Is Green Transition Inflationary?—An Endogenous Growth Perspective*

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Abstract

Policymakers at central banks warn that the green transition achieved with a gradual increase in emission taxes might be inflationary. The earlier literature argues that the textbook New Keynesian model with exogenous growth predicts that green transition is deflationary due to the negative wealth effects of higher taxes. Instead, we use an endogenous growth model and show that higher taxes leads to lower innovation and a deceleration of growth which—joint with downward nominal wage rigidity—leads to gradually higher inflation. We also discuss policies that foster green innovation.

Keywords: green transition, emission taxation, inflation, endogenous growth, green innovation

JEL: D84, E31, Q58.

1 Introduction

The European Union has to goal to reduce greenhouse gas emissions to zero by 2050. This goal is consistent with the Paris Agreement to limit global warming to below 2 Celsius degrees. To achieve this goal they tax carbon emissions. Higher taxes raise production costs and might lead to higher inflation which central banks take into consideration when setting the policy

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rate. The primary mandate of central banks is to maintain price stability. Secondary mandate is to promote growth as long as price and financial stability are not at risk. Recent episodes of Covid-2019, the associated supply chain disruptions (2021) and the energy crises (2022 summer) has led policy makers question whether the green transition will trigger additional inflation or not (see e.g. Schnabl, 2022a, 2022b). Recent empirical evidence also indicates that green transition is likely to increase energy price inflation but not core inflation see e.g. Cicarelli and Marotta (2023) as well as Moessner (2022).

In this paper we investigate the effects of climate transition using a dynamic equilibrium model with endogenous growth and New Keynesian features. In our model emission reduction during the climate transition is achieved by emission taxes levied in a progressive way. In our model endogenous growth results from research and development of firms which innovate to improve the quality of intermediary goods. Innovator firms operate under monopolistic competition and, thus, they set the price of their product over the marginal cost earning profits.

To highlight the workings of our model we start with a simple setup where the intermediary is emitting greenhouse gases. Since the government is taxing emissions the intermediary tries to reduce emissions (abatement). We introduce emissions in the intermediary goods' sector where R&D and, eventually, the growth rate of the economy is determined. We assume that there is downward nominal wage rigidity referring to the contractual wage excluding bonuses.

To achieve net-zero emissions the regulator implements a linear tax schedule during the green transition i.e. tax rate increases from zero to about 15 percent over 120 quarters. Due to the wealth effects of higher taxes consumption, output, labour and profits decline during the green transition. Due to downward nominal wage rigidity the negative labour gap will not exert negative effects on inflation. Instead, inflation is governed by the cost channel of higher taxes in the price of intermediary inputs. Our model predicts lower R&D investment and a deceleration of the endogenous growth rate due to higher taxes. Due to inverse relationship between growth rate and inflation the model predicts gradually increasing inflation during the transition.

Related literature. We are closely related Fornaro et al. (2024) who also employ an endogenous growth model and show the slow-down of growth in the dirty sector during transition might lead to inflation. While Fornaro et al. (2024) model green transition with caps on the availability of brown goods we, instead, follow the emission taxation approach with a gradual increase in taxes. Hence, our model predicts more muted inflation at the beginning of the transition. In Fornaro et al. (2024) there is a second channel which is inflationary (not included in our study): supply constraints increase the price of the brown good putting upward pressure on inflation.

We are also related to several papers in the exogenous growth New Keynesian literature. Ferrari and Nispi-Landi (2023) use a New Keynesian model with exogenous growth and argue that emission taxes are deflationary unless expectations are formed non-rationally. Coenen et al. (2023) shows using a detailed medium-scale model with exogenous growth and reports moderate, positive and temporary inflation at the start of the climate transition period.

[more to be added soon]

2 The endogenous growth model

We introduce carbon emissions, emission abatement and taxation into the endogenous growth model of Fornaro and Wolf (2023). In the spirit of Ferrari and Nispi-Landi (2023) we first study a simple economy without a distiction between green (clean) and brown (dirty) goods to highlight the main channel of our model. The representative household derives utility from consumption. The present discounted utility is given by:

$$\sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-1/\psi}}{1-1/\psi},$$

where β is the discount factor, and ψ is the elasticity of intertemporal substitution (EIS). The budget constraint of the household is given by:

$$W_t L_t + R_{t-1} B_{t-1} = B_t + C_t$$

Beyond nominal wage income, $W_t L_t$ the household holds one period nominal default-free government bonds, which pays the gross rate R_t.

Consumption smoothing implies the following Euler equation:

$$1 = \beta \left(\frac{C_t}{C_{t+1}} \right)^{1/\psi} \frac{R_t}{\Pi_{t+1}}.$$

where is Π_t gross inflation.

A perfectly competitive firm produces the final good with labour, L_t, and a continuum of intermediate goods, $x_{j,t}$:

$$Y_t = (L_t)^{1-\alpha} \int_0^1 A_{j,t}^{1-\alpha} x_{j,t}^{\alpha} dj. \tag{1}$$

where $A_{j,t}$ captures the fact that the quality of intermediate goods are growing through time and is the source of endogenous growth in the model. Alternatively, we can interpret $A_{j,t}$ as a labour-augmenting technology. This formulation of the production technology is widely-used in the endogenous growth literature since the expansion in intermediate goods—unlike labour—is not limited.

The cost-minimisation problem of the final goods' producer is given by:

$$\underset{\{x_{jt}, L_t\}}{min} \{w_t L_t + p_{j,t} x_{j,t}\}$$

with respect to the production function in equation (1).

The first-order conditions are the following:

$$w_t = (1-\alpha)(L_t)^{-\alpha} \int_0^1 A_{j,t}^{1-\alpha} x_{j,t}^{\alpha} dj \tag{2}$$

$$p_{j,t} = \alpha (L_t)^{1-\alpha} A_{j,t}^{1-\alpha} x_{j,t}^{\alpha-1} \tag{3}$$

Monopolistically competitive firms produce intermediary goods using final goods as input. Further, we assume that these firms emit greenhouse gases, E_t which are related to production in a linear form as in Barrage and Nordhaus (2023). Specifically, they reduce a fraction of the emissions, $\gamma_{j,t}$ in each period:

$$E_{j,t} = (1-\gamma_{j,t}) x_{j,t}.$$

In line with the climate literature the abatement spending is a convex function of the abated emission (see e.g. Heutel, 2012). For simplicity and in line with the literature we assume that abatement cost has a quadratic form:

$$Z_{j,t} = \upsilon \frac{\gamma_t^2}{2} x_{j,t}$$

where $\upsilon/2$ captures the output share in abatement.

The intermediary takes the demand of the final good producer as given and maximises its profits with respect to the price and abatement spending[1]:

$$\max_{\{p_{j,t},\gamma_t\}} \{p_{j,t}x_{j,t} - x_{j,t} - \tau_t E_{j,t} - Z_{j,t}\}$$

The first-order condition with respect to abatement spending, γ_t gives way to:

$$v\gamma_t = \tau_t. \tag{4}$$

The first-order condition with respect to the price yields:

$$p_{j,t} = \frac{1}{\alpha} + \frac{\tau_t(1-\gamma_t)}{\alpha} + v\frac{\gamma_t^2}{2\alpha}. \tag{5}$$

In the absence of abatement and taxes, $\tau_t = \gamma_t = 0$, the price of the intermediate good is the constant markup, $p_{j,t} = 1/\alpha$ (over unit marginal cost) as in Fornaro and Wolf (2023).

Using equation (4) we rewrite equation (5) as:

$$p_{j,t} = \frac{1}{\alpha} + \tau_t\left(\frac{1}{\alpha} - \frac{\tau_t}{2v\alpha}\right). \tag{6}$$

The combination of equation (3) and (6) leads to the equilibrium demand for the intermediary good:

$$x_{j,t} = \left(\frac{1}{\alpha}\right)^{1/(\alpha-1)}\left[\frac{1}{\alpha} + \tau_t\left(\frac{1}{\alpha} - \frac{\tau_t}{2v\alpha}\right)\right]^{1/(\alpha-1)} A_{j,t}L_t.$$

Again, the choice of $\tau_t = 0$ delivers the expression in Fornaro and Wolf (2023), $x_{j,t} = \alpha^{2/(1-\alpha)}A_{j,t}L_t$.

Hence, the maximised profit of the intermediary is given by:

$$PR_{j,t} = \left(\frac{1}{\alpha} + \tau_t\left(\frac{1}{\alpha} - \frac{\tau_t}{2v\alpha}\right) - 1\right)\left(\frac{1}{\alpha}\right)^{1/(\alpha-1)}\left[\frac{1}{\alpha} + \tau_t\left(\frac{1}{\alpha} - \frac{\tau_t}{2v\alpha}\right)\right]^{1/(\alpha-1)} A_{j,t}L_t.$$

The aggregate resource constraint can be written as:

$$GDP_t = Y_t - \int_0^1 x_{j,t}dj = \Psi_t L_t = C_t + S_t.$$

[1] We could have introduced Rotemberg price adjustment costs but price rigidity is not needed for our main result. Wage rigidity is introduced below.

where

$$\Psi_t = (p_{j,t})^{\frac{\alpha}{\alpha-1}} \left(1 - (p_{j,t})^{-1}\right).$$

The intermediary can invest to improve the quality of its product. Intangible capital accumulates due to investment spending, $S_{j,t}$ and is given by:

$$A_{j,t+1} = A_{j,t} + \chi S_{j,t}^{\zeta} A_t^{1-\zeta}, \tag{7}$$

where the constant ζ captures decreasing return in the innovation sector and parameter χ helps to calibrate the share of R&D in GDP. The aggregate stock of knowledge A_t has positive spillover effects on the productivity of an individual firm. Let the discount factor of the patent producer be defined as:

$$\frac{\delta_t}{\delta_{t-1}} = 1 + r_t + \eta \tag{8}$$

where the η is a constant that is calibrated to set a discount rate of about 14 percent for the patent producer (consistent with the empirical evidence in Gormsen and Huber, 2022). [2] Moreover, ζ helps to calibrate a growth rate of about two percent and a low risk-free rate. To derive the optimal path of innovation spending the firm maximises profits, PR minus R&D investment, S:

$$\sum_{t=0}^{\infty} \frac{1}{\delta_t} \left(PR_{j,t} - S_{j,t}\right)$$

with respect to equation (8) and equation (7).

Using equation (8) we can express the problem as:

$$\sum_{t=0}^{\infty} \prod_{j=1}^{t} \frac{1}{1 + r_t + \eta} \left(PR_{j,t} - S_{j,t}\right).$$

We take the first-order conditions with respect to $I_{j,t}$ and $A_{j,t+1}$ and derive the equation which describes the optimal path of investment:

$$\left(\frac{S_{j,t}}{A_{j,t}}\right)^{\frac{(1-\zeta)}{\zeta}} = \frac{1}{1 + r_t + \eta} \left(\chi \zeta PR_{t+1} + \left(\frac{S_{j,t+1}}{A_{j,t+1}}\right)^{\frac{(1-\zeta)}{\zeta}}\right). \tag{9}$$

[2] Note that the wedge η has effects similar to patent obsolescence, ϕ which can be introduced as $A_{j,t+1} = (1-\phi)A_{j,t} + \chi S_{j,t}^{\zeta} A_t^{1-\zeta}$. Hence, it increases the discount rate of the patent producer.

Iterating equation (9) forward we observe that innovation spending (or using equation (7) to replace innovation spending with growth) derives from the present discounted value of profits.

Inflation. We follow the shortcut in Gali and Gambetti (2020) as well as Fornaro and Wolf (2023), and assume that there is a wage setting rule in the form of:

$$\frac{W_t^{nom}}{W_{t-1}^{nom}} = G\left(\frac{L_t}{L}\right)^{\xi} \Pi_{t-1}^{\lambda}, \tag{10}$$

where the growth rate of nominal wages depends on the steady-state growth rate of the economy, G, the labour gap, L_t/L as well as indexation to past inflation, Π_{t-1}. ξ and λ denote the strength of the reaction of wage inflation to the labour gap and to past inflation.

Using labour demand from equation (2) and the wage setting rule in equation (10) one can show that

$$\Pi_t = \frac{G}{G_{t-1}}\left(\frac{L_t}{L}\right)^{\xi} \Pi_{t-1}^{\lambda}$$

such that price inflation today responds to the endogenous growth rate of technology, G, the labour gap, and past inflation. When labour gap is positive it is acting as a push on inflation.

Hence, the sign of inflation in the model ultimately depends on the sign of the labour gap. The labour gap is negative during the green transition (the economy is producing below the full employment steady-state, L) and there is deflation if $\xi > 0$ (the cost channel of higher taxes would be absent). Since, there is strong empirical evidence in favour of downward nominal wage rigidity we set $\xi = 0$. Hence, our results will be governed by the cost-channel.[3] This is reasonable choice since inflation in this case will be determined by endogenous changes in productivity.

Monetary policy reacts to both inflation and the labour gap:

$$R_t = R\left(\frac{L_t}{L}\right)^{\phi} \Pi_t$$

[3]This is obviously a short-cut to capture downward nominal wage rigidity but we think it is a useful simplification. We think of downward nominal wage rigidity as referring to the wage written in the job contract, and which is indexed in each year if there is positive inflation. We exclude bonuses from the nominal wage which could in fact be cyclical. Hence, in this setup real wages will 'grease the wheels' in the economy and will decline with inflation consistent with arguments in Olovsson and Vestin (2023).

Table 1: Calibration

Notation	Description	Value	Target
β	time discount factor	0.995	nominal interest rate of 2%
α	share of intermediary goods	0.163	growth rate of 2.3%
χ	constant in innov. function	1.7	innov. spending-to-GDP ratio of 2%
η	constant in discounting	0.115	corporate discount rate of 14%
ζ	curvature of innov.	0.97	following Fornaro and Wolf (2023)
ψ	el. of intert. subst. (EIS)	2	common choice in literature
ϕ	response to labour gap	0.12	following Fornaro and Wolf (2023)
ξ	resp. of wages to labour gap	0	to mimic downward wage rigidity
λ	persistence of inflation	0.5	following Gali and Gambetti (2020)

where R is the steady-state of gross nominal interest rate. ϕ governs the strength of the response in the policy rate to the labour gap.

3 Calibration

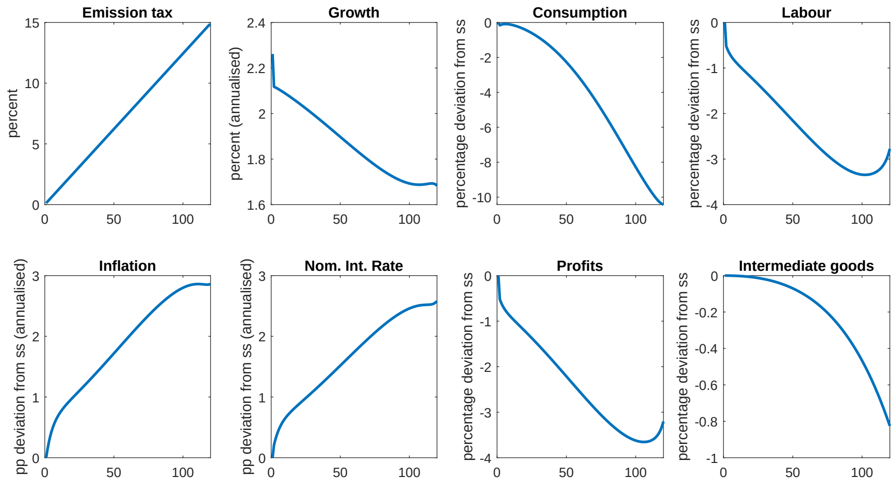
We report the benchmark calibration of the model in Table 1.

Production and innovation technology. β is chosen to set a nominal interest rate of 2.5 percent in the initial steady-state of the transition experiment. α helps to calibrate a growth rate of 2.3 percent in the initial steady-state. χ is a mutiplicative constant in the innovation production function and is set to deliver an innovation-to-GDP ratio of two percent. η intends to capture the empirical fact that corporate discount rates are substantially higher than the risk-free rate since investment into research and development is highly risky. These targets roughly capture post-war US time-averages.

Household preferences. The elasticity of intertemporal substitution, EIS is chosen to be two which is a usual choice in the long-run risk literature. A choice of an EIS$>$1 means that wealth effects of the tax increase are less strong relative to a lower value of the IES.

Wage setting rule. $\xi > 0$ is originally intended to capture the inflationary pressures of positive labour gap. In our transition experiment the labour gap is negative which would generate deflation. To capture the empirical fact that nominal wages are downwardly rigid we set $\xi = 0$. Following Gali and Gambetti (2020) we choose $\lambda > 0$ to capture the persistent nature of inflation.

Figure 1: Green Transition



Notes: time is in quarters on the horizontal axis. pp means percentage points.

Interest rate rule. We set ϕ to mimic the value in Fornaro and Wolf (2023). We find that a value of $\phi > 0.1$ is necessary for determinacy of the solution. A low value of ϕ is consistent with the primary mandate of price stability at central banks with some focus on setting ϕ such that labour gap is closed.

4 Results

Following Ferrari and Nispi-Landi (2023, 2024) we model green transition with a gradual increase in emission taxes from 0 to 15 percent during 120 quarters. The results are displayed on figure 1. The negative wealth effect of taxes reduce output, consumption, labour, intermediary goods and also leads to a reduction in profits. The fall in profits reduces innovation spending and growth. With downward nominal wage rigidity the slow-down in productivity implies gradually rising inflation. Intuitively, firms fail to invest into productivity enhancing innovation which, in the medium-run, raises their marginal cost which is reflected by inflation.

5 Extensions

i) Green and Brown sectors [to be added]

ii) Our model does not include price rigidity is a usual element of the exogenous growth New Keynesian literature. We have thus extended both the final good and the intermediate good sectors with price setting frictions. We find that our main results are minimally affected by price rigidity.

6 Conclusion

We study green transition executed with rising emission taxes in an endogenous growth model. The previous literature using exogenous growth models argue that green transition is deflationary unless expectations formed non-rationally. In our model green transition is inflationary due to decline in productivity induced by higher taxes. Inflation increases gradually with rising tax rates during the green transition.

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