \kappa^o(y_t - y_t^* + (1-\gamma)(s_t - s_t^*)) + \beta \mathbb{E}_t \pi_{t+1}^o, \tag{6}$$

$$\pi_t^d = \kappa^d(y_t - y_t^* - \gamma(s_t - s_t^*)) + \beta \mathbb{E}_t \pi_{t+1}^d, \tag{7}$$

$$s_t = s_{t-1} + \pi_t^d - \pi_t^o, \tag{8}$$

$$\pi_t = \gamma \pi_t^o + (1-\gamma)\pi_t^d. \tag{9}$$

Here lower case variables denote log-deviations from the new, high-tax steady state: y_t denotes (the log-deviation of) aggregate output and $s_t := p_t^d - p_t^o$ denotes the price of dirty goods relative to other goods. $y_t^* := -(1-\gamma)\mu_t^d$ and $s_t^* := \mu_t^d$ denote the log-deviations of the flexible price values of y_t and s_t, and their evolution is given by

$$\mu_t^d = \rho^{t+1}\mu_{-1}^d, \quad \mu_{-1}^d \leq 0, \quad s_{-1} = \mu_{-1}^d < 0.$$

(where with some abuse of notation μ_t^d denotes the log-deviation of $\widetilde{\mu}_t^d$ from steady state). Note that $\mu_0^d < 0$ means that μ_t^d is initally below its new steady state value.

Equations (6) and (7) are Phillips curves for the other and dirty sectors. These equations relate inflation in the two sectors (π_t^o and π_t^d respectively) to the deviation of aggregate output y_t and relative prices s_t from their flexible price levels, y_t^* and s_t^*. These starred variables do not depend on monetary policy, but *do* depend on climate policy: as described above, the gradual introduction of a tax on dirty goods will gradually increase s_t^*, and reduce potential output y_t^*, towards their new steady state levels. The sectoral Phillips curve slopes κ^o and κ^d measure the degree of price flexibility in the other and dirty sectors respectively; again, Table 1 suggests that the empirically relevant case is $\kappa^d > \kappa^o$. Equation (8) is an accounting identity stating that the change in relative prices equals the difference in sectoral inflation rates. Finally, equation (9) defines overall CPI inflation (where γ and $1-\gamma$ denote the expenditure shares of the other and dirty sectors respectively).

Why do relative prices enter the sectoral Phillips curves (6) and (7)? As in a 1-sector New Keynesian model, inflation in each sector depends on the marginal cost in that sector. This in turn depends on that sector's *product wage*, i.e. nominal wages deflated by the price of that sector's output. For any given *real wage* (i.e. nominal wages deflated by the CPI), an increase in the relative price of dirty goods s_t increases the product wage in the other sector, adding to inflationary pressure there, and reduces the product wage in the dirty sector. Mathematically (abstracting from changes in productivity and taxes):

$$\underbrace{mc_t^i}_{\substack{\text{marginal cost}\\ \text{in sector } i}} = \underbrace{w_t - p_t^i}_{\text{product wage}} = \underbrace{w_t - p_t}_{\substack{\text{real wage}\\ = y_t}} - \underbrace{(p_t^i - p_t)}_{\substack{\text{relative price}\\ \text{of sector } i}} = \begin{cases} y_t + (1-\gamma)s_t & \text{for } i = o, \\ y_t - \gamma s_t & \text{for } i = d. \end{cases}$$

4.2 The Role of Relative Price Stickiness

To understand what happens in our model economy when nominal prices are slow to adjust, it is instructive to consider a few special cases.

Case 1: Other prices fixed, dirty prices flexible. Start with the extreme case where dirty prices are fully flexible ($\kappa^d = \infty$), while they are completely sticky in nominal terms – that is, fixed – for the remainder of the economy ($\kappa^o = 0$). In this case, our system reduces to

$$s_t = s_t^* + \frac{1}{\gamma}(y_t - y_t^*), \tag{10}$$

$$\pi_t = (1-\gamma)\pi_t^d = (1-\gamma)\Delta s_t. \tag{11}$$

Equation (10) states that the relative price of dirty goods can rise above its flexible price level when the output gap is positive (which raises wages and costs in the dirty sector); equation (11) states that inflation is driven by dirty sector prices since other prices are fixed. In such a situation it is obvious that the green transition would be inflationary: the only way to reduce the share of the dirty sector, and increase the *relative* price of dirty goods, is for the dirty prices to move up (from

(8), if $\pi_t^o = 0$, implementing $\Delta s_t > 0$ requires $\pi_t^d > 0$). Since all other prices are fixed, overall inflation needs to move up as well (from the definition of CPI inflation (7), if $\pi_t^d > 0$ and $\pi_t^o = 0$, $\pi_t > 0$).[10] Changes in relative prices are necessarily associated with aggregate inflation.

Case 2: Other prices sticky, dirty prices flexible. Now maintain the assumption that dirty prices are fully flexible ($\kappa^d = \infty$), but suppose that prices for the rest of the economy are sticky, but not completely rigid ($0 < \kappa^o < \infty$). In this case, our system becomes

$$s_t = s_t^* + \frac{1}{\gamma}(y_t - y_t^*), \tag{12}$$

$$\pi_t^o = \frac{\kappa^o}{\gamma}(y_t - y_t^*) + \beta \mathbb{E}_t \pi_{t+1}^o, \tag{13}$$

$$\pi_t = \pi_t^o + (1-\gamma)\Delta s_t. \tag{14}$$

Here the central bank has a choice: as (14) shows, the central bank can engineer whatever level of overall inflation π_t it wants, while still allowing relative prices s_t to increase, by picking inflation in the non-dirty sector π_t^o. However, since π_t^o is determined by the Phillips curve (13), the only way to achieve this objective amounts to picking the level of output gap $y_t - y_t^*$ for the economy. In turn, this gives rise to the tradeoff mentioned at the beginning of this section.

For concreteness, suppose the central bank has a zero inflation target. In order to implement such a target, and at the same time to achieve the required adjustment in relative prices, if dirty output prices are rising there needs to be deflation in the rest of the economy. Such deflation can only be accomplished by having a negative output gap, that is, a recession. Hence it is still true that the green transition is *per se* neither inflationary nor deflationary. But in order to achieve the desired level of inflation the central bank needs to exert some influence on aggregate economic activity, so as to affect marginal costs in the sticky sector. Intuitively, in the presence of stickiness the required nominal adjustment in the sticky sector needs a push from the central bank. This push is not costless, as it hinges on the output gap and therefore generates a tradeoff.

If prices are sticky also in the dirty sector, $\kappa^d < \infty$, as will be the case in the numerical examples discussed in the next section, the conclusions do not change. As long as prices are stick*ier* in the rest of the economy, the central bank can only achieve zero overall inflation by generating a contraction in economic activity. Conversely, if prices were stickier in the dirty sector, implementing zero inflation would require a boom in economic activity.

Case 3: Prices equally sticky in both sectors. However, in the knife-edge case where stickiness is the same in both sectors ($\kappa^o = \kappa^d \equiv \kappa$), no output gap is needed to achieve the required adjustment in relative prices. Nominal prices in both sectors are just as sluggish, and will gradually adjust in opposite directions without affecting overall inflation. Mathematically, our

[10] Vice versa, in the opposite case where dirty prices are fixed while they are fully flexible in the rest of the economy, average inflation would have to be negative. The green transition is then deflationary, because all the adjustment in relative prices would have to come from the non-dirty sector.

system becomes

$$\pi_t = \kappa(y_t - y_t^*) + \beta \mathbb{E}_t \pi_{t+1}, \tag{15}$$

$$\Delta s_t = -\kappa(s_t - s_t^*) + \beta \mathbb{E} \Delta s_{t+1}. \tag{16}$$

That is, we can write a standard aggregate Phillips curve for CPI inflation in terms of an output gap which does not depend directly on relative prices. Similarly, relative prices are governed by a second order difference equation which depends on their flexible price level s_t^*, but not directly on output.[11] In this special case (but *only* in this case!), aggregate inflation is fully determined by the aggregate output gap, while the evolution of relative prices depends on fundamental factors and is unaffected by monetary policy. Despite the green transition, the monetary authority can close the output gap while implementing zero inflation.

To understand this result, recall that changes in relative prices have opposite-signed effects on marginal costs in the two sectors: an increase in the relative price of dirty goods s_t raises marginal cost for the clean sector, and reduces it for the dirty sector. These effects must cancel out for (expenditure-weighted) average marginal cost for the economy as a whole:

$$\overline{mc}_t := \gamma mc_t^o + (1-\gamma) mc_t^d = w_t - p_t - \underbrace{\left[\gamma(p_t^o - p_t) + (1-\gamma)(p_t^d - p_t)\right]}_{=0 \text{ by definition of } p_t}.$$

In general, *average* marginal costs are not what determines aggregate inflation. Instead, marginal costs in the more flexible price sector have an outsized effect on aggregate inflation. But in the special case where $\kappa^o = \kappa^d = \kappa$, it is average marginal costs that matter: we can simply aggregate the sectoral Phillips curves to get the same aggregate Phillips curve as in a one-sector model, equation (15).

There are two things to note about this special case. First, a zero output gap $(y_t - y_t^*)$ still implies that the *level* of output is declining in line with potential y_t^*. But in itself, this does not necessarily indicate an adverse tradeoff. Presumably when setting the tax on the dirty sector, the fiscal authority traded off the cost of lower output against the (unmodeled) benefit from lower carbon emissions. The monetary authority would not want to completely offset the effect of the tax and prevent dirty output from declining, even if it was feasible to do so.

Second, while in this case the central bank can keep *aggregate* output equal to its flexible price level while maintaining zero inflation, it does not follow that relative prices and sectoral output are equal to their flexible-price levels. Nominal rigidities slow down the adjustment of relative prices

[11] Solving this equation yields $s_t = \lambda s_{t-1} + \psi s_t^*$, where $\lambda = \dfrac{1+\beta+\kappa-\sqrt{(1+\beta+\kappa)^2-4\beta}}{2\beta} \in (0,1)$, $\psi = \dfrac{\kappa}{1+\kappa+\beta(1-\rho-\lambda)} > 0$. In the limit as prices in both sectors become fully rigid ($\kappa \to 0$), $\lambda \to 1$, and $\psi \to 0$, i.e. relative prices are fixed ($s_t = s_{t-1}$) and do not move towards their flexible price level; in the limit as both sectors become fully flexible ($\kappa \to \infty$), $\lambda \to 0$, $\psi \to 1$, i.e. relative prices jump instantly to their flexible price level ($s_t = s_t^*$).

(this is easiest to see in the limiting case where $\kappa \to 0$; clearly if prices are fixed in *both* sectors, (8) implies that relative prices and sectoral output shares can *never* adjust). In fact, in this case monetary policy cannot do anything to speed up the transition. Not only do relative prices not affect aggregate inflation; by the same token, the aggregate level of economic activity does not affect relative prices.

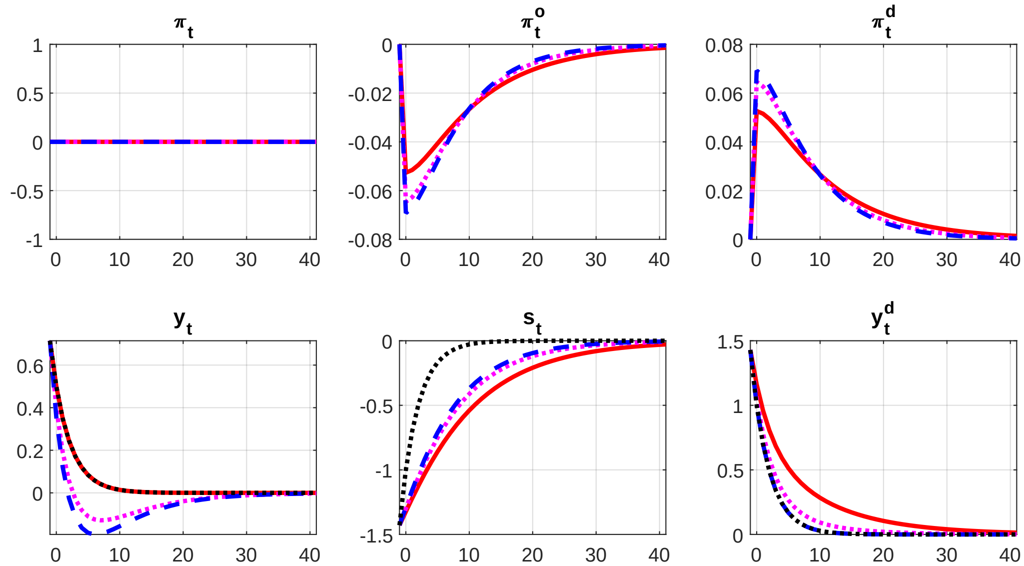
4.3 A Numerical Example

When moving beyond the special cases just described, one way to illustrate the monetary policy tradeoffs associated with the green transition is to compare outcomes under two extreme policies: strict inflation targeting, which sets $\pi_t = 0$, and strict output gap targeting, which sets $y_t - y_t^* = 0$. The figures below present a numerical example (this is not intended to be quantitative, and the parameterization and results are only illustrative). The calibration is described in detail in Appendix A.1. The red lines show a calibration with $\kappa^d = \kappa^o = 0.01$; blue-dashed lines illustrate the case with flexible prices in the dirty sector ($\kappa^d = \infty$); magenta-dotted lines illustrate an intermediate case where the slope of the Phillips curve is 5 times larger in the dirty sector, $\kappa^d = 0.05$. Black dotted lines show the flexible-price levels of s_t, y_t, and dirty sector output y_t^d. Dirty output (shown in the bottom-right panel) is given by $y_t^d = y_t - \gamma s_t$; this variable can also be interpreted as the level of emissions, and so the difference between the colored lines and black dotted lines in the bottom right panel illustrates how nominal rigidities slow down the green transition, relative to the flexible price benchmark. Figure 2 plots dynamics under strict inflation targeting $\pi_t = 0$. Figure 3 plots dynamics under strict output gap targeting, $y_t = y_t^*$. All variables are plotted as log-deviations relative to the new steady state featuring lower output and a higher relative price s_t.

As described above, when $\kappa^o = \kappa^d$, inflation targeting is equivalent to output gap targeting and so the red lines are identical across the two figures. Output remains equal to potential and declines towards its new lower steady state level. The relative price of dirty goods increases, but more slowly than in a flexible price economy since prices take time to adjust. Inflation in the dirty goods sector is balanced by deflation in the clean goods sector.

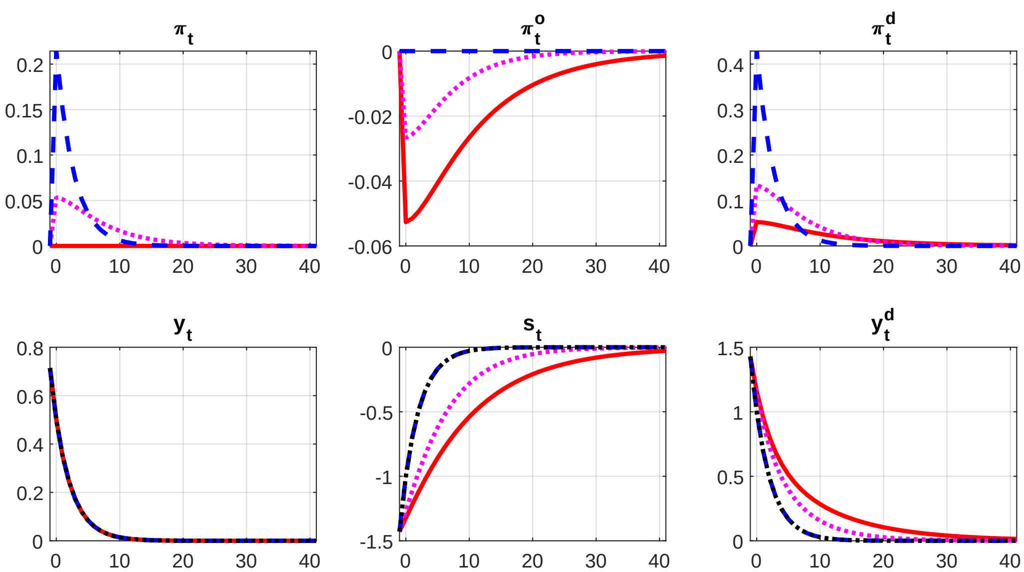
When prices are more flexible in the dirty goods sector, the equivalence between inflation targeting and output gap targeting breaks down. Maintaining an unchanged inflation target ($\pi_t = 0$) requires implementing a larger decline in output, i.e. a negative output gap: output undershoots its longer-run level. Conversely, keeping output equal to potential requires tolerating an initial increase in overall inflation. A higher degree of price flexibility in the dirty sector makes this tradeoff between output gap and overall inflation stabilization more pronounced. Under output gap targeting, marginal costs increase in the dirty sector and fall in the clean sector (owing to lower economic activity), but the increase in costs in the dirty sector has a larger impact on sectoral inflation since prices in this sector are more flexible (compare the dotted-magenta and dashed-blue

Figure 2. Dynamics under strict inflation targeting



Notes: Red lines denote calibration with $\kappa^o = \kappa^d$, dashed blue lines denote calibration with $\kappa^d = \infty$, magenta dotted lines denote calibration with $\kappa^d = 5\kappa^d$, and dotted black lines denote flexible price allocations.

Figure 3. Dynamics under strict output gap targeting



Notes: Red lines denote calibration with $\kappa^o = \kappa^d$, dashed blue lines denote calibration with $\kappa^d = \infty$, magenta dotted lines denote calibration with $\kappa^d = 5\kappa^d$, and dotted black lines denote flexible price allocations.

lines in the top-middle and top-right panels of Figure 3). Thus, overall inflation increases (top-left panel). Offsetting this and stabilizing overall inflation would require reducing economic activity even more to bring down marginal costs and prevent π_t^d from spiking.

4.4 Subsidies versus Taxes

In the experiment described above, the green transition is implemented through taxes on a dirty sector. In reality, climate policy often (perhaps increasingly) instead consists of subsidizing "clean" sectors – such as renewable energy or electric vehicles – which are substitutes for polluting activities. Fully extending our analysis to allow for such subsidies would require (at least) a three-sector model which explicitly models substitution between dirty and clean consumption. And arguably in order to understand the motivation for (and potential advantages of) a subsidy-centered approach, it would also be necessary to model the effect of subsidies on investment and endogenous technical change, as well as the distributional effects of various policies. But as a very first pass, we can analyse the *inflationary effect* of subsidies by ignoring the dirty sector altogether, and reinterpreting the sector of our economy with more flexible prices as a clean sector whose production the government wishes to subsidize.

In this case, the logic of our analysis above goes through exactly but with a minus sign, and the conclusions are reversed. In the long run, subsidies reduce the relative price of clean goods, and increase their production. If all prices were fully flexible, this change in relative prices need not be deflationary. Even with nominal rigidities, the monetary authority could in principle offset the effect of subsidies on aggregate inflation by appropriately choosing the level of the output gap. But if the clean sector's prices adjust more rapidly than in the rest of the economy, strict inflation targeting requires engineering a *positive* output gap. An output gap-targeting central bank would be forced to tolerate lower inflation.

In this sense, the model suggests that *in principle* policies such as the Inflation Reduction Act passed by Congress – the climate component of which primarily consists of subsidies to the clean energy sector rather than taxes on polluting activities – could actually be deflationary as advertised. Needless to add, our model is not designed to quantitatively assess whether this is actually the case.

4.5 Input-Output Linkages

We briefly discuss how our conclusions would change if we allow the rest of the economy to use dirty output as an input in production (this extension is described in detail in Appendix A.2). Consider first the flexible-price economy, and suppose the policymaker introduces a tax on dirty output in order to engineer the same proportional reduction in the gross output of the dirty sector as in our baseline model. Holding the consumption share of dirty goods $(1-\gamma)$ fixed, the same reduction in dirty output now implies a larger reduction in aggregate *potential* output y^*, since it also curtails production in the rest of the economy which uses dirty goods as an input. However, a given reduction in dirty sector output can now be achieved with a smaller change in relative prices s^*, because dirty goods are used as an input to produce other goods, and so a tax on dirty goods raises costs for the other sector.

With nominal rigidities, input-output linkages also quantitatively affect the tradeoff monetary authorities face between stabilizing inflation and closing the output gap, although our qualitative results remain largely unchanged. The Phillips curve for the dirty sector (7) remains the same, since dirty goods producers still only use labor as an input. The Phillips curve for the other sector becomes

$$\pi_t^o = \kappa^o \left[(1-\omega_{od})(y_t - y_t^*) + (1-\gamma+\gamma\omega_{od})(s_t - s_t^*)\right] + \beta \mathbb{E}_t \pi_{t+1}^o \tag{17}$$

where $\omega_{od} > 0$ denotes the cost share of dirty goods in the production of other goods (and $1-\omega_{od}$ the labor share). Higher usage of dirty output by the other sector $\omega_{od} > 0$ makes the other sector's Phillips curve less sensitive to aggregate economic activity, but more sensitive to the relative price of dirty goods. Intuitively, an increase in dirty sector prices now increases marginal costs directly via the price of inputs, as well as indirectly by increasing the product wage for a given real wage.

Suppose prices are perfectly flexible in the dirty sector ($\kappa^d = \infty$) but somewhat sticky in the other sector ($0 < \kappa^o < \infty$). As in our baseline model, since the relative price of dirty goods s_t is increasing, a central bank committed to stabilizing CPI inflation π_t must engineer deflation in the other sector, which requires a negative output gap; however, this tradeoff is less severe than in our baseline model. The relationship between inflation in the other sector π_t^o and the output gap is the same as in our baseline. This is because the lower slope of the dirty sector Phillips curve with respect to the output gap ($\kappa^o(1-\omega_{od})$) is exactly compensated by the higher sentitivity to $s_t - s_t^*$. Since the output gap also has an effect on the relative price s_t (dirty goods producers set prices equal to marginal costs, which depend on wages and hence on the output gap) the overall effect is identical. Thus as in our baseline, stabilizing the output gap implies zero inflation in the other sector, and so positive CPI inflation. However, since the required increase in relative prices is less dramatic than in our baseline, the gap between dirty and other sector inflation is smaller, and so overall CPI inflation is lower, though still positive.[12]

Again, the presence of a tradeoff depends on the assumption that prices are more flexible in the dirty sector. Recall that when prices are equally sticky in both sectors ($\kappa^o = \kappa^d$), there is no tradeoff between stabilizing CPI inflation and closing the output gap in our baseline economy. With input-output linkages, since firms produce not only for consumers but for other firms, CPI inflation is not the relevant benchmark: instead, there is no tradeoff between stabilizing *PPI* inflation and closing the output gap.[13] PPI is higher than CPI inflation in the scenarios we consider, since it puts a higher weight on dirty goods prices which are increasing during the transition. Thus, while IO linkages may not change the tradeoff faced by a PPI-targeting central bank, they do make the tradeoff less severe for a CPI-targeting central bank. In fact, when $\kappa^d = \kappa^o$, the sign of the tradeoff

[12] Mathematically, $\pi_t = \pi_t^o + (1-\gamma)\Delta s_t$; given π_t^o, a smaller Δs_t implies smaller π_t.

[13] Since CPI equals PPI in our baseline economy without intermediate inputs, this implies that IO linkages do not change the tradeoff between stabilizing PPI and closing the output gap.

reverses: stabilizing CPI inflation requires running a *positive* output gap, i.e. preventing output from falling as much as potential.

In sum, in the empirically realistic case where dirty sector prices are significantly more flexible, the standard tradeoff remains, but IO linkages generally make it less severe. This is a somewhat surprising result, as one might have thought that IO linkages would put the central bank in a more difficult spot. Again though, while the tradeoff between stabilizing CPI inflation and the output *gap* $y_t - y_t^*$ is less severe, IO linkages also increase the decline in y_t^*, so closing the output gap implies a steeper decline in the *level* of output y_t.

5 Conclusion

It has been argued that the green transition will be inflationary. In this paper we investigated whether this is the case in the context of a simple two-sector model. We show that whether the green transition is inflationary crucially depends on (1) price stickiness, (2) central bank policy, (3) whether the green transition consists of taxes or subsidies. If prices were flexible there would be no reason for the green transition to be inflationary or deflationary, regardless of (3). If prices of non-dirty goods and services in the economy are stickier than prices in the dirty sectors – an arguably realistic situation – then policies aimed at reducing production in the dirty sector impose a tradeoff on the central bank between stabilizing inflation and closing the output gap. These conclusions are reversed if the green transition consists of subsidies to a clean energy sector, as for example in the recent Inflation Reduction Act, as long as prices in this sector are more flexible than in the rest of the economy.

References

Aoki, Kosuke, "Optimal monetary policy responses to relative-price changes," *Journal of Monetary Economics*, 2001, *48* (1), 55–80.

Bartocci, Anna, Alessandro Notarpietro, and Massimiliano Pisani, ""Green" fiscal policy measures and non-standard monetary policy in the Euro Area," 2022. Bank of Italy Temi di Discussione (Working Paper) No. 1377.

Ciccarelli, Matteo and Fulvia Marotta, "Demand or supply? An empirical exploration of the effects of climate change on the macroeconomy," 2021. ECB Working Paper No. 2608.

European Commission and Joint Research Centre, M. Román, T. Corsatea, A. Amores, F. Neuwahl, A. Velázquez Afonso, J. Rueda-Cantuche, I. Arto, and S. Lindner, *World input-output database environmental accounts : update 2000-2016*, Publications Office, 2019.

Faccia, Donata, Miles Parker, and Livio Stracca, "Feeling the heat: extreme temperatures and price stability," December 2021. ECB Working Paper No. 2626.

Ferrari, Alessandro and Valerio Nispi Landi, "Will the green transition be inflationary? Expectations matter," 2022. Bank of Italy Occasional Paper No. 686.

Golosov, Mikhail, John Hassler, Per Krusell, and Aleh Tsyvinski, "Optimal taxes on fossil fuel in general equilibrium," *Econometrica*, 2014, *82* (1), 41–88.

Gordon, Robert J, "Alternative responses of policy to external supply shocks," *Brookings Papers on Economic Activity*, 1975, *1975* (1), 183–206.

Känzig, Diego R., "The unequal economic consequences of carbon pricing," 2022. Mimeo, Northwestern University.

Konradt, Maximilian and Beatrice Weder di Mauro, "Carbon Taxation and Greenflation: Evidence from Europe and Canada," September 2021. CEPR Discussion Paper DP16396.

McKibbin, Warwick, Maximilian Konradt, and Beatrice Weder di Mauro, "Climate Policies and Monetary Policies in the Euro Area," in "ECB Forum on Central Banking, Conference Proceedings" 2021.

Metcalf, Gilbert E. and James H. Stock, "The Macroeconomic Impact of Europe's Carbon Taxes," *American Economic Journal: Macroeconomics*, Forthcoming.

Moessner, Richhild, "Effects of Carbon Pricing on Inflation," February 2022. CESifo Working Paper No. 9563.

Pasten, Ernesto, Raphael Schoenle, and Michael Weber, "The propagation of monetary policy shocks in a heterogeneous production economy," *Journal of Monetary Economics*, 2020, *116*, 1–22.

Rubbo, Elisa, "Networks, Phillips curves, and Monetary Policy," 2022. Mimeo, University of Chicago, Booth School of Business.

Schnabel, Isabel, "A new age of energy inflation: climateflation, fossilflation and greenflation," in "Speech given at a panel on "Monetary Policy and Climate Change" at The ECB and its Watchers XXII Conference, March" 2022.

Timmer, Marcel P., Erik Dietzenbacher, Bart Los, Robert Stehrer, and Gaaitzen J. de Vries, "An Illustrated User Guide to the World Input–Output Database: the Case of Global Automotive Production," *Review of International Economics*, August 2015, *23* (3), 575–605.

Woodford, Michael, *Interest and prices*, Princeton Univ. Press, 2003.

Appendix A Model Details

A.1 Calibration for Figures

When plotting the figures shown in the main text, we set $\beta = 0.99$, $\gamma = 0.5$, and $\kappa^o = 0.01$. In terms of the path of climate policy, we set $\mu_0^d = -1$, implying a long-run reduction in the size of the dirty sector of $\dfrac{e^{\mu_0^d} - e^0}{e^{\mu_0^d}} \approx 63\%$. We set $\rho = 0.7$, implying that taxes on the dirty sector increase relatively rapidly towards their new higher steady state level.

A.2 Input-Output Linkages

We now allow for the two sectors to use each other's products as intermediate inputs. Firms in sector $i = o, d$ have the constant returns to scale production function

$$X_t^i = A_t^i (X_t^{io})^{\omega_{io}} (X_t^{id})^{\omega_{id}} (L_t^i)^{\omega_{il}},$$

where $\omega_{io} + \omega_{id} + \omega_{il} = 1$ (in our baseline model, $\omega_{io} = \omega_{id} = 0, \omega_{il} = 1$). Here X_t^{od} (for example) denotes the quantity of dirty goods used by firms in the "other" sector. In particular, if $\omega_{od} > 0$, production of other goods requires dirty goods as input. The index of intermediate inputs used by firms in sector k and produced by a firm in sector i is given by the same CES aggregate as household's consumption of sector i goods. Thus, the demand for the variety produced by firm j in sector i still has the form

$$X_t^i(j) = X_t^i \left(\frac{P_t^i(j)}{P_t^i} \right)^{-\varepsilon_t^i}.$$

Now, however, X_t^i denotes *gross* output of sector i, which in general will differ from value added or net output (which we still refer to as Y_t^i or Y_t for sectoral and aggregate net output respectively). The market clearing conditions for each sector are

$$C_t^i + X_t^{oi} + X_t^{di} = X_t^i = A_t^i (X_t^{io})^{\omega_{io}} (X_t^{id})^{\omega_{id}} (L_t^i)^{\omega_{il}}, \; i = o, d.$$

Nominal marginal cost for a firm in sector i now equals

$$M_t^i = \frac{1}{A_t^i} \left(\frac{P_t^o}{\omega_{io}} \right)^{\omega_{io}} \left(\frac{P_t^d}{\omega_{id}} \right)^{\omega_{id}} \left(\frac{W_t}{\omega_{il}} \right)^{\omega_{il}} + \mathcal{T}_t^i.$$

Deflating by product prices in each sector, real marginal costs are given by

$$\begin{aligned} \frac{M_t^o}{P_t^o} &= \frac{1}{\omega_o A_t^o} (bY_t)^{\omega_{ol}} S_t^{\omega_{od} + \omega_{ol}(1-\gamma)} + \frac{\mathcal{T}_t^o}{P_t^o}, \\ \frac{M_t^d}{P_t^d} &= \frac{1}{\omega_d A_t^d} (bY_t)^{\omega_{dl}} S_t^{-\omega_{do} - \omega_{dl}\gamma} + \frac{\mathcal{T}_t^d}{P_t^d}, \end{aligned}$$

where we define $\omega_i = (\omega_{io})^{\omega_{io}}(\omega_{id})^{\omega_{id}}(\omega_{ld})^{\omega_{ld}}$, $i = o, d$. Cost minimization implies that the quantities of intermediate inputs and labor used by sector i are given by

$$
\begin{aligned}
X_t^{io} &= \frac{X_t^i}{A_t^i}\left(\frac{P_t^o}{\omega_{io}}\right)^{\omega_{io}-1}\left(\frac{P_t^d}{\omega_{id}}\right)^{\omega_{id}}\left(\frac{W_t}{\omega_{il}}\right)^{\omega_{il}}, \\
X_t^{id} &= \frac{X_t^i}{A_t^i}\left(\frac{P_t^o}{\omega_{io}}\right)^{\omega_{io}}\left(\frac{P_t^d}{\omega_{id}}\right)^{\omega_{id}-1}\left(\frac{W_t}{\omega_{il}}\right)^{\omega_{il}}, \\
L_t^{i} &= \frac{X_t^i}{A_t^i}\left(\frac{P_t^o}{\omega_{io}}\right)^{\omega_{io}}\left(\frac{P_t^d}{\omega_{id}}\right)^{\omega_{id}}\left(\frac{W_t}{\omega_{il}}\right)^{\omega_{il}-1}.
\end{aligned}
$$

Flexible-price benchmark. In the flexible price equilibrium, we have

$$
\begin{aligned}
\frac{1}{\widetilde{\mu}_t^o} &= \frac{1}{\omega_o A_t^o}(bY_t)^{\omega_{ol}} S_t^{\omega_{od}+\omega_{ol}(1-\gamma)}, \\
\frac{1}{\widetilde{\mu}_t^d} &= \frac{1}{\omega_d A_t^d}(bY_t)^{\omega_{dl}} S_t^{-\omega_{do}-\omega_{dl}\gamma},
\end{aligned}
$$

which implicitly define equilibrium net output Y_t and relative prices S_t. The quantities of inputs used by sector i satisfy

$$
X_t^{io} = \frac{\omega_{io}}{P_t^o} P_t^i X_t^i \frac{1}{\widetilde{\mu}_t^i}, \qquad X_t^{id} = \frac{\omega_{id}}{P_t^d} P_t^i X_t^i \frac{1}{\widetilde{\mu}_t^i}, \qquad L_t^{i} = \frac{\omega_{il}}{W_t} P_t^i X_t^i \frac{1}{\widetilde{\mu}_t^i}.
$$

Substituting these into the resource constraints, we obtain a relation between the value of net and gross output:

$$
\begin{aligned}
P_t^o X_t^o &= \gamma P_t Y_t + \frac{\omega_{oo}}{\widetilde{\mu}_t^o} P_t^o X_t^o + \frac{\omega_{do}}{\widetilde{\mu}_t^d} P_t^d X_t^d, \\
P_t^d X_t^d &= (1-\gamma) P_t Y_t + \frac{\omega_{od}}{\widetilde{\mu}_t^o} P_t^o X_t^o + \frac{\omega_{dd}}{\widetilde{\mu}_t^d} P_t^d X_t^d.
\end{aligned}
$$

Dividing through by P_t, we can represent this in matrix form as

$$
\boldsymbol{s} \circ \boldsymbol{x} = \boldsymbol{\gamma} Y_t + \boldsymbol{\Omega}' \widetilde{\boldsymbol{\mu}}^{-1}(\boldsymbol{s} \circ \boldsymbol{x}),
$$

where $\circ$ denotes the element-wise product, $\boldsymbol{s} = (P_t^o/P_t, P_t^d/P_t)'$, $\boldsymbol{x} = (X_t^o, X_t^d)'$, $\boldsymbol{\gamma} = (\gamma, 1-\gamma)'$, $\widetilde{\boldsymbol{\mu}}$ denotes the diagonal matrix with $\widetilde{\mu}_t^i$ on the diagonal, and $\boldsymbol{\Omega}$ denotes the 2×2 matrix of intermediate input shares ω_{ij}, $i = o, d$, $j = o, d$. Rearranging, we have

$$
\begin{aligned}
\boldsymbol{s} \circ \boldsymbol{x} &= (I - \boldsymbol{\Omega}' \widetilde{\boldsymbol{\mu}}^{-1})^{-1} \boldsymbol{\gamma} Y_t, \\
\boldsymbol{x} &= Y_t \boldsymbol{s}^{-1} \circ \left[(I - \boldsymbol{\Omega}' \widetilde{\boldsymbol{\mu}}^{-1})^{-1} \boldsymbol{\gamma}\right].
\end{aligned}
$$

In our baseline model without input-output linkages, $\boldsymbol{\Omega}$ is a matrix of zeros, and the vector of sectoral gross output is simply $\boldsymbol{x} = Y_t \boldsymbol{s}^{-1} \circ \boldsymbol{\gamma}$, which is the vector of sectoral net output or consumption.

To simplify the analysis, we will focus on the case where $\omega_{od} > 0$, $\omega_{oo} = \omega_{dd} = \omega_{do} = 0$, $\omega_{ol} = 1 - \omega_{od}$, $\omega_{dl} = 1$. That is, the only linkage is that dirty goods are used by the other sector as inputs. In this case, flexible-price net output and relative prices are given by

$$\begin{aligned} S_t &= \left(\frac{\omega_o A_t^o}{\widetilde{\mu}_t^o}\right)\left(\frac{\omega_d A_t^d}{\widetilde{\mu}_t^d}\right)^{-(1-\omega_{od})}, \\ Y_t &= \frac{1}{b}\left(\frac{\omega_o A_t^o}{\widetilde{\mu}_t^o}\right)^{\gamma}\left(\frac{\omega_d A_t^d}{\widetilde{\mu}_t^d}\right)^{1-\gamma+\gamma\omega_{od}}, \\ Y_t^d &= (1-\gamma)Y_t S_t^{-\gamma} = \frac{1-\gamma}{b}\left(\frac{\omega_d A_t^d}{\widetilde{\mu}_t^d}\right). \end{aligned}$$

Turning from net to gross output, in this special case we have

$$(I - \mathbf{\Omega}'\widetilde{\boldsymbol{\mu}}^{-1})^{-1} = \begin{pmatrix} 1 & 0 \\ -\omega_{od}(\widetilde{\mu}_t^o)^{-1} & 1 \end{pmatrix}^{-1} = \begin{pmatrix} 1 & 0 \\ \omega_{od}(\widetilde{\mu}_t^o)^{-1} & 1 \end{pmatrix},$$

and the formula above implies

$$X_t^o = \gamma Y_t S_t^{1-\gamma}, \qquad X_t^d = Y_t S_t^{-\gamma}[\gamma\omega_{od}(\widetilde{\mu}_t^o)^{-1} + 1 - \gamma] = \frac{\gamma\omega_{od}(\widetilde{\mu}_t^o)^{-1} + 1 - \gamma}{b}\left(\frac{\omega_d A_t^d}{\widetilde{\mu}_t^d}\right).$$

The use of dirty output as an intermediate input ($\omega_{od} > 0$) increases this sector's gross output, all else equal. In particular, the share of expenditures on dirty goods as a fraction of gross output is $\frac{\gamma\omega_{od}(\widetilde{\mu}_t^o)^{-1} + 1 - \gamma}{\gamma\omega_{od}(\widetilde{\mu}_t^o)^{-1} + 1} > 1 - \gamma$. Nonetheless, as in our baseline, $\widetilde{\mu}_t^d$ can still be interpreted as the *proportional* reduction in dirty sector output under flexible prices.

The firm's problem has the same structure as before, except that gross output X_t^i replaces net output Y_t^i (we assume price adjustment costs are also scaled by gross output):

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} Q_{t|0}\left\{(P_t^i(j) - M_t^i)X_t^i\left(\frac{P_t^i(j)}{P_t^i}\right)^{-\varepsilon_t^i} - \frac{\Psi^i}{2}\left(\frac{P_t^i(j)}{P_{t-1}^i(j)} - 1\right)^2 P_t^i X_t^i\right\}.$$

Taking FOCs and assuming a symmetric equilibrium, we have:[14]

$$\Pi_t^i\left(\Pi_t^i - 1\right) = \frac{\varepsilon_t^i}{\Psi^i}\left(\frac{M_t^i}{P_t^i} - \frac{1}{\mu_t^i}\right) + \beta\frac{Y_t}{Y_{t+1}}\frac{\Pi_{t+1}^i}{\Pi_{t+1}}\frac{X_{t+1}^i}{X_t^i}\Pi_{t+1}^i\left(\Pi_{t+1}^i - 1\right).$$

Defining the 'virtual markup' $\widetilde{\mu}_t^i$ as before, and log-linearizing around a zero inflation steady state, we have the sectoral Phillips curves:

$$\begin{aligned} \pi_t^o &= \kappa^o((1-\omega_{od})y_t + [1-\gamma+\gamma\omega_{od}]s_t) + \beta\mathbb{E}_t\pi_{t+1}^o, \\ \pi_t^d &= \kappa^d(y_t - \gamma s_t + \mu_t^d) + \beta\mathbb{E}_t\pi_{t+1}^d. \end{aligned}$$

[14]Since net output need not equal gross output, the term $\frac{Y_t}{Y_{t+1}}\frac{\Pi_{t+1}^i}{\Pi_{t+1}}\frac{X_{t+1}^i}{X_t^i}$ is not necessarily equal to 1 as in our baseline model. This will not affect the linearized Phillips curve given that we log-linearize around a zero-inflation steady state.

While the dirty sector Phillips curve is unchanged from our baseline, $\omega_{od} > 0$ makes the other sector's Phillips curve less sensitive to aggregate economic activity, but more sensitive to the relative price of dirty goods. Log-linearizing the expressions above describing the flexible-price levels of Y_t and S_t, we have $y_t^* = -(1 - \gamma + \gamma\omega_{od})\mu_t^d$ and $s_t = (1 - \omega_{od})\mu_t^d$, which can be used to obtain the Phillips curves in the main text. Note that the same proportional reduction in dirty output μ_t^d results in a larger reduction in aggregate output when $\omega_{od} > 0$.

With $\omega_{od} > 0$, if prices are equally flexible in both sectors ($\kappa^o = \kappa^d = \kappa$), stabilizing CPI inflation will not close the output gap. Multiplying the two Phillips curves by their consumption expenditure weights γ and $1 - \gamma$, summing, and using the expressions for y_t^* and s_t^*, we obtain the CPI Phillips curve

$$\pi_t = \kappa\left[(1 - \gamma\omega_{od})(y_t - y_t^*) + \gamma\omega_{od}(s_t - s_t^*)\right] + \beta\mathbb{E}_t\pi_{t+1}.$$

Since $s_t < s_t^*$ during the transition, stabilizing CPI inflation allows output to run somewhat above potential (though recall that potential output is itself declining more sharply than in our baseline model without IO linkages). If instead we weight the two Phillips curves by their *gross* expenditure shares $\dfrac{\gamma}{\gamma\omega_{od} + 1}$ and $\dfrac{\gamma\omega_{od} + 1 - \gamma}{\gamma\omega_{od} + 1}$, we obtain the PPI Phillips curve[15]

$$\pi_t^{PPI} := \frac{\gamma}{\gamma\omega_{od} + 1}\pi_t^o + \frac{\gamma\omega_{od} + 1 - \gamma}{\gamma\omega_{od} + 1}\pi_t^d = \frac{\kappa}{\gamma\omega_{od} + 1}(y_t - y_t^*) + \beta\mathbb{E}_t\pi_{t+1}^{PPI}.$$

In this special case, it is stabilizing PPI inflation that is equivalent to closing the output gap. PPI puts a higher weight on dirty sector prices, which are increasing during the transition. Consequently, stabilizing PPI inflation would require a more aggressive monetary policy response than stabilizing CPI.

If prices are sticky (or even perfectly fixed) in the other sector, but perfectly flexible in the dirty sector, then as in our baseline, the dirty sector Phillips curve reduces to $s_t = \dfrac{1}{\gamma}(y_t + \mu_t^d)$. Substituting into the Phillips curve for the other sector, we have

$$\pi_t^o = \frac{\kappa^o}{\gamma}(y_t - y_t^*) + \beta\mathbb{E}_t\pi_{t+1}^o,$$

as in our baseline economy without IO linkages. When prices in the dirty sector are completely flexible, stabilizing inflation in the rest of the economy implements flexible price allocations; stabilizing overall CPI inflation instead requires a negative output gap.

To recap: if prices are equally flexible in both sectors ($\kappa^d/\kappa^o = 1$), stabilizing CPI inflation implies running output above potential, but if prices are infinitely more flexible in the dirty sector ($\kappa^d/\kappa^o = \infty$), stabilizing CPI implies running output below potential as in our baseline. Is there

[15] Here, as in the experiments in our baseline, we assume $\widetilde{\mu}_t^o = 1$, i.e. there is a constant subsidy to correct distortions from monopolistic competition in the other sector.

some degree of relative price flexibility at which stabilizing inflation closes the output gap, and there is no tradeoff? Yes: this will be the case when

$$\frac{\kappa^d}{\kappa^o} = 1 + \frac{\gamma\omega_{od}}{1-\gamma}.$$

Intuitively, in this knife-edge case, the difference in price flexibility exactly offsets the difference between PPI and CPI weights. To prove this, assume that $\kappa^d = \left(1 + \frac{\gamma\omega_{od}}{1-\gamma}\right)\kappa^o$ and add the expenditure-weighted Phillips curves to obtain the CPI Phillips curve:

$$\begin{aligned}\pi_t &= \gamma\kappa^o\left[(1-\omega_{od})y_t + (1-\gamma+\gamma\omega_{od})s_t\right] + (1-\gamma+\gamma\omega_{od})\,\kappa^o\left[(y_t - y_t^*) - \gamma(s_t - s_t^*)\right] + \beta\mathbb{E}_t\pi_{t+1}\\ &= \kappa^o(y_t - y_t^*) + \beta\mathbb{E}_t\pi_{t+1}.\end{aligned}$$

Table A1. Mean price change frequency of a good in a given sector and CO2 emissions/value added across 30 sectors in USA in 2014

Sector	Code	CO2/VA	Price Δ Freq.
Other			
Publishing activities	J58	0.0002	0.055
Telecommunications	J61	0.011	0.121
Activities auxiliary to fininance and insurance activities	K66	0.018	0.191
Mfg of computer, electronic and optical products	C26	0.018	0.084
Insurance, reinsurance and pension funding	K65	0.021	0.204
Wholesale trade	G46	0.026	0.290
Legal and accounting activities	M69-M70	0.029	0.061
Mfg of motor vehicles, trailers and semi-trailers	C29	0.039	0.195
Mfg of fabricated metal products	C25	0.067	0.066
Mfg of electrical equipment	C27	0.076	0.136
Fishing and aquaculture	A03	0.076	0.448
Printing and reproduction of recorded media	C18	0.077	0.066
Mfg of other transport equipment	C30	0.081	0.091
Mfg of furniture; other manufacturing	C31-C32	0.087	0.074
Forestry and logging	A02	0.116	0.132
Dirty			
Accommodation and food service activities	I	0.125	0.147
Mfg of machinery and equipment n.e.c.	C28	0.153	0.075
Sewerage; waste collection, and treatment	E37-E39	0.183	0.053
Warehousing and support activities for transportation	H52	0.200	0.032
Mfg of food products, beverages and tobacco products	C10-C12	0.241	0.229
Mining and quarrying	B	0.288	0.295
Crop and animal production	A01	0.300	0.218
Mfg of paper and paper products	C17	0.585	0.183
Mfg of chemicals and chemical products	C20	0.604	0.204
Mfg of coke and refined petroleum products	C19	0.786	0.273
Land transport and transport via pipelines	H49	1.030	0.224
Mfg of basic metals	C24	1.903	0.279
Air transport	H51	2.318	0.258
Water transport	H50	3.466	0.210
Electricity, gas, steam and air conditioning supply	D35	7.714	0.393

Notes: This table presents sector-level emissions intensity (CO2/VA) and price rigidity data (Price Δ Freq.) for dirty and other sectors. The emissions intensity data are constructed using information from Timmer et al. (2015) and European Commission and Joint Research Centre et al. (2019) for the year 2014. The mean price change frequency data are constructed using information from Pasten et al. (2020), where the average is taken across goods at the WIOD sector-level.