Trilemma or Trinity? The nexus of economic growth, circular economy and net zero

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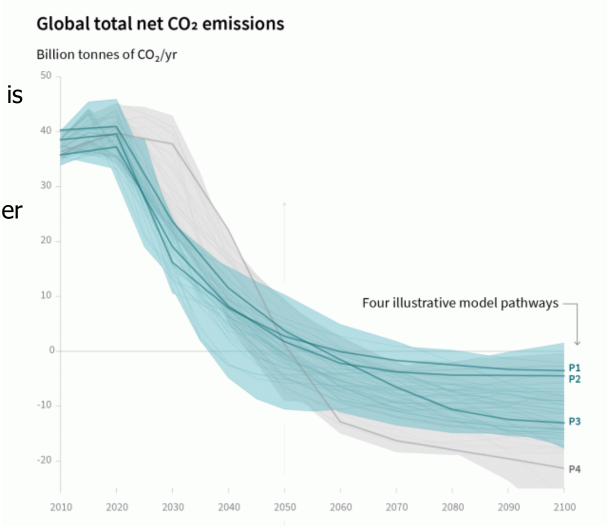
Outline

- Motivation
- Literature
- Model
- Main findings
- Extensions
- Conclusion

Net zero emissions targets

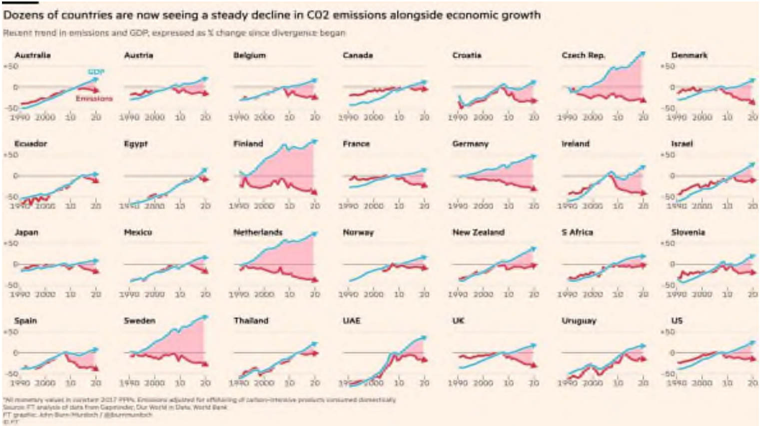
For any global temperature objective, there is a finite budget of carbon dioxide that is allowed into the atmosphere, alongside other GHGs.

Beyond this budget, any further release must be balanced by removal into sinks – that is, aggregate emissions are "net zero".



Source: IPCC, 2018

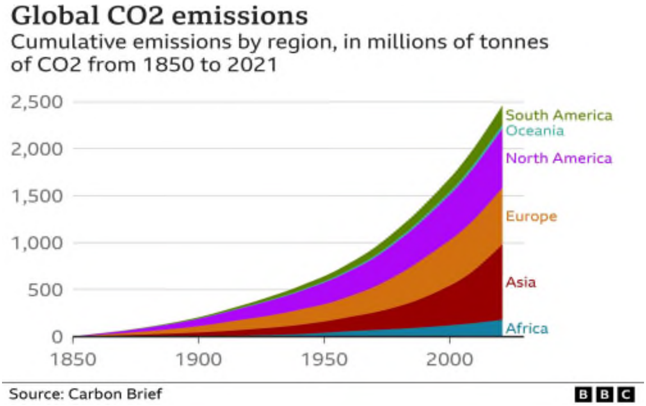
Emissions intensity of GDP



Source: FT, 23.09.2022

… we're becoming more 'efficient' at producing goods from resources

Global stock of carbon dioxide emissions



… but the absolute stock of emissions continues to rise

Policy solutions

- Replace fossil fuels with renewable (zero-carbon) energy sources such as solar and wind energy for electricity production, and its derivatives such as renewable hydrogen and renewable ammonia for hard-to-abate sectors: **The Energy Transition**.

- Adopt circular economy practices to convert waste and pollutants from the production of economic output including carbon (e.g. CCUS) and reintroduce them into the production process in a circular loop.

Policy Context

- Policy shapes a dominant role in the energy transition – climate change and pollution (collective public good)

- In emerging economies that are building out their economic infrastructure, governments seeking to align their net zero targets with wider economic growth and industrial agendas. Similar in OECD economies which have greater infrastructure lock-in.

- Green growth presented as a 'win-win' for society as it is seen as fostering environmental protection while speeding up (or not reducing) economic growth (Ajayi and Pollitt, 2022). Green fiscal stimulus to drive post-Covid recovery (O'Callaghan et al., 2022).

- OECD countries, including Denmark, France, Spain, Portugal, Chile, Costa Rica, and most recently the UK, have announced an end to new fossil fuel extraction, while committing greater resources to renewable energy.

- For OECD economies that have exhausted economies of scale, sustainable growth is relevant: long run balanced growth with minimised (ideally eliminated) pollution.

Research questions

- Is sustainable growth achievable in a net zero, circular economy?
- Do countries face trade-offs between growth and net zero targets in the energy transition?
- What (optimal) policy instruments could help countries balance trade-offs, if any?

Objectives

- Establish a simple neoclassical growth model that integrates three fundamental pillars of economics: (i) the net-zero carbon target (ii) the circular economy (iii) sustainable growth

- Offer a representation of dynamics between these pillars, offering a framework or tool of analysis, in terms of balancing trade-offs and priorities, and a set of possible outcomes.

- Explore different policy scenarios:

(i) 'Passive' policy: government sets fixed targets (e.g. rate of recycling and/or abatement)

(ii) 'Active' policy: government mandates that emissions reduction (through increasing the stock of renewable resources), recycling, and capture/use of residual hard-to-abate carbon, must increase over time at a certain rate.

- Extend our analysis to look at how policy instruments might be used to balance trade-offs (new companion paper)

Literature – nexus between growth, CE and NZ

Traditional	Theoretical	Empirical
Hotelling (1931) optimum path of extracting exhaustible natural resources. Schumpeter (1934, 1942), invention-innovation-diffusion paradigm. Wright (1936) and Arrow (1962), learning as a source of technical change. Solow (1956) and Swan (1956) exogenous growth models. Meadows (1972) The Limits to Growth. Koopmans (1973) and Stiglitz (1974), Dasgupta and Heal (1974), follow up on limits to growth and exhaustible natural resources, incl. uncertainty, technical change, and elasticity of substitution between reproducible and exhaustible capital as key factor for policy**.**	Hartwick (1977), Cohen et al. (2018), Acemoglu (2012) substitutability of reproducible inputs for long-run sustainable growth. Brock and Taylor (2003; 2005; 2010), Noda and Kano (2021), Ono (20030relationship between sustainable growth and environmental targets; modelling abatement as an economic activity whose intensity must rise over time; kindergarten rule of pollution abatement; environmental taxation to control emissions. George et al. (2015); Myrto and Thanasis (2023), Zhou and Smulders (2021) circular economy models with polluting and recyclable inputs; the EKC and sustainable growth; circular economy policies and productivity-enhancing innovations.	Brock and Taylor (2010) – look at growth, pollution abatement and emissions intensities in 173 countries over 40 years pre-Kyoto period. Busu and Nedelcu (2018), Lieder and Rashid (2016), Murray et al. (2018), Busu and Trica (2019) – EU economic growth. Argue that sustainability and the circular economy impact on economic growth is not increased by a simple shift to renewable resources or materials but require recycling rates and environmental innovation. Hysa et al. (2018) – 28 European countries finds a positive correlation between circular economy and economic growth. Chen et al .(2020) study on Chinese provinces Ajayi and Pollitt (2022) – UK will struggle to grow under conventional GDP measures in net zero setting. Hossain (2024) – green growth and GHG emissions intensity in 10 Canadian provinces; argues that if green growth is to be achieved ratio of GDP/GHG emissions must increase dramatically.

Literature – contribution

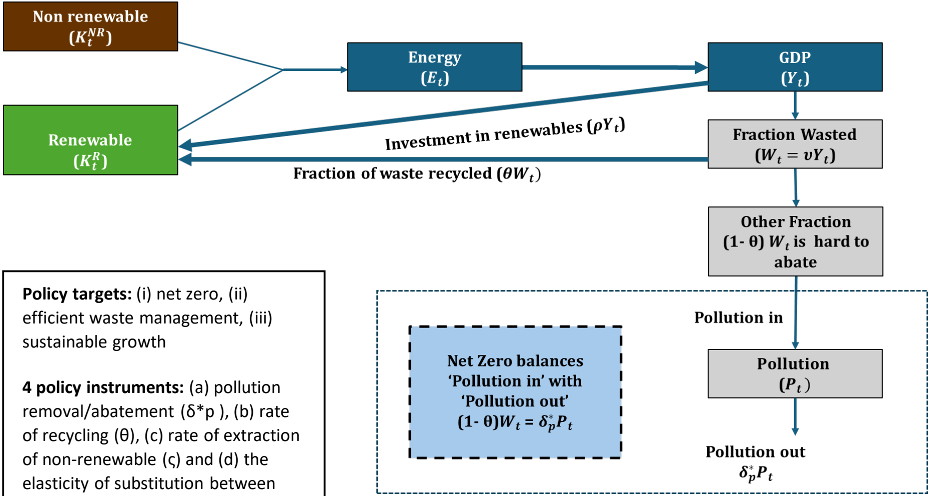
- Brings new challenges in reconciling sustainable growth with net zero carbon in a unifies growth model using features of circular economy. Using this growth theoretic framework, we also address optimal waste management and pollution abatement policies. Contributes to Gomes et al (2024), extends the work of Brock and Taylor (2003; 2005; 2010), George et al. (2015), and Noda and Kano (2021).

- Provides clarity on the relationship between renewable substitution and the ending of non-renewable extraction. Without high rates of substitution with renewables, ceasing the extraction of renewables could affect sustainable endogenous growth.

- Demonstrates how the setting of optimal policy targets for abatement and recycling can aid in achieving net zero sustainable growth.

- Provide some new theoretical insights around costs. Economies that have a higher 'distaste' for pollution and thus a higher incentive to abate may have to bear a higher fiscal cost. However, these economies are found to be more resilient to 'climate shocks'. Higher incentives for private investment in renewables, for instance when firms wish to reduce their costs of recycling, can reduce fiscal cost.

Simple model of a net zero circular economy



Policy targets: (i) net zero, (ii) efficient waste management, (iii) sustainable growth

4 policy instruments: (a) pollution removal/abatement (δ^*p), (b) rate of recycling (θ), (c) rate of extraction of non-renewable (ς) and (d) the elasticity of substitution between non-renewables and renewables (σ).

Model (2)

- Aggregate production function

$$Y_t = Z_t \left[(1-\omega) K_t^{N^{\frac{\sigma-1}{\sigma}}} + \omega K_t^{R^{\frac{\sigma-1}{\sigma}}} \right]^{\frac{\sigma}{\sigma-1}} \quad (1)$$

where Z_t is the total factor productivity (TFP) which is specifed as

$$Z_t = \frac{A}{1 + \alpha P_t + \beta P_t^2} \quad (2)$$

with A is a positive constant. The stock of pollutants (P_t) adversely affects current TFP. As P_t approaches zero, the TFP reaches the upper bound A. We assume all pollutants emit carbon, contributing to global warming. In reality, there are other pollutants - such as plastics, which pollute the earth's soil. As this paper focuses on carbon emissions, and the net-zero carbon emissions target, we abstract from these complications here.

Model (3)

A fraction (v) of final output (Y_t) goes to a stock of waste (W_t). In other words,

$$W_t = vY_t \tag{3}$$

Let a fraction θ of the waste be recycled and converted to renewable capital (K^R_{t+1}) at the end of date t. Renewable capital is also created through direct investments such as into solar and wind power generation, and hydroelectricity. The law of motion of renewable is therefore:

$$K^R_{t+1} = (1 - \delta_R)K^R_t + \theta W_t + \rho Y_t \tag{4}$$

Model (4)

Non-renewable capital is extracted from fixed, exhaustible resources. Let $\overline{K}^{EX}$ be the total stock of exhaustible resources. Investment in nonrenewable (I^N_t) entails extracting exhaustible resources (say crude oil). The rate of extraction (ς) is a policy instrument. Let I^N_t rise at the rate of the real interest rate. In other words,

$$I^N_t = (1 + \varsigma) I^N_{t-1} \tag{5}$$

The time path of non-renewable is thus:

$$K^N_{t+1} = \overline{K}^{EX} - I^N_t \tag{6}$$

The dynamics of pollution is given by

$$P_{t+1} = (1 - \delta_p) P_t + (1 - \theta) W_t \tag{7}$$

Model (5)

Net-zero target

$$NETCO2_t = (1 - \theta)W_t - \delta^*_p P_t \quad (8)$$

Imposing the net zero target, $NETCO2_t = 0$ and use of (3), gives rise to the following equation for the pollution intensity:

$$\frac{P_t}{Y_t} = \frac{(1 - \theta)v}{\delta^*_p} \quad (9)$$

The immediate implication is that net zero carbon does not necessarily eliminate pollution from the environment. Even if the policy authority removes the existing carbon entirely from the environment by setting $\delta^*_p = 1$, the residual pollution due to hard to abate waste is still $(1 - \theta)v$. Unless the recycling is done to the fullest extent (setting $\theta = 1$), the pollution cannot be entirely eliminated from the environment. This makes the circular economy a necessary condition for pollution abatement.

Proposition:

Net zero carbon does not eliminate pollution unless it is aided by efficient waste management

Model (6)

- Long run growth or a balanced growth path is defined as a scenario where the final output (Y_t) and the stock of renewables (K_t^R) grow at the same rate while the stock of nonrenewables (K_t^N) vanishes, dictated by policy. We have the following key result.

Proposition

If $\sigma > 1$, when K_t^N goes to zero, we get an AK technology as a limiting form:

$$Y_t = A[\omega^{\frac{\sigma}{\sigma-1}}]K_t^R \tag{10}$$

and the balanced growth rate is given by: ()

$$G = 1 - \delta_R + (v\theta + \rho)A\omega^{\frac{\sigma}{\sigma-1}} \tag{11}$$

Model (7)

$$\frac{Y_{t+1}}{Y_t} = \left(\frac{Z_{t+1}}{Z_t}\right)\left[\frac{(1-\omega)\left(\frac{K^N_{t+1}}{K^R_{t+1}}\right)^{\frac{\sigma-1}{\sigma}}+\omega}{(1-\omega)\left(\frac{K^N_t}{K^R_t}\right)^{\frac{\sigma-1}{\sigma}}+\omega}\right]^{\frac{\sigma}{\sigma-1}}\left(\frac{K^R_{t+1}}{K^R_t}\right) \tag{12}$$

- Over time as the economy traverses along the short run path, as the stock of pollutants (P_t) approaches the steady state, the first term ($\frac{Z_{t+1}}{Z_t}$) which is the TFP ratio approaches unity.
- As long as $\sigma > 1$, the second term also approaches unity as the ratio of nonrenewable to renewable resources decreases and the second square bracket term approaches unity.
- Output dynamics: The economy converges to the balanced growth path where output and renewable grow at the same rate.

Main findings

- The long run growth rate is rising in ω - growth is higher in an economy with a greater renewable bias in the technology.
- The long run growth rate is rising in σ. The greater the substitutability between nonrenewable and renewable capital, the higher the long run growth rate.
- The long run growth rate is higher if recycling rate θ and investment rate ρ are higher.
- The long run growth rate in a circular economy (with $v > 0$) is higher than in a linear economy with $v = 0$.
- The last two features of long run growth highlight the importance of a circular economy, for growth.

Illustrative simulations

We consider 4 policy targets: (i) net-zero carbon, (ii) efficient waste management, (iii) sustainable renewable growth, (iv) time to convergence.

We consider 4 policy instruments: (a) pollution removal/abatement ($\delta^*{}_p$), (b) rate of recycling (θ), (c) rate of extraction of non-renewable (ς) and (d) the elasticity of substitution between nonrenewable and renewable (σ).

We report the results of a few simulation experiments regarding the effects of tinkering with these instruments on our targets. The time unit is a quarter. Given that 2050 is the target year for net-zero, we set $T = 128$ as our time span (although that does not necessarily mean that the economy converges to long run growth path in year 2050).

Illustrative simulations (2)

- For illustration, we set the structural parameters at the following levels. $A = 1, \alpha = 0.01$, $\beta = 0.02, \omega = 0.5$, $v = 0.05$, $\rho = 0.1, \delta_R = 0.001$.

- The four policy instruments are set at the baseline levels, $\zeta = 0.02$, $\delta^*_p = 0.9$, $\theta = 0.9$, $\sigma = 2$. For such an economy the long run quarterly growth rate is a reasonable rate of 2.28% and the steady state carbon intensity is 0.0077 which is close to zero.

- Starting from initial conditions where $K_R = K_N = P = 1$, we trace out the time paths of the economy. The stock of exhaustible resources K^{EX} is fixed at 10.

This is currently a limitation in our model – calibration needs to be refined

Illustrative simulations (3)

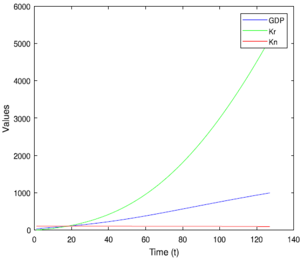


Fig. 1. Simulation of the GDP, Renewable, Nonrenewable

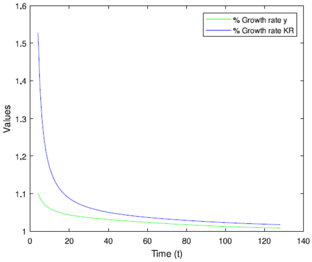


Fig. 2. Simulation of the Growth rate output and renewable

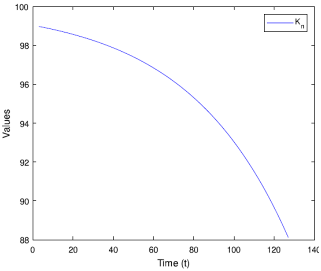


Fig. 3. Stock of nonrenewable

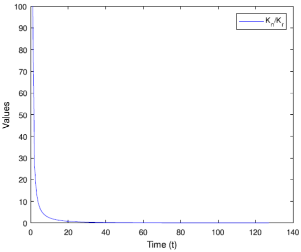


Fig. 4. Ratio of nonrenewable to renewable

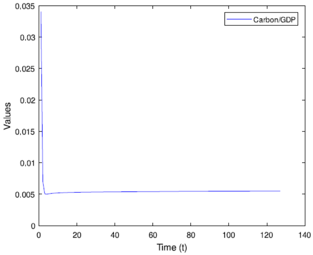


Fig. 5. Carbon Intensity

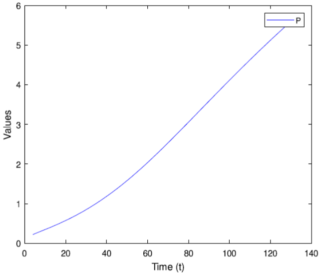


Fig. 6. Carbon

Illustrative simulations (4)

Table 1
Sensitivity of time to convergence to elasticity of substitution between N and R.

σ	2.0	2.5	3.0	3.5
T	61	49	43	39

Table 2
Sensitivity of growth rate to recycling of waste.

θ	0.3	0.5	0.7	0.9
Long run growth rate	1.52%	1.77%	2.03%	2.28%

Table 3
Sensitivity of growth rate to the renewable-nonrenewable substitution.

σ	2	2.5	3.0	3.5
Long run growth rate	2.28%	2.89%	3.26%	3.35%

The effect of 'proactive' policy

- Though the net zero carbon target is achieved with a decline in pollution intensity, the stock of pollution (carbon) does not decrease.

- To lower carbon in the economy, proactive environmental policy is needed where the government takes direct control by mandating a time path of pollution removal and recycling.

- The government lays out a path for θ_t and δ_{pt} as follows:

$$\delta_{pt} = 1 - \frac{1}{\lambda_1^t} \tag{13}$$

$$\theta_t = 1 - \frac{1}{\lambda_2^t} \tag{14}$$

- $\lambda_1 > 1$ and $\lambda_2 > 1$. It is guaranteed that δ_{pt} and θ_t asymptotically approach unity. The higher the sizes of λ_1 and λ_2, the greater the proactiveness of the authority to adhere to zero as well as net zero

Illustrative simulations with proactive policy

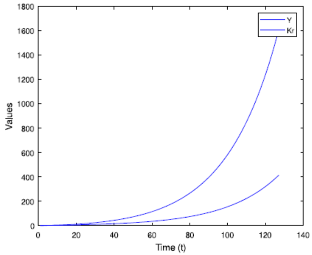


Fig. 7. Simulation of the GDP, Renewable

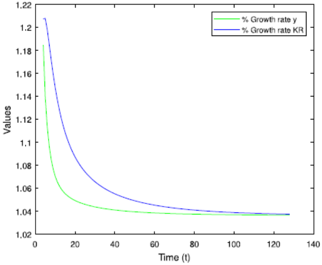


Fig. 8. Simulation of the Growth rate output and renewable

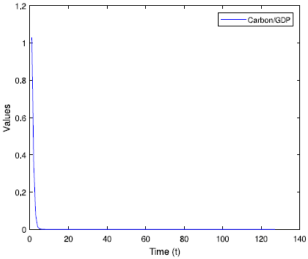


Fig. 9. Carbon Intensity

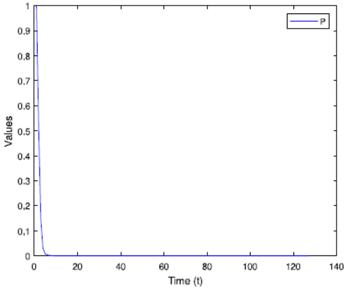


Fig. 10. Carbon

Extensions

- The policy authority mandates that the investment in extraction of non-renewables (fossil fuels) must go down at a specified rate ρ_n – this determines the rate of investment in non-renewables (rather than the Hotelling rule / real interest rate)

- The policy authority mandates rates for recycling and pollution abatement: we explore whether we can use recycling (θ) and abatement (δ^*_p) to maximise societal welfare. We add cost functions for each (κ_1 and κ_2) which we assume lead to a tax burden

- We explore how societal aversion to pollution (i.e. 'pollution distaste parameter, *b*) versus its preference for growth, affects rates of growth, recycling, abatement, and the associated fiscal costs

- The policy authority incentivises the private sector to invest more (ρ) in renewables (to reduce the fiscal costs of 'cleaning up')

- We explore the impact of a 'climate shock' (i.e. a spike in carbon emissions) on growth

Extensions – limit investment in non-renewables

- Non-renewable capital is extracted from fixed exhaustible resources at rate ς . As more investment in nonrenewables takes place, it draws down the fixed exhaustible resource.

- Let $\overline{K}^{EX}$ be the total stock of exhaustible resources. Investment in non-renewable (I_t^N). entails extracting exhaustible resources (say crude oil). The government lays out a time path of the extraction of exhaustible resources as follows. sets an upper bound $\overline{I}_N$. In other words, starting from an initial extraction I_0^N the time path of extract is given by

$$I_t^N = (1 - \rho_n) I_N + \rho_n I_{t-1}^N$$

where $\rho_n \in (0,1)$ and I_N is the target extraction of exhaustible

- In other words, if $I^N > \overline{I}_N$, the government mandates that it must go down at a rate ρ_n. The time path of non-renewable resource is thus: $K_{t+1}^N = \overline{K}^{EX} - I^N$

and it reaches the target: $\overline{K}^{EX} - \overline{I}_N$.

Extensions – optimal recycling and abatement

What are the optimal θ (recycling) and pollution abatement (δ_p)?
To answer this question, we need to lay out the government objective.

Suppose the government cares about long run growth environment. Let the cost functions for recycling and abatement be $0.5\kappa_1\theta^2$ and $0.5\kappa_2\delta^2_p$.

The government chooses θ and δ_p to maximise societal welfare:
$W = G - b(P/Y) - 0.5\kappa_1\theta^2 - 0.5\kappa_2\delta^2_p$. The rationale for the term P/Y is that net-zero carbon does not eliminate carbon fully.
Plugging the steady state P/Y in the welfare function, we get: $W = G - b((1-\theta)v/\delta_p) - 0.5\kappa_1\theta^2 - 0.5\kappa_2\delta^{*}{}_p^2$ where b is the pollution distaste parameter.

Extensions – optimal recycling and abatement

The social planner maximises W with respect to θ and δ_p^* s.t. $\delta_p^* > \delta_p$

Assuming an interior solution, it is straightforward to verify that the optimal, θ^* and δ_p^* are given by:

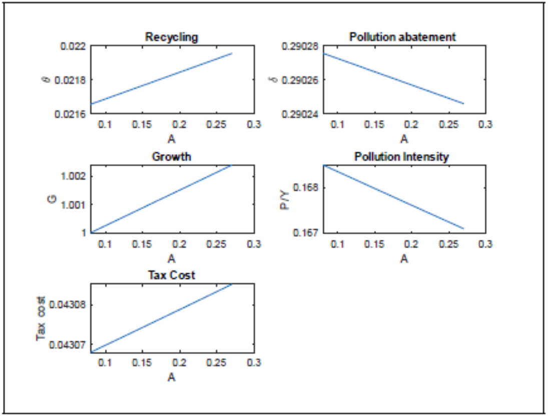
$$\theta^* = \frac{vA\omega^{\frac{\sigma}{\sigma-1}} + bv/\delta_p}{\kappa_1}$$

and

$$\delta_p^* = \left(\frac{b(1-\theta)v}{\kappa_2}\right)^{1/3}$$

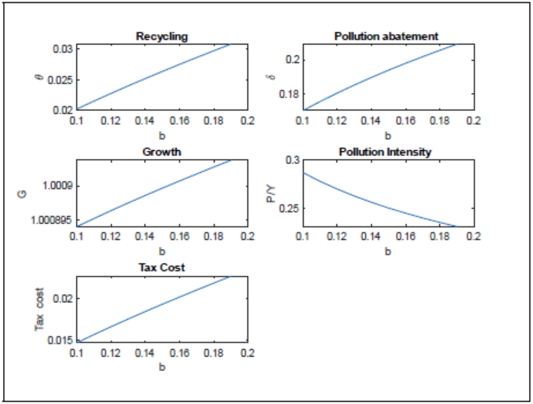
Extensions – illustrative simulations

More productive economies (higher A) may recycle more but abate less. Pollution intensity is lower and growth is higher. The cost of abatement is lower while cost of recycling is higher. The total cost borne by society (tax cost) is higher but the rise is negligible in more productive economies due to offsetting movements in recycling and abatement cost.



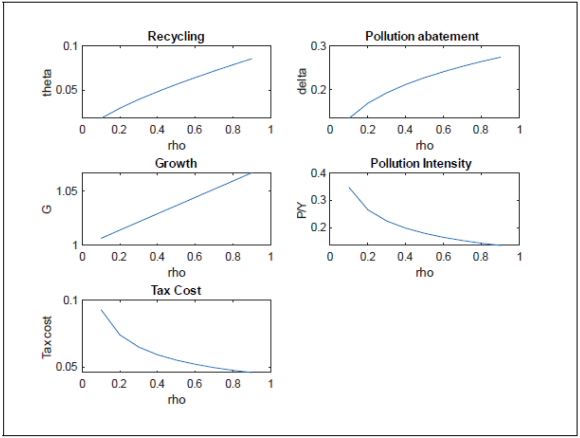
Extensions – illustrative simulations

Countries with more concern for pollution (higher b) would recycle more, abate more as well. Growth experience will be better and pollution intensity will be less. Costs of pollution abatement and recycling will be considerably higher than more productive economies. This implies potentially greater tax burden.



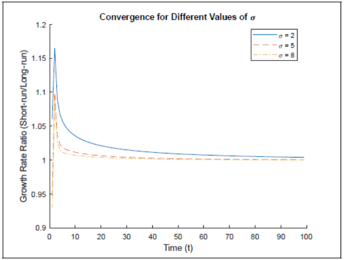
Extensions – illustrative simulations

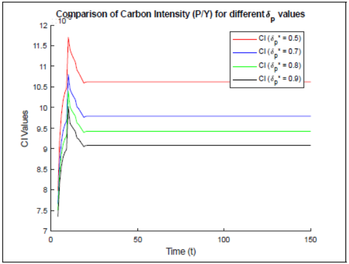
Incentivising the private sector to invest more in renewables lowers their tax burden as it reduces the cost of pollution abatement and waste management. Less need for public investment in 'cleaning up' which lowers the tax cost.



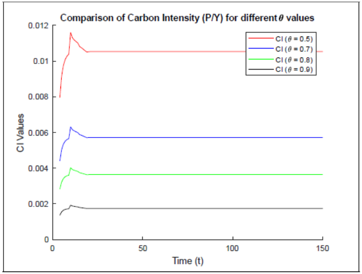
Extensions – illustrative simulations

Effect of σ in convergence to long run growth >>





Effect of δ^*_p on recovery from a 'climate shock' >>



Effect of θ on recovery from a 'climate shock' >>

Conclusion – 'active' policies for NZ, growth and circularity

- We portrayed two policy scenarios: active and passive.

- A passive approach aligns closely with a market based approach where the government sets some targets for pollution removal and play with market instruments to achieve them. In an active approach may involve stronger regulations.

- The reality lies between two extremes. Government could incentivize higher rates of substitution between renewable and non-renewable capital (e.g. support schemes for renewable energy in the UK); it could combine this with regulation (e.g. Denmark, Costa Rica, France, and Sweden have pledged to end new fossil fuel extraction)

- Net zero emissions can be achieved faster with sustainable growth in a circular economy framework, with active policy intervention in four areas: increasing the elasticity of substitution between non-renewable and renewable capital; increasing the rate of recycling; promoting pollution removal (including of hard-to-abate carbon emissions); and, disincentivizing investments into non-renewables.

Conclusion – some fundamentals in a net zero, circular growth framework

- Countries must achieve high rates of substitution to renewable technologies, prior to policy mandates which halt investment in non-renewables. Since the production function is subject to constant returns to scale in both non-renewable and renewable inputs, once non-renewables cease to grow, the prospect of sustainable growth is compromised. Technically, this requires the production function to have ***$\sigma > 1$.*** Higher the elasticity, greater the growth potential from substitution.

- Net-zero target does not necessarily mean zero pollution. Given that a fraction of GDP is wasted every period, along a balanced growth path, the stock of pollution also grows at the same rate as GDP. The steady state pollution intensity (pollution/GDP ratio) is thus positive unless the waste removal technology is so efficient that it does not generate any hard-to-abate wastes. This makes circularity fundamental.

- Given that a fraction of GDP is wasted, the rate of pollution (carbon) abatement needs to be higher than the natural depletion of carbon to achieve a net zero carbon target without compromising a sustainable growth target. In our model this is done through setting optimal policy targets for abatement and recycling.

- Fiscal costs of abatement and recycling lower if policymakers incentivise private sector to invest in renewables, lowering burden on taxpayers. Countries with effective abatement and waster management policies are more resilient to 'climate shocks'.

Thank you

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Recycling

ABSTRACT

How can economies achieve economic growth without causing negative environmental externalities? There are two aspects to the long-standing debate on 'sustainable growth'. A first-best solution is for economies to replace fossil fuels with renewable energy sources, mitigating carbon emissions. A second-best solution is to also adopt efficient waste management, recycling residual waste and pollutants (including hard-to-abate carbon) from production (circular economy). We establish a simple growth model that integrates three fundamental pillars of economics: (i) the net zero carbon target in environmental economics (ii) the circular economy, dealing with waste management in resource economics, and (iii) sustainable growth, in growth economics. We argue that growth, circularity and net zero emissions present a trinity of solutions to the sustainable growth problem, showing that the circular economy is a necessary condition for achieving net zero. We show that an economy with 'active' environmental policy achieves net zero faster than one with 'passive' policy, and also eliminates carbon emissions.

- Link to paper

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