CESifo WORKING PAPERS

9838
2022

July 2022

Temporary Super Depreciation Allowances for Green and Digital Investments

Michael Funke, Raphael Terasa

CESifo

Impressum:

CESifo Working Papers
ISSN 2364-1428 (electronic version)
Publisher and distributor: Munich Society for the Promotion of Economic Research - CESifo GmbH
The international platform of Ludwigs-Maximilians University's Center for Economic Studies and the ifo Institute
Poschingerstr. 5, 81679 Munich, Germany
Telephone +49 (0)89 2180-2740, Telefax +49 (0)89 2180-17845, email office@cesifo.de
Editor: Clemens Fuest
https://www.cesifo.org/en/wp
An electronic version of the paper may be downloaded
· from the SSRN website: www.SSRN.com
· from the RePEc website: www.RePEc.org
· from the CESifo website: https://www.cesifo.org/en/wp

CESifo *Working Paper No. 9838*

Temporary Super Depreciation Allowances for Green and Digital Investments

Abstract

As an incentive to increase high-impact investment and boost growth, the German Federal Government is planning to introduce a targeted temporary super depreciation allowance to support much-needed green and digital transitions. Using a calibrated multi-sector DSGE model, we find that the temporary super deduction could trigger an uplift of 10 percentage points for green and digital capital spending, turbo-charging green growth ambitions. However, with the temporary measure set to end after two years, there is a risk that business investment could tail off at a crucial time, when post-COVID-19 recovery is levelling out. Thus, additional longer-term climate policies are needed to drive the green transition, facilitated by broad policy packages.

JEL-Codes: E220, E600, H250, Q540, Q580.

Keywords: climate economics, business taxation, firm investment, depreciation allowances, DSGE model, Germany.

Michael Funke
Department of Economics
Hamburg University / Germany
michael.funke@uni-hamburg.de

Raphael Terasa
Department of Economics
Hamburg University / Germany
raphael.terasa@gmail.com

Hamburg, July 2022

1. Introduction

According to the coalition agreement of the German Federal Government, "More Progress - A Partnership for Liberty, Justice, and Sustainability," the traffic light coalition (named in reference to the customary political party colors of the SPD, the Bündnis 90/the Greens, and the FDP) intends to temporarily increase the generosity of tax depreciation allowances for firms investing in climate protection and digitalization for a two-year period. The coalition agreement has termed this time-limited tax policy measure *super depreciation*.[1] The aim is to encourage firms to prioritize investment into green infrastructure and information and communication technologies (ICTs) by providing significant, time-limited, enhanced tax reliefs for expenditure on qualifying assets.

Firstly, the focus on green infrastructure is a response to looming climate change and energy challenges, which have made accelerated decarbonization increasingly *de rigueur*. The transition to greener energy requires building new infrastructure based on electric vehicles, wind and solar power, battery storage, and green hydrogen. Recent years have taken the idea that governments should incorporate climate change considerations into their policies from radical to plain common sense. Climate scientists are in no doubt: we must act now and vigorously if global warming is to be kept below 2 degrees Celsius—with the aim of 1.5 degrees Celsius—relative to preindustrial temperatures. In other words, the world has reached a point where proactive climate policies are no longer a choice to be considered, but an inevitable necessity that cannot be sidelined. Decarbonization is not only essential, but also presents genuine opportunities.[2]

Secondly, the focus on ICTs stems from the insight that, in the current era of digitalization, the competitiveness of firms, industries, and countries is driven by technological advancement based on the application of ICTs. This has the potential to trigger progress along the global value chain to a more knowledge-intensive economy. In the digital era, leadership in emerging technologies engenders global market shares, the ability to set standards, and above-average profits. New services built on data, such as artificial intelligence, machine learning, next generation 5G networks, and quantum computing, have paved the way for new growth engines that promise to transform entire industries and lift productivity. Due to economies of scale and scope and our increasingly digitalized and networked world, new growth engines have taken shape and technological leadership is highly prized. Taken together, the goal is to incentivize investments in the future for attaining the UN's Sustainable Development Goals (SDGs) and the 2015 Paris Climate Change Treaty objectives.

[1] See https://www.bundesregierung.de/breg-de/service/gesetzesvorhaben/koalitionsvertrag-2021-1990800, p. 164.
[2] The urgent need for decarbonization and modernization of the economy emphasized by the German government is part of a pan-European strategy in this context. An example of this new mindset is the EUR 750 billion "Next Generation EU Recovery Fund," which focuses on environmental and climate policy. See https://ec.europa.eu/info/sites/default/files/business_economy_euro/banking_and_finance/documents/sustainable-finance-taxonomy-spotlight_en.pdf. The policy proposal is also in line with the IMF's (2020, pp. 85-113) view that a medium-run green investment push is needed to place economies on more sustainable footing.

The temporary super depreciations for investments in climate protection and digitalization are expected to encourage firms to bring such investments forward, thus unleashing innovation.[3] Beyond increasing the expected return on investment and the liquidity advantage, the generous depreciation allowance also reduces uncertainties and risks related to these investments, since the tax-life of the capital good is shortened. When designing and evaluating the measure, it is important to keep in mind that the enhanced tax reliefs for business investment in priority industries will be introduced against the backdrop of the ongoing COVID-19 pandemic, which has up to now chilled business investment.[4]

Ultimately, the proposed tax measure is not as unconventional as it might seem at first glance. The term *super depreciations* appears to have been inspired by the *super deductions* currently applicable in the UK. These have given an "above-the-line" 130% first-year depreciation allowance to firms investing in qualifying assets (i.e., most new plants and machinery, including processing equipment, production machinery, and ICT equipment or services) during the period from 1 April 2021 until 31 March 2023.[5] As with all tax depreciation allowances, if the full super deduction cannot be used by the firm to set against its profits, a loss will be created which can be carried forward (or back under the new temporary three year loss carry back rules).[6] Another precursor to the proposed tax measure has been facilitated depreciation under Italy's 2016 Stability Law. According to this policy, Italian firms have benefitted from an increased first-year depreciation of 140% for machinery and equipment. In Italy, this tax measure was termed *Super Ammortamento al 140%*. Originally, the facilitated super depreciation allowance was planned as a temporary measure for the period from 15 October 2015 to 31 December 2016. However, it was subsequently extended until 2020, albeit with a reduction in the super depreciation rate from 140% to 130%. The Italian 2020 Budget Law finally changed the structure of the super depreciation into a tax credit (see Zangari, 2020). Also notable is China's temporary super deduction earmarked for research and development (R&D) expenditures. China's State Council announced in spring 2021 that the super deduction for R&D expenses will be further raised from 175% to 200% in order to encourage innovation. The measure has also been extended for three years, until 31 December 2023.[7] The above examples illustrate that the planned German super depreciation allowance is only one among many global measures of similar design. This implies that the theoretical framework and the numerical simulations also have relevance beyond one specific case.

In a nutshell, our model-based analysis shows that the temporary earmarked super depreciation allowance is an investment promotion scheme for the prioritized green and digital industries. In other

[3] With the next phase of digitization and automation unfolding, various OECD countries are promoting new technologies through monetary support or incentives to buy ICT equipment or services. See OECD (2019).

[4] The COVID-19 pandemic has profoundly affected the global relationship with digital technologies. Never before has such dependency on digital technology touched all aspects of society. Examples of the most strongly affected fields include education, health, remote work, online learning, and e-commerce.

[5] See https://www.gov.uk/guidance/super-deduction. For a brief initial assessment, see https://www.ft.com/content/728d2c12-b5dd-4f85-86a2-fe50dbbe4ff6.

[6] https://www.gov.uk/government/publications/extended-loss-carry-back-for-businesses/extended-loss-carry-back-for-businesses.

[7] Regarding the incentive effects of R&D tax incentives for firm-level innovative activity, see Tian et al. (2020).

words, the propagation mechanism encourages multiple sectors to progress toward a more sustainable world. However, with the temporary measure set to end after two years, there is a risk that business investment could tail off at a crucial moment, when post-COVID-19 recovery is levelling out at modest rates in the face of increasing geopolitical risks.

The remainder of this paper is organized as follows. Section 2 presents relevant background information and data on the size and macroeconomic significance of the earmarked industries. Section 3 specifies our two-sector dynamic stochastic general equilibrium (DSGE) modelling framework to evaluate the earmarked super depreciation tax policy agenda of the German government.[8] Section 4 presents the model parameterization. Section 5 illustrates the quantitative properties and policy implications of the model in light of recent economic developments, providing an in-depth analysis of how the policy tool may be designed to leverage the benefits of the business tax policy channels and mitigate their risks. The final section concludes.

2. The Earmarked Green and Digital Industries

In view of the selective nature of the temporary tax measure on capital spending, this section first reviews the size of the targeted green and digital industries, along with an international comparison. "Green" is a buzzword that, in recent years, has increasingly been used in association with the environmental policy debate. It is therefore unsurprising that the term "green economy" has not been defined clearly or consistently. It remains a novel concept, and refers to a mix of existing and emerging sectors, topics, principles, and concepts. The apparent difficulty is that standard industrial codes have significant limitations for measuring the green economy. Therefore, measuring the green economy using national statistics is a difficult task, frequently requiring additional surveys and research.

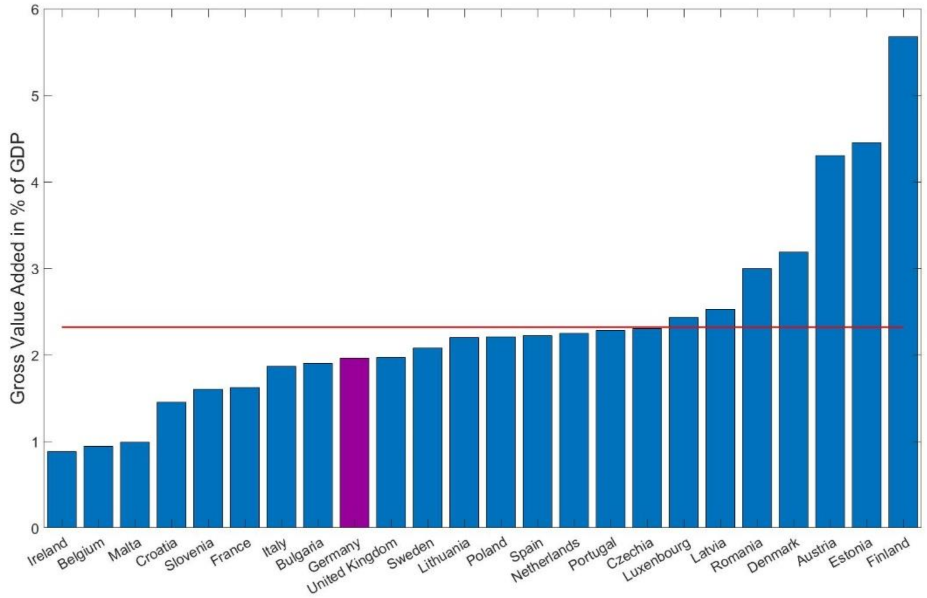
An authoritative green economy delimitation can be sourced from the statistical office of the EU. As part of their reporting on the progress of EU member states toward Sustainable Development Goals (SDGs), Eurostat produces wide-ranging statistics on the implementation of the EU's sustainable development strategy. Within the overall SDG framework, the gross value added in the environmental goods and services sector is calculated alongside other measures in the 12th SDG, titled "Responsible Production and Consumption." The environmental goods and services sector is defined as that part of a country's economy engaged in producing goods and services that are used in environmental protection and resource management activities either domestically or abroad. Gross value added in the environmental goods and services sector represents the contribution of the environmental goods and services sector to GDP, and is defined as the difference between the value of the sector's output and

[8] The analysis in Clemens et al. (2021a) ultimately does not achieve this. In the underlying modelling framework, permanently enhanced depreciation allowances across the board are assumed. In other words, the earmarked temporary super depreciation proposal is not modelled.

intermediate inputs. It is considered vital for the EU's transition toward a climate-neutral economy, as envisioned under the SDGs and the European Green Deal.[9]

Figure 1 illustrates EU member states' GDP shares of the environmental goods and services sector for the year 2018. Within Figure 1, EU member states have been ranked according to their respective environmental goods and services sector shares in GDP, and the EU average has been marked by the horizontal red line. Furthermore, Germany has been highlighted in purple. The sector's relevance as measured by the ratio of its value added relative to GDP varies significantly among the EU member states, with outsized impact in Finland, Estonia, and Austria. At the other end of the spectrum are Ireland, Belgium, and Malta. At 1.9%, Germany is slightly below the EU27 average of 2.3%.

Figure 1: Gross Value Added for the Environmental Goods and Services Sector Relative to GDP in %, 2018



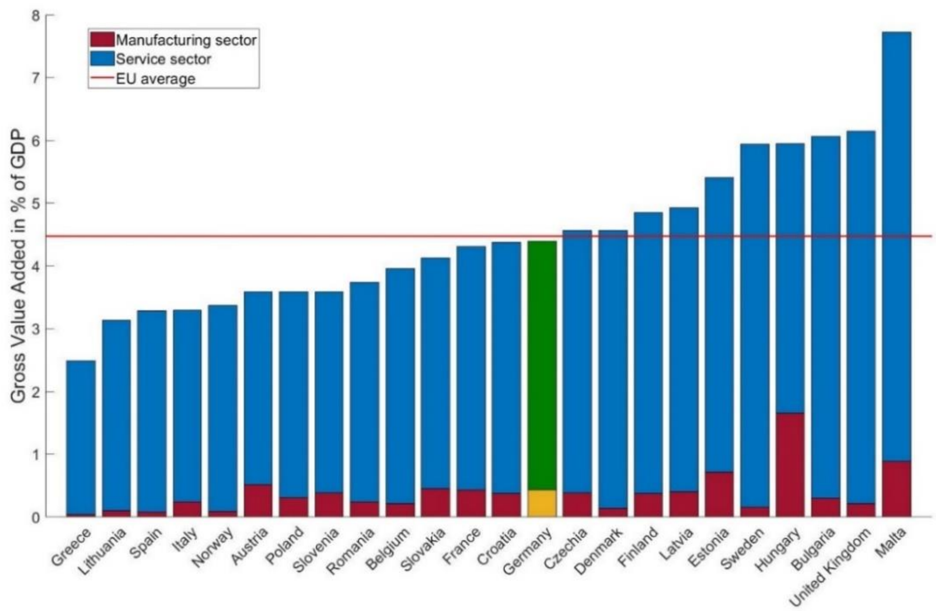
Notes: For Germany, more up-to-date data for the years 2019 and 2020 are not available. For the sector delimitation, see https://ec.europa.eu/eurostat/databrowser/view/sdg_12_61/default/table?lang=en.
Source: https://ec.europa.eu/eurostat/cache/metadata/en/sdg_12_61_esmsip2.htm.

Figure 2 presents a closer look at the importance of the digital sector from a cross-country perspective. The metric used for this purpose is the ICT value added relative to GDP in 2018. A further distinction is made between ICT manufacturing and ICT services. ICT investment is defined as the acquisition of equipment and computer software that is used in production for more than one year, and consists of information technology equipment, communications equipment, software, and services. This offers a snapshot of the digital industry. We have ranked all countries according to the relative size of the ICT sector. To provide context, the EU27 average of 4.5% is also given. The EU average is again marked by the horizontal red line, and Germany is highlighted green.

[9] See https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

Figure 2 illustrates how EU economies are characterized by a high degree of ICT heterogeneity across member states. The vastly predominant portion of the EU ICT industry's value added is supplied by information and communications technology services (i.e., telecommunications and computer-related services such as software, programming, data processing, and repairs). Conversely, Asian countries are in general much stronger in manufacturing (i.e., producing electronic components, communication equipment, computers, and consumer electronics. Among the EU member states, the relative weight of the ICT sector - as measured by the ratio of its value added relative to GDP - fared best in Malta, the UK, and Bulgaria. By contrast, value added by the ICT sector was lowest in Greece, Lithuania, and Spain. Germany again ranks somewhere mid-range. Against the background of the policy objectives of the new German government, the relatively modest role played by the value added from the earmarked climate and ICT industries in Germany indicates that significant efforts are needed to boost climate-responsible and digital investment decisions.

Figure 2: Gross Value Added for the ICT Industry Relative to GDP in %, 2018



Source: https://ec.europa.eu/eurostat/web/products-datasets/-/tin00074.

The following section lays out the modelling framework that guides this paper's quantitative analysis and assessment of the super depreciation policy proposal.

3. Conceptual Framework

How can we assess the economic effects of the super depreciation flagship project for green and digital investments? This paper studies the transmission channels and the effectiveness of the policy in a multi-sector DSGE modelling framework with endogenous capital accumulation, in the spirit of Bouakez et al. (2022). DSGE models play a major role by providing tools and concepts that are able to bridge theory and quantitative results. The present paper sits at the intersection of two strands of literature. The first introduces multi-sector DSGE models with interrelated industries that vary in their type of products, degree use of factor intensities, use of intermediate goods, and contribution to final demand. The multi-sector setting allows us to illustrate the impact of earmarked depreciation allowance shocks on industry outputs and aggregate output while taking production linkages into consideration. The second area of literature studies the design and effectiveness of corporate tax systems to achieve sustainable economic development. Important issues in this context include the acceleration of green and digital investment spending, pathways to sustainable growth, and the coordination of economic agents toward a forward-looking climate and innovation policy.[10]

3.1 Households

3.1.1 Intertemporal Choices

Time is discrete and continues forever, indexed by $t = 0,1,\cdots,\infty$. We assume that the economy is populated by intertemporally optimizing representative households who supply labor, consume, invest in physical capital, and hold sovereign bonds. They derive utility from consumption, C_t, and disutility from labor, N_t.[11] Each household maximizes its expected discounted utility, as given by

$$\max_{N_t,C_t} E_0 \sum_{t=0}^{\infty} \beta^t \left(\log(C_t - hC_{t-1}) - \chi \frac{N_t^{1+\varphi}}{1+\varphi} \right) \tag{1}$$

where $E_0[\cdot]$ denotes the mathematical conditional expectation operator $E_t[\cdot]$ at $t = 0$. C_t is aggregate consumption, which is a CES bundle of green and digital consumption goods on the one hand and miscellaneous consumption goods on the other. Throughout this paper, we denote the goods of the two industries with the indices g (green and digital) and m (miscellaneous), respectively. Consumers discount future values at the rate $0 < \beta < 1$, while $h \in (0,1)$ is the consumption habit parameter, χ measures the relative weight of the disutility of labor, and φ is the inverse of the Frisch elasticity of labor. N_t is the CES bundle of labor supplies to the two intermediate goods industries $s \in \{g, m\}$.

[10] In recent years, the integration of environmental issues in macroeconomic models has been and is still advancing. A recent comprehensive overview of analyses can be found in Annicchiarico et al. (2022). However, the literature points to critical uncertainties surrounding different environmental feedback channels. Pindyck (2013) provides an in-depth critical view of these uncertainties, arguing that many of the inputs are arbitrary and that climate change modules often lack theoretical or empirical underpinnings.

[11] Insofar as was possible, the variable labels used resemble those in Bouakez et al. (2022). This suits readers wishing to link the modelling framework below with their study.

The household maximization problem is subject to a sequence of budget constraints, taking the form

$$P_t^C C_t + \sum_s I_{s,t} + B_t = W_t N_t + \left(1-\tau_t^k\right)\sum_s R_{s,t}^k u_{s,t} K_{s,t-1} + \tau_t^k \sum_s \hat{\delta}_{s,t} I_{s,t} + R_t B_{t-1} - \tau_t + \left(1-\tau_t^k\right)\Pi_t \tag{2}$$

where $s \in \{g, m\}$. Turning to the terms in the budget constraint, B_t is the amount of one-period, risk-free sovereign bonds paying a gross interest rate R_t. Households own the capital stock $\sum_s K_{s,t}$ and lease this capital to firms in a perfectly competitive rental market at the real rental rate of $R_{s,t}^k$.[12] To simplify the analysis, profits are taxed at the same rate, τ_t^k, as returns on physical capital income. The representative household's total labor income is given by $W_t N_t$, where W_t is an aggregate wage index composed of the sectoral wages. The government levies lump-sum taxes on labor income, as denoted by τ_t. The assumption of lump-sum taxation is for simplicity. P_t^C denotes the composite consumption price index (CPI). Thus, the CPI inflation rate is given by $\pi_t^C = P_t^C / P_{t-1}^C$. The symbol Π_t denotes profits stemming from the ownership of the monopolistically competitive intermediate goods firms. The variable $u_{s,t}$ denotes the industry-specific capital utilization rate, and $I_{s,t}$ is industry investment.

Since households are the ultimate firm owners, capital taxation is assumed to occur at the household level. In other words, the modelling framework assumes that transactions within the corporate sector are not taxable, and that only transactions between capital owners and firms are subject to taxation. Such a taxation on the equity distribution base corresponds with the S-base tax proposal.[13] Returns on physical capital are taxed at the rate of τ_t^k. Turning to changes in capital depreciation allowances, we introduce earmarked industry-specific super deductions for tax purposes, which are represented by $\hat{\delta}_{s,t}$. The targeted super deductions may impact investment decisions via two main channels: 1.) changes to the after-tax cost of capital, and 2.) changes to the cash flow. Together, these two effects can generate an incentive to increase investment in the earmarked industries. Given the temporary nature of the super deduction, they may also influence the timeline of green and digital investment expenditures by shifting investments forward.[14]

---

[12] In our analysis, we focus on the temporary super depreciation allowance and abstract from changes in R_s^k, which is assumed to be unaffected by the super deduction in the counterfactual scenarios.

[13] Corporate tax systems should be neutral with respect to firm decisions. However, corporate tax systems in many countries have distortionary effects. Typically, debt is tax-favoured over equity and distributed profits are taxed more heavily than retained profits. Named after the Meade report, the S-base tax is also called the "Meade tax" (see Meade et al., 1978). Bond and Devereux (2003) have proved that the S-base tax is neutral under uncertainty.

[14] The general presumption is that investors have the internal funds available to finance an investment project. COVID-19 recovery presents major investment opportunities coupled with ample pent-up savings to finance investment. Households in the euro area are estimated to have accumulated about eight percent of GDP in excess savings during the pandemic, as of mid-2021 (IMF, 2022).

In the following analysis, differences between $\hat{\delta}_{s,t}$ and the economic depreciation rate of physical capital $\delta(u_{s,t})$ aimed at stimulating investment in the green and digital industry g are focal.[15] Furthermore, in the numerical model evaluation below, geometric depreciation allowances permitting an accelerated amortization during the first years of the asset life are also analyzed. The law of motion for physical capital in both industries $s \in \{g, m\}$ is given by

$$K_{g,t} = \left(1 - \delta(u_{g,t})\right)K_{g,t-1} + \left(1 - \frac{\kappa^i}{2}\left(\frac{I_{g,t}}{I_{g,t-1}} - 1\right)^2\right)I_{g,t} \tag{3}$$

and

$$K_{m,t} = \left(1 - \delta(u_{m,t})\right)K_{m,t-1} + \left(1 - \frac{\kappa^i}{2}\left(\frac{I_{m,t}}{I_{m,t-1}} - 1\right)^2\right)I_{m,t} \tag{4}$$

where $\delta(u_{s,t}) = \delta_0 + \delta_1(u_{s,t} - 1) + \frac{\delta_2}{2}(u_{s,t} - 1)^2$ is the utilization-dependent depreciation rate, δ_0 is the steady-state depreciation rate, and δ_1 and δ_2 are adjustment cost parameters. Finally, the parameter $\kappa^i > 0$ governs the convex investment adjustment costs (see, among others, Ireland, 2003). When it is costly to adjust the physical capital stock, agents choose to increase investment slowly over time, generating a hump-shaped response pattern.

Maximizing equation (1) subject to (2), (3) and (4) yield the following first-order conditions for consumption, sovereign bonds, labor supply, physical capital in industry $s \in \{g, m\}$, investment in industry $s \in \{g, m\}$, and the capital utilization rate in industry $s \in \{g, m\}$, respectively:

$$\frac{1}{(C_t - hC_{t-1})} - \frac{\beta E_t h}{(C_{t+1} - hC_t)} = \lambda_t \tag{5}$$

$$\frac{E_t \beta \Lambda_{t+1} R_t}{\pi_{t+1}^C} = 1 \tag{6}$$

$$\chi N_t^{\varphi} = \lambda_t W_t \tag{7}$$

$$\beta E_t \Lambda_{t+1}\left(\left(1 - \delta(u_{s,t})\right)Q_{s,t+1} + R_{s,t+1}^k u_{s,t+1}\left(1 - \tau_t^k\right)\right) = Q_{s,t} \quad \text{for } s \in \{g, m\} \tag{8}$$

[15] See Auerbach (1989) and Mertens and Ravn (2011). Note that most DSGE models abstract from tracking depreciation of the capital stock for tax purposes, and instead apply the economic depreciation rate to the productive capital stock. If the tax depreciation rate differs from the economic depreciation rate, such an approximation would bias the effect of the depreciation channel.

$$1-\hat{\delta}_{s,t}\tau_t^k = Q_{s,t}\left[1-\frac{\kappa^i}{2}\left(\frac{I_{s,t}}{I_{s,t-1}}-1\right)^2-\kappa^i\left(\frac{I_{s,t}}{I_{s,t-1}}\right)\left(\frac{I_{s,t}}{I_{s,t-1}}-1\right)\right]$$

$$+\kappa^i\beta E_t\left\{Q_{s,t+1}\Lambda_{t+1}\left[\left(\frac{I_{s,t+1}}{I_{s,t}}\right)^2\left(\frac{I_{s,t+1}}{I_{s,t}}-1\right)\right]\right\} \quad \text{for } s\in\{g,m\} \tag{9}$$

$$\delta_1+\delta_2\left(u_{s,t}-1\right)=R_{s,t}^k\left(1-\tau_t^k\right) \quad \text{for } s\in\{g,m\} \tag{10}$$

where λ_t is the Lagrange multipliers of the maximization program representing the marginal utility of consumption, $\beta\Lambda_{t+1}=\beta\lambda_{t+1}/\lambda_t$ is the stochastic discount factor, and $Q_{s,t}$ are the Lagrange multipliers representing the shadow prices of investment in both industries $s\in\{g,m\}$. The variable $Q_{s,t}$ in industry $s\in\{g,m\}$ at time t, representing Tobin's q, is equal to the ratio of the Lagrange multipliers attached to the capital accumulation equation and the budget constraint, respectively. The first-order condition with respect to consumption gives rise to the Euler equation, summarizing the intertemporal consumption allocation choices of households. The first-order conditions with respect to investment and capital equate the marginal costs and benefits of additional investment and capital.

In summary, the first-order conditions (5)–(10) yield a fully state-contingent plan for a household's choice variables looking forward from the planning date t_0 and into the foreseeable future. In other words, the optimal plan is a series of instructions on how to behave in response to the realization of white noise shocks, given expectations about the future, rather than a one-time decision on how to react on each future date.

3.1.2 Labor Supply

We posit that the aggregate labor supply N_t provided by the representative household is a CES bundle of labor supplied to each industry $s\in\{g,m\}$, as given by

$$N_t=\left[\omega_N^{-\frac{1}{\nu_N}}N_{m,t}^{\frac{\nu_N+1}{\nu_N}}+\left(1-\omega_N\right)^{-\frac{1}{\nu_N}}N_{g,t}^{\frac{\nu_N+1}{\nu_N}}\right]^{\frac{\nu_N}{\nu_N+1}} \tag{11}$$

where $\omega_N\in(0,1)$ is a distribution parameter denoting the share of labor supplied to each industry s, while $\nu_N\geq 0$ represents the elasticity of substitution of labor across industries. If $\nu_N=0$, then labor supplies would be perfectly immobile between the two industries. Conversely, if $\nu_N\to\infty$, then labor supplies across industries would be perfectly mobile between sectors.

The representative household is assumed to choose the optimal amount of labor supplied to both sector by maximizing $W_tN_t-W_{g,t}N_{g,t}-W_{m,t}N_{m,t}$ with respect to (11), which yields the following first-order conditions:

$$N_{g,t} = (1-\omega_N)\left(\frac{W_{g,t}}{W_t}\right)^{\nu_N} N_t \tag{12}$$

and

$$N_{m,t} = \omega_N \left(\frac{W_{m,t}}{W_t}\right)^{\nu_N} N_t, \tag{13}$$

where $W_t = \left[\omega_N W_{m,t}^{1+\nu_N} + (1-\omega_N) W_{g,t}^{1+\nu_N}\right]^{\frac{1}{1+\nu_N}}$ denotes the CES weighted aggregate wage index.

3.2 Production

The production structure of both industries follows the model design presented in Bouakez et al. (2022) and features four production stages. First, monopolistically competitive intermediate goods producers produce differentiated varieties. Second, perfectly competitive wholesalers aggregate the differentiated varieties into a single sectoral final good. Third, the final intermediate inputs used by producers of industry $s \in \{g, m\}$ are assembled by intermediate-input retailers. Finally, consumption goods retailers produce a consumption bundle composed of green and miscellaneous consumption goods which are then sold to households on a perfectly competitive market.

3.2.1 Intermediate Goods Producers

In both industries, there is a continuum of producers combining rented capital, labor services supplied by households, and a bundle of intermediate inputs to produce differentiated varieties of goods by means of the following Cobb-Douglas production function:

$$Z_{s,t}(i) = A_{s,t}\left((u_{s,t}K_{s,t}(i))^{\alpha} N_{s,t}(i)^{1-\alpha}\right)^{\alpha_{H,s}} \left(H_{s,t}(i)\right)^{1-\alpha_{H,s}} \quad \text{for s} \in \{g, m\} \tag{14}$$

where $A_{s,t}$ denotes the industry-specific total factor productivity, $K_{s,t}$ denotes the rented period-t effective capital stock, $N_{s,t}$ denotes employment in the production process, $H_{s,t}$ denotes the bundle of intermediate inputs used by the producer, $\alpha \in (0,1)$ denotes the share of capital in the production function, and $\alpha_{H,s} \in (0,1)$ denotes the labor and capital intensity in the production function.[16] The profit function of the intermediate good producer i in sector $s \in \{g, m\}$ takes the form below.

[16] A recent strand of literature uses microeconomic data to model the importance and consequences of digital goods as an intermediate input. Jones and Tonetti (2020) provide alternative model specifications in the context of corresponding data.

$$\Pi_{s,t}(i) = Z_{s,t}(i) - R^k_{s,t} u_{s,t} K_{s,t}(i) - W_{s,t} N_{s,t}(i) - P^H_{s,t} H_{s,t}(i) \tag{15}$$

Maximizing each firm's profits yields the following first-order conditions for labor, capital, and intermediate inputs, respectively, in each sector $s \in \{g, m\}$:

$$W_{s,t} = MC_{s,t} \alpha_{H,s} (1-\alpha) \frac{Z_{s,t}(i)}{H_{s,t}(i)} \tag{16}$$

$$R^k_{s,t} = MC_{s,t} \alpha_{H,s} \alpha \frac{Z_{s,t}(i)}{u_{s,t} K_{s,t}(i)} \tag{17}$$

$$P^H_{s,t} = MC_{s,t} \left(1-\alpha_{H,s}\right) \frac{Z_{s,t}(i)}{H_{s,t}(i)} \tag{18}$$

where $MC_{s,t}$ denotes the sector-specific marginal cost and $P^H_{s,t}$ denotes the price of the intermediate input. Intermediate goods producers are subject to Calvo-type price-setting frictions, and can only reset prices with a constant probability $1-\theta$.[17] Conversely, this means that, in each period, a fraction θ of firms cannot optimally reset prices. The ensuing optimization problem in industry $s \in \{g, m\}$ is given as

$$\max_{p_{s,t(i)}} E_t \sum_{j=0}^{\infty} (\beta\theta)^j \Lambda_{t+j} \left(\frac{P_{s,t}(i)}{P_{s,t+j}} \left(\frac{P_{s,t}(i)}{P_{s,t+j}} \right)^{-\epsilon} Z_{s,t+j} - MC_{s,t+j} \left(\frac{P_{s,t}(i)}{P_{s,t+j}} \right)^{-\epsilon} Z_{s,t+j} \right) \tag{19}$$

which yields the following rearranged first-order condition for the producer price.

$$P_{s,t}(i) = \frac{\epsilon}{\epsilon-1} \frac{E_t \sum_{j=0}^{\infty} (\beta\theta)^j \Lambda_{\mathrm{t+j}} MC_{s,t+j} P^{\epsilon}_{s,t+j} Z_{s,t+j}}{E_t \sum_{j=0}^{\infty} (\beta\theta)^j \Lambda_{\mathrm{t+j}} P^{\epsilon-1}_{s,t+j} Z_{s,t+j}} \qquad \text{for } s \in \{g, m\} \tag{20}$$

3.2.2 Wholesalers

Perfectly competitive wholesalers buy differentiated intermediate goods and bundle them into a single industry final good, as given by

$$Z_{s,t} = \left[\int_0^1 Z_{s,t}(i)^{\frac{\epsilon-1}{\epsilon}} di \right]^{\frac{\epsilon}{\epsilon-1}} \tag{21}$$

[17] The empirical results of Gorodnichenko and Weber (2016) are consistent with DSGE models in which firms have heterogeneous price stickiness.

where $\epsilon \geq 0$ denotes the elasticity of substitution between intermediate goods varieties. Final goods producers maximize the following profit function:

$$\max_{Z_{s,t}(i)} P_{s,t}\left[\int_0^1 Z_{s,t}(i)^{\frac{\epsilon-1}{\epsilon}}\,di\right]^{\frac{\epsilon}{\epsilon-1}} - \int_0^1 P_{s,t}(i)Z_{s,t}(i)di \tag{22}$$

which implies that the price level of industry s is as given below.

$$P_{s,t} = \left[\int_0^1 P_{s,t}(i)^{1-\epsilon}\;\; di\right]^{\frac{1}{1-\epsilon}} \tag{23}$$

3.2.3 Intermediate-Input Producers

The final intermediate inputs used by producers of industry s are aggregated by perfectly competitive intermediate-input retailers by means of the standard CES aggregator, given as

$$H_g = \left[\omega_{H,g}\left(H_{g,g,t}\right)^{\frac{\nu_H-1}{\nu_H}} + \left(1-\omega_{H,g}\right)\left(H_{g,m,t}\right)^{\frac{\nu_H-1}{\nu_h}}\right]^{\frac{\nu_H}{\nu_H-1}} \tag{24}$$

and

$$H_m = \left[\omega_{H,m}\left(H_{m,m,t}\right)^{\frac{\nu_H-1}{\nu_H}} + \left(1-\omega_{H,m}\right)\left(H_{m,g,t}\right)^{\frac{\nu_H-1}{\nu_H}}\right]^{\frac{\nu_H}{\nu_H-1}} \tag{25}$$

where $\omega_{H,s} \in (0,1)$ denotes the share of intermediate input s in each CES bundle and $\nu_H \geq 0$ governs the elasticity of substitution of intermediate inputs across sectors. If $\nu_H = 0$ ($\nu_H \to \infty$), then the two intermediate inputs are perfect substitute (complementary).

Intermediate input producers in each sector s maximize $P^H_{s,t}H_{s,t} - \sum_x \sum_s P_{s,t}H_{x,s,t}$ with respect to (24) or (25). Through cost minimization, this yields downward-sloping demand functions for intermediate inputs used by industry $s \in \{g, m\}$ as follows.

$$H_{g,g,t} = \omega_{H,g}\left(\frac{P_{g,t}}{p^H_{g,t}}\right)^{-\nu_H} \qquad H_{g,m,t} = \left(1-\omega_{H,g}\right)\left(\frac{P_{m,t}}{p^H_{g,t}}\right)^{-\nu_H} \tag{26}$$

$$H_{m,m,t} = \omega_{H,m}\left(\frac{P_{m,t}}{p^H_{m,t}}\right)^{-\nu_H} \qquad H_{m,g,t} = \left(1-\omega_{H,m}\right)\left(\frac{p_{g,t}}{p^H_{m,t}}\right)^{-\nu_H} \tag{27}$$

Thus, the associated optimality conditions for price-setting are as given below.

$$P_{g,t}^{H} = \left[\omega_{H,g}\left(P_{g,t}\right)^{1-\nu_H} + \left(1-\omega_{H,g}\right)\left(P_{m,t}\right)^{1-\nu_H}\ \right]^{\frac{1}{1-\nu_H}} \tag{28}$$

$$P_{m,t}^{H} = \left[\omega_{H,m}\left(P_{m,t}\right)^{1-\nu_H} + \left(1-\omega_{H,m}\right)\left(P_{g,t}\right)^{1-\nu_H}\ \right]^{\frac{1}{1-\nu_H}} \tag{29}$$

3.2.4 Consumption Goods Retailers

The next step in the model involves deriving how the household's aggregate consumption C_t is channeled to each industry by perfectly competitive consumption goods retailers. The households' consumption goods preferences in our economy are given by

$$C_t = \left[\omega_C^{\frac{1}{\nu_C}}\left(C_{m,t}\right)^{\frac{\nu_C-1}{\nu_C}} + \left(1-\omega_C\right)^{\frac{1}{\nu_C}}\left(C_{g,t}\right)^{\frac{\nu_C-1}{\nu_C}}\right]^{\frac{\nu_C}{\nu_C-1}} \tag{30}$$

where the parameter ω_C $(1-\omega_C)$ depicts the weight in the consumption goods basket attached to goods produced in industry m (g). The parameter $\nu_C \geq 0$ is the elasticity of substitution between the two consumer goods bundles.

Maximizing $P_t^C C_t = P_{g,t}C_{g,t} + P_{m,t}C_{m,t}$ with respect to (30) yields the standard first-order conditions for demand from each industry $s \in \{g, m\}$, as given by

$$C_{m,t} = \omega_C\left(\frac{P_{m,t}}{P_t^C}\right)^{-\nu_C} C_t \tag{31}$$

and

$$C_{g,t} = \left(1-\omega_C\right)\left(\frac{P_{g,t}}{P_t^C}\right)^{-\nu_C} C_t \tag{32}$$

where $P_{g,t}$ $\left(P_{m,t}\right)$ denotes the price index of green and digital (miscellaneous) goods, while the economy-wide CPI index is as given below.

$$P_t^C = \left[\omega_C P_{m,t}^{1-\nu_C} + \left(1-\omega_C\right)P_{g,t}^{1-\nu_C}\right]^{\frac{1}{1-\nu_C}} \tag{33}$$

3.3 Fiscal Authority

The fiscal authority is characterized by the following income statement identity:

$$B_t = R_t B_{t-1} + G_{g,t} + G_{m,t} - \tau_t^k \left(\sum_s u_{s,t} R_{s,t}^k K_{s,t-1} - \sum_s \hat{\delta}_{s,t} I_{s,t} \right) - \tau_t \tag{34}$$

where B_t are risk-free, one-period sovereign bonds which pay the risk-free interest rate R_t, τ_t is the lump sum tax paid by households, τ_t^k is the capital income tax, the term $\tau_t^k \hat{\delta}_{s,t} I_{s,t}$ represents the depreciation allowance for tax purposes, and $G_{g,t}$ and $G_{m,t}$ denote the exogenous purchase of goods from industry $s \in \{g, m\}$.[18]

Following Leeper et al. (2010), fiscal policy adjusts lump-sum taxes in response to the state of government debt, according to

$$\tau_t = \tau + \phi^b (B_t - B) \tag{35}$$

where τ is the steady-state level of lump-sum taxation and the parameter $\phi^b > 0$ determines the strength of the adjustment. Imposing the assumption that ϕ^b exceeds the real interest rate guarantees that any increase in government debt creates an expectation that future taxes will rise by enough to both service the higher debt and retire it back.

3.4 Monetary Authority

The central bank sets the risk-free nominal interest rate in response to the current inflation gap and the output gap, with a certain degree of inertia, as given by

$$R_t = \left[\frac{R_{t-1}}{R}\right]^{\rho^r} \left[\left(\frac{\pi_t}{\pi}\right)^{\rho^\pi} \left(\frac{Y_t}{Y}\right)^{\rho^y} \right]^{(1-\rho^r)} \tag{36}$$

where R_t is the monetary policy rate, $0 < \rho^r < 1$ govern monetary policy inertia, (π_t/π) is the inflation gap, (Y_t/Y) is the output gap, and ρ^y and ρ^π are the responsiveness parameters for the output gap and the inflation gap, respectively. The omission of time subscripts indicates steady-state values.[19]

---

[18] We do not take a stance on the micro-foundation of government spending decisions. Shifting the composition of public spending toward green and digital goods could additionally strengthen the private-sector impact of the super depreciation policy.

[19] It is beyond the scope of this paper to discuss the possibility of strategic interactions between fiscal and monetary policymakers.

3.5 Market Clearing and Aggregation

The value added in industry $s \in \{g, m\}$ is given by the difference between output and intermediate inputs, as below.

$$Y_{g,t} = Z_{g,t} - H_{g,g,t} - H_{m,g,t} \tag{37}$$

$$Y_{m,t} = Z_{m,t} - H_{m,m.t} - H_{g,m.t} \tag{38}$$

Market clearing in both industries implies that

$$Y_{g,t} = C_{g,t} + I_{g,t} + G_{g,t} \tag{39}$$

and

$$Y_{m,t} = C_{m,t} + I_{m,t} + G_{m,t} \tag{40}$$

while market clearing on the intermediate goods market implies that

$$\int_0^1 Z_{s,t}(i) = Z_{s,t} dp_{s,t} \tag{41}$$

where $dp_{s,t}$ denotes the sectoral price dispersion $dp_{s,t} = \int_0^1 \left(\frac{p_{s,t}(i)}{p_{s,t}}\right)^{-\epsilon} di$. Finally, aggregated output is given as below.

$$Y_t = \sum_s Y_{s,t} = C_t + I_t + G_t \tag{42}$$

This completes the sufficiently detailed yet clearly focused model representation. Increased detail within the model would come at the cost of confusion regarding the mechanisms that deliver the main results. In the subsequent sections of this paper, the theoretical DSGE model is mapped step-by-step onto the data.

4. Model Calibration

The calibrated baseline parameters, matched to their empirical counterparts and consistent with the quarterly frequency, are shown in Table 1. An attempt has been made to define parameters specific to the German economy. For the most part, we employ standard parameters as found in the literature, and thus our discussion can be brief.

The first step involves the parameters governing preferences toward labor. The discount factor uses the standard setting of $\beta = 0.99$. The consumption habit formation parameter is set to $h = 0.78$ following the estimates of Pytlarczyk (2005). The inverse Frisch elasticity is calibrated to $\varphi = 0.4$, which is in line with the literature review provided by Whalen and Reichling (2017). The parameter ν_N governing the intra-sectoral labor elasticity of substitution is set to 5 following Hinterlang et al. (2021). Similarly, Bouakez et al. (2021) chose to impose perfect substitutability between labor supplies, and thus the labor disutility parameter is adjusted to $\chi = 3.57$. The share of labor supplied to the miscellaneous sector $\omega_N = 0.9$ is calibrated following Hinterlang et al. (2021).

Table 1: Calibrated Baseline Parameters

Parameter	Description	Value
h	Habit formation	0.78
β	Discount factor	0.99
φ	Inverse Frisch elasticity	0.5
χ	Labor disutility parameter	3.57
δ_0	Depreciation rate of capital	0.025
δ_1	Linear capital utilization parameter	0.0349
δ_2	Quadratic capital utilization parameter	0.01
α	Share of capital	0.33
$\alpha_{H,g}$	Capital and labor factor intensity in the green sector	0.52
$\alpha_{H,m}$	Capital and labor factor intensity in the miscellaneous sector	0.6
ν_H	Elasticity of substitution between intermediate inputs	0.1
ν_C	Elasticity of substitution between consumption goods	2
ν_N	Intra-sectoral labor elasticity of substitution	10
$\omega_{H,g}$	Green intermediate input CES function distribution parameter	0.6
$\omega_{H,m}$	Miscellaneous intermediate input CES function distribution parameter	0.9
ω_C	Consumption goods CES function distribution parameter	0.85
ω_N	Labor supply CES function distribution parameter	0.9
ϵ	Elasticity of substitution between varieties	4.33
$\epsilon/(\epsilon - 1)$	Steady-state markup	1.33
τ^k	Capital tax rate	0.25
G/Y	Government spending-to-GDP ratio	22%
B/Y	Sovereign debt-to-GDP ratio	70%
κ^i	Investment adjustment cost parameter	11
ϕ^b	Lump-sum tax reaction parameter to sovereign debt	0.1
ρ^r	Monetary rule interest rate smoothing parameter	0.8
ρ^y	Monetary policy rule reaction parameter to output gap	0.250
ρ^π	Monetary policy rule reaction parameter to inflation	1.5
θ	Calvo parameter	0.75
$\hat{\delta}_s$	Depreciation allowance rate for tax purpose	0.025
Y_g/Y	Green GDP over total GDP	0.07

Turning to the production parameters, the parameter ν_C governing the substitutability between green and miscellaneous consumption goods is set to 2 following Hinterlang et al. (2021). The CES function parameter is set at $\omega_C = 0.89$. As is standard, the share of capital in the Cobb-Douglas production function is set at $\alpha = 0.33$. Based on an aggregation of the sectoral data in Hinterlang et al. (2021), the capital and labor factor intensities in the green and miscellaneous sectors are set to $\alpha_{H,g} = 0.51$ and $\alpha_{H,m} = 0.6$, respectively. The parameter governing the elasticity of substitution between intermediate goods varieties is set to $\epsilon = 4.33$ in order to match a steady-state markup of 1.3. The Calvo parameter uses the standard calibration of $\theta = 0.75$ so that prices remain constant for about four quarters. Following Hinterlang et al. (2021) and Bouakez et al. (2022), we impose a high degree of complementarity between intermediate inputs by setting the parameter $\nu_H = 0.1$. Additionally, we calibrate the intermediate input CES aggregates' distributional parameters to $\omega_{H,m} = 0.9$ and $\omega_{H,g} = 0.6$. The steady-state depreciation rate of physical capital is set to $\delta_0 = 0.025$, which implies an annual depreciation rate of 10%. The quadratic capital utilization parameters are set to $\delta_1 = 0.0349$ and $\delta_2 = 0.01$. Finally, we set the baseline investment adjustment cost parameter at $\kappa^i = 11$. Given the parameters above, the implied steady state share of the green and digital (miscellaneous) industries in GDP is $\frac{Y_g}{Y} = 0.07$ ($\frac{Y_m}{Y} = 0.93$). Thus, the model has steady-state properties close to the data described in Section 2.

The fiscal policy parameters are set broadly in line with German data. The public spending-to-GDP ratio is set to $G/Y = 0.224$, the sovereign debt-to-GDP ratio is set to 70%, and the corporate tax rate is assumed to be $\tau^k = 0.25$. The quarterly baseline physical capital depreciation rate for tax purpose is set to $\widehat{\delta_s} = 0.025$. The fiscal debt sensitivity parameter is calibrated as $\phi^b = 0.1$. Finally, following standard conventions, the monetary policy Taylor rule coefficients are set to $\rho^\pi = 1.5$, $\rho^y = 0.250$, and $\rho^r = 0.8$, respectively. The following section illustrates the quantitative properties and takeaways of the model, and conducts counterfactual policy analyses.

5. Model Dynamics

The described modeling framework provides a laboratory for the analysis of corporate tax policies. In the following, we numerically explore the properties of the model. In doing so, we cast a special focus on facilitating green and digital investment through temporary super depreciation allowances. We also conduct various policy experiments and robustness checks. Our analysis is designed to answer certain key questions. What is the role of different super depreciation policies in shaping the green and digital transition? How will super depreciation affect reallocation across industries? In more metaphorical terms, we conceive of the presented model as a form of quantitative storytelling. Our experiments can serve as a tool for policymakers seeking actionable insights on their country's economic policy strategy.

We employ the perfect foresight rational expectations solution method for solving the model. The basic idea is that agents have perfect foresight regarding the super depreciation allowance shocks. This feature makes it suitable for the announced duration of the tax reduction, limited to two years. After reverting to the initial tax rates, all the shocks are zero. Therefore, the system can be solved backwards from this point. The Newton-Raphson algorithm takes into consideration the special structure of the Jacobian matrix in dynamic models with forward-looking agents. The details of the algorithm can be found in Juillard (1996).[20] For the earmarked super depreciation shock, we assume that the preferential depreciation shock occurs unexpectedly at t_0. In contrast, the temporary tax measure is known to exist for two years. In a nutshell, agents are surprised by the primal change in the depreciation allowance but perceive the policy decision as credible and the measure thus as temporary.[21]

Figure 3 shows the baseline response of investment and aggregate growth to straight-line super depreciation shocks of different degrees. For this analysis, it is generally assumed that firms have balances on deferred tax allowances and deferred tax assets. The model is set up in quarterly frequency, and all graphs show the percentage change compared to the steady state.[22] Within the graphs, straight-line annual depreciation allowance shocks from 10% initially up to the enhanced levels of 25% (solid blue), 50% (dashed red), 75% (dotted black), and 100% (dashed green) in the earmarked green and digital industries are presupposed. The assumed maturity of the measure is always two years. In the remaining miscellaneous sectors of the economy, the annual straight-line depreciation allowance remains at 10% throughout. The selection of impulse response functions in Figure 4 illustrates the sectoral granularity within the DSGE model.

One result distinguishes itself immediately. The "above-the-line" super depreciation allowance is an economically sizable investment promotion scheme for the earmarked industries. In terms of magnitude, an assumed biennial accelerated depreciation allowance of 100% (all other things being equal) triggers an uplift in investment spending of about 10% for the earmarked green and digital industries. How can such quantitative properties of the model be justified from the perspective of theory and data? The quantitative impacts are broadly consistent with an analysis of the "Office for Budget Responsibility" (OBR), which estimated that business investment would increase by up to 10% during 2022–2023 due to the impacts of the temporary super deduction in the UK.[23] The modelling results also confirm the findings of previous studies that have examined different episodes of temporary tax incentives. For example, House and Shapiro (2008) and Zwick and Mahon (2017) reported strong effects from capital allowances on investment triggered by the temporary 2003 bonus depreciation in the US. From a qualitative viewpoint, the impact is also consistent with the German survey assessment of the targeted measure in the December 2021 "Ifo and Frankfurter Allgemeine Zeitung Economists Panel," in which it was overwhelmingly rated as effective (Gründler et al., 2022, p. 54). Finally, Furlanetto and Seneca (2014)

[20] See Armstrong et al. (1998) and Juillard et al. (1998) for a comparison of elementary first-order iterative methods and Newton-based algorithms.

[21] The modelling assumption of an unexpected roll-out date is consistent with the fact that the original plan for a 2022 introduction has been postponed, with the concurrent announcement that a separate draft bill is being prepared. In other words, the corporate tax system is a moving target.

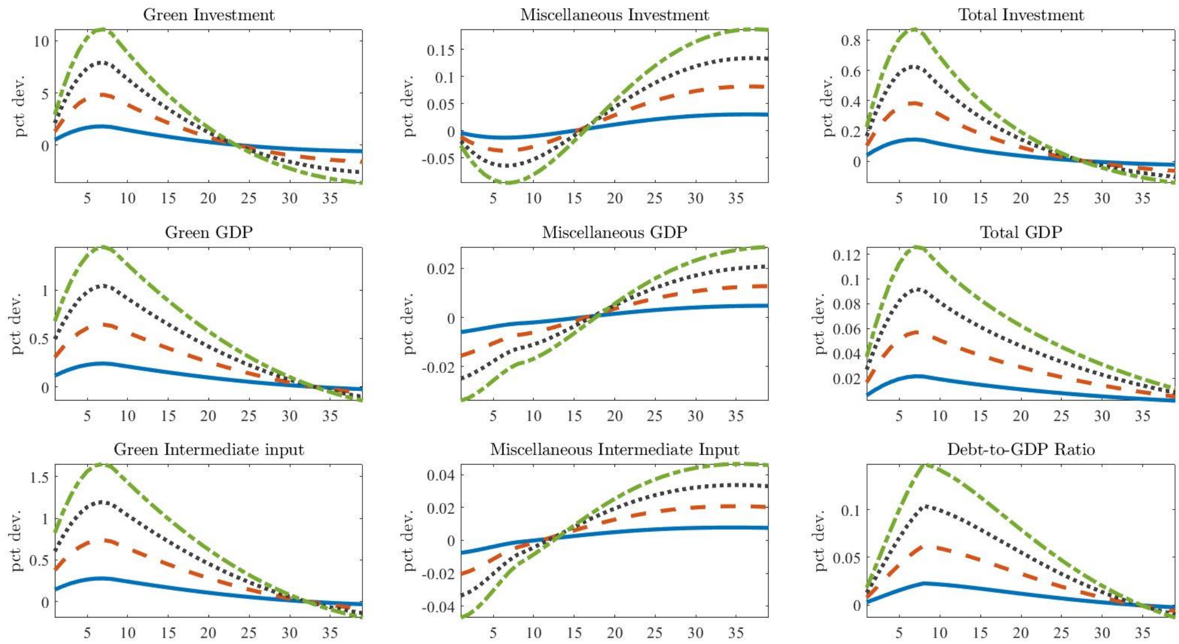
[22] Throughout all model simulations, we assume that the super depreciation scheme is easy to audit. In other words, that firms and tax authorities find it straightforward to identify investment expenditures that are qualified for the tax measure. Spurring climate and digital investment also requires eschewing gimmicks, including greenwashing.

[23] See https://obr.uk/efo/economic-and-fiscal-outlook-march-2021/.

have shown that shocks to the rate of capital depreciation in the capital accumulation equation are important drivers of business cycles in DSGE models.

In addition to this impact, four features of the results are worth noting. First, the decline in targeted investment after the expiry of the temporary measure illustrates a significant pull-forward effect. In other words, the impulse responses allow us to identify how much of the earmarked investment increase reflects changes in the timing of investment (previously planned investment being brought forward), as opposed to an increase in long-term (previously unplanned) investment.[24] Second, the first-round effects in the targeted industries are just the beginning. Subsequent rounds in the miscellaneous industries reflect the responses of firms and households and the mutual interdependencies among the different intermediate and final goods industries in the multi-sector DSGE model. Third, due to the more generous tax deductibility, the measure leads to a temporary increase in public debt. Finally, the overall GDP impact of the earmarked measure is mild due to the single-digit GDP share of the green and digital industries.

Figure 3: Impulse Responses to Alternative Biennial Super Depreciation Shocks in the Green and Digital Industries



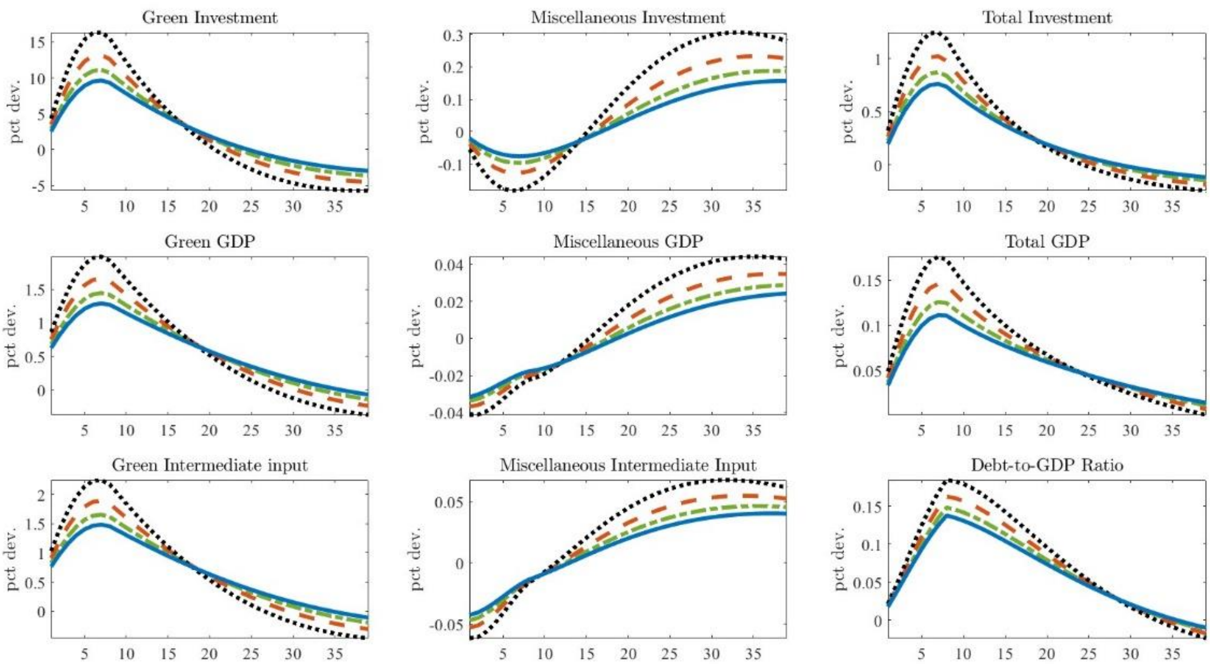
Notes: The impulse responses to biennial straight-line super depreciation shocks in the earmarked industries from 10% initially up to the levels of 25% (solid blue), 50% (dashed orange), 75% (dotted black), and 100% (dashed green) in the green and digital industries are plotted. All remaining parameters correspond to the baseline model calibration in Table 1.

[24] In the UK, firms have reported that just over a third of the expected investment increase corresponds to investment brought forward from future years after March 2023, with the remaining two-thirds of the expected investment increase accounted for by higher overall investment (see Bunn et al., 2021). Such a pull-forward effect has also occurred in the case of the temporary German VAT cut by half from 1 July 2020 through 31 December 2020 in response to the COVID-19 pandemic. For an assessment of this measure, see Funke and Terasa (2022).

It is important to examine how robust the results in Figure 3 are in view of the various assumptions underlying the numerical analysis. We therefore complement our analysis by providing additional policy scenarios and robustness checks. It is reasonable to suspect that the effectiveness of the super depreciation measure depends on two model parameters in particular: 1.) the level of the investment adjustment costs, and 2.) the maturity of the preferential super depreciation. The sensitivity of the outcomes with respect to both model parameters will be described in Figures 4 and 5, respectively. Subsequently, their mutual interaction will be illustrated graphically in a three-dimensional scatterplot.

In general, preferential depreciation allowances for plants and equipment disproportionally benefit capital-intensive industries, precisely where capital adjustment costs are high. Therefore, Figure 4 displays the impulse responses for alternative adjustment cost parameters κ^i.[25] The depicted range of capital adjustment costs comprises $\kappa^i = 12$ (solid blue), $\kappa^i = 10$ (dashed green), $\kappa^i = 8$ (dashed orange), and $\kappa^i = 6$ (dotted black). In all impulse responses, a straight-line super depreciation allowance shock in the targeted industries from 10% initially up to the enhanced level of 100% has been presupposed.

Figure 4: Impulse Responses to a Biennial Super Depreciation Shock in the Green and Digital Industries for Alternative Adjustment Cost Parameters

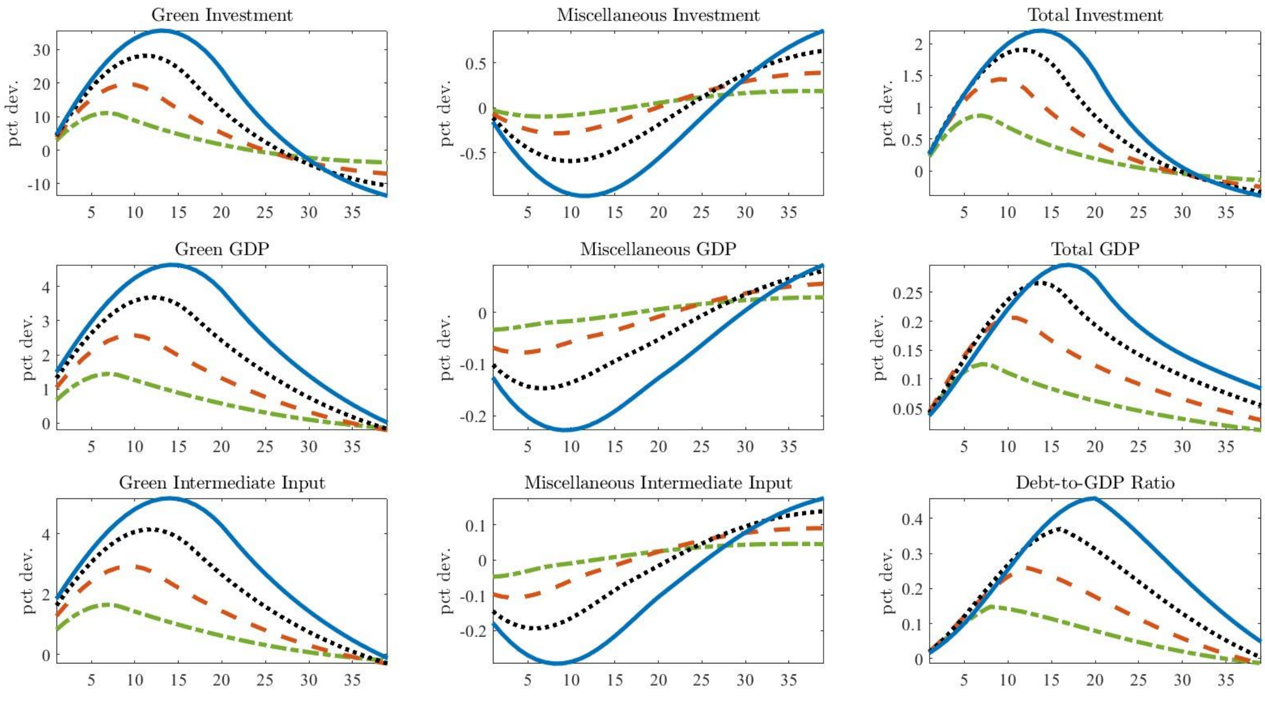


Notes: Impulse responses for super depreciation shock assuming alternative adjustment cost parameters κ^i are plotted. The depicted range of values for κ^i comprises $\kappa^i = 12$ (solid blue), $\kappa^i = 10$ (dashed green), $\kappa^i = 8$ (dashed orange), and $\kappa^i = 6$ (dotted black). In all model evaluations, a straight-line super depreciation allowance shock in the targeted industries from 10% initially up to the enhanced level of 100% has been presumed. All remaining parameters correspond to the baseline model calibration in Table 1.

[25] Regarding the importance of adjustment costs for the dynamics of the DSGE model, see Groth and Khan (2010).

It is apparent that even moderate κ^i variations induce significant changes in the response pattern. This can be interpreted in two ways. In the context of the multi-sectoral DSGE model, this enhances the uncertainty about the overall impact for investments with a lengthy planning lead time. An alternative interpretation results from a microeconomic perspective. From this angle, the impulse responses for different κ^i parameters suggest a lumpy investment pattern. This is consistent with theoretical models in which fixed investment adjustment costs predict lumpy investment dynamics, with a large number of firms undertaking zero investments in response to stimulus policies (Winberry, 2021). The lumpy investment interpretation is also compatible with the microeconomic "Decision Maker Panel" survey evidence, which showed a wide range of responses to the super depreciation measure in the UK. The "Decision Maker Panel" is a representative monthly survey of firms in the UK, with around 3,000 responses each month. Most firms (78%) reported that they expect the tax measure to have no impact on investment. Meanwhile, 20% of businesses reported that they expected a positive impact, and 2% expected negative impacts (see Bunn et al., 2021).

Figure 5: Impulse Responses to a Preferential Super Depreciation Shock in the Green and Digital Industries for Alternative Maturities of the Measure



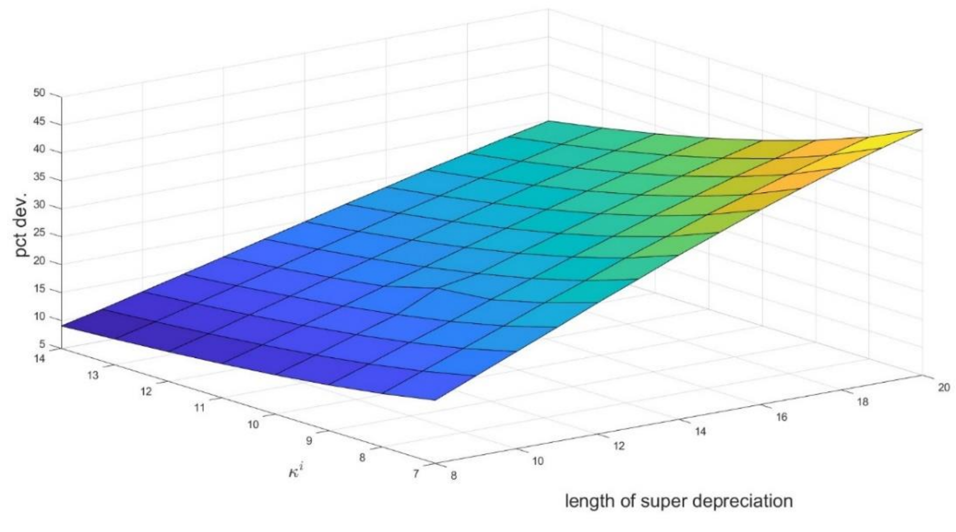
Notes: In all model evaluations, a straight-line super depreciation allowance shock in the earmarked industries from 10% initially up to the enhanced level of 100% has been presumed. The depicted range of maturities comprises 2 years (dashed green), 3 years (orange dashed), 4 years (dotted back), and 5 years (solid blue). All remaining parameters correspond to the baseline model calibration in Table 1.

The German super depreciation allowance is envisaged as a temporary policy, and is expected to expire after two years. Larger investments in particular generally require a considerable amount of lead time, which potentially limits the number of new (currently unplanned) investment projects that firms will be able to accomplish before the expiry date. Some firms may shorten the timeline for investments that are already under consideration, but that is only achievable up to a certain degree. Accordingly, Figure 5 presents firm reactions to an earmarked immediate write-off measure for alternative maturities of the measure. The periods considered range from two to five years. In all model evaluations, a super depreciation allowance shock in the earmarked industries from 10% initially up to 100% has been presumed. The dashed green scenario corresponds to the baseline dashed green scenario in Figure 3.

As expected, the measure's overall impact on the green and digital industries increases with a longer time horizon for the measure. The flip side of this result is that the miscellaneous industries shrink accordingly. Alongside this, public debt increases as well. From this angle, it is important to make the preferential depreciation allowance more permanent. Permanency implies certainty, which is an essential factor especially for long-term investment decisions.

Finally, the dynamic response of the system evident in Figures 4 and 5 is shown from a different angle in a scatterplot in Figure 6.

Figure 6: Scatterplot of the of the Maximum Investment Increase in the Green and Digital Industries Due to the Earmarked Super Depreciation Allowance Shock as a Function of the Adjustment Cost Level and the Duration of the Measure



Note: A straight-line super depreciation allowance shock in the earmarked industries from 10% initially up to 100% has been presupposed.

In Figure 6, the maximum investment increase in the earmarked green and digital industries (given by the upper inflection point in the impulse responses in Figures 4 and 5) is shown for each parameter combination. Overall, Figure 6 yields two major takeaways. First, low adjustment costs and longer maturities reinforce each other. Second, the sensitivity of investment with respect to the measure's maturity is particularly pronounced. Private-sector investments in low-carbon technologies tend to be capital-intensive and are characterized by long time horizons. The corollary is that such investments require a high level of future climate policy stringency for planning purposes.

As an alternative to the baseline straight-line depreciation assumption, geometric-degressive depreciation may also be permitted as an investment promotion scheme. In this case, the asset is depreciated each period by a fixed percentage of its value in the previous period. Thus, it is highest in the asset's first year and approaches zero asymptotically as the asset ages. The stylized fact about second-hand asset prices is that the age-price profile is convex. This is especially true for assets which are exposed to rapid changes in technology, and it is most particularly true of the earmarked climate and digital capital goods. On these grounds, our study additionally evaluates the impact of a declining balance depreciation pattern.

To mirror the accelerated geometric depreciation pattern in the DSGE framework, we follow Born and Pfeifer (2013, 2014) and Mertens and Ravn (2011). Within the geometric depreciation pattern, the budget constraint of the representative household is given as below.

$$\begin{aligned} P_t^C C_t + \sum_s I_{s,t} + B_t \\ = W_t N_t + \left(1-\tau_t^k\right) \sum_s u_{s,t} R_{s,t}^k K_{s,t-1} + \sum_s \phi_{s,t}^k + R_t B_{t-1} - \tau_t + \left(1-\tau_t^k\right)\Pi_t \end{aligned} \quad (43)$$

The term $\phi_{s,t}^k$ in equation (43) is thereby defined as below.

$$\phi_{s,t}^k = \tau_t^k \sum_{i=1}^{\infty} \hat{\delta}_{s,t} \left(1-\hat{\delta}_{s,t}\right)^{i-1} I_{s,t-i} \quad (44)$$

Inside the sum symbol, the term $\left(1-\hat{\delta}_{s,t}\right)^{i-1} I_{s,t-i}$ denotes the non-depreciated book value of the capital bought i periods before. Thus, $\hat{\delta}_{s,t}\left(1-\hat{\delta}_{s,t}\right)^{i-1} I_{s,t-i}$ represents the depreciation of the remaining book value at time t. The associated first-order condition for investment behavior is given by

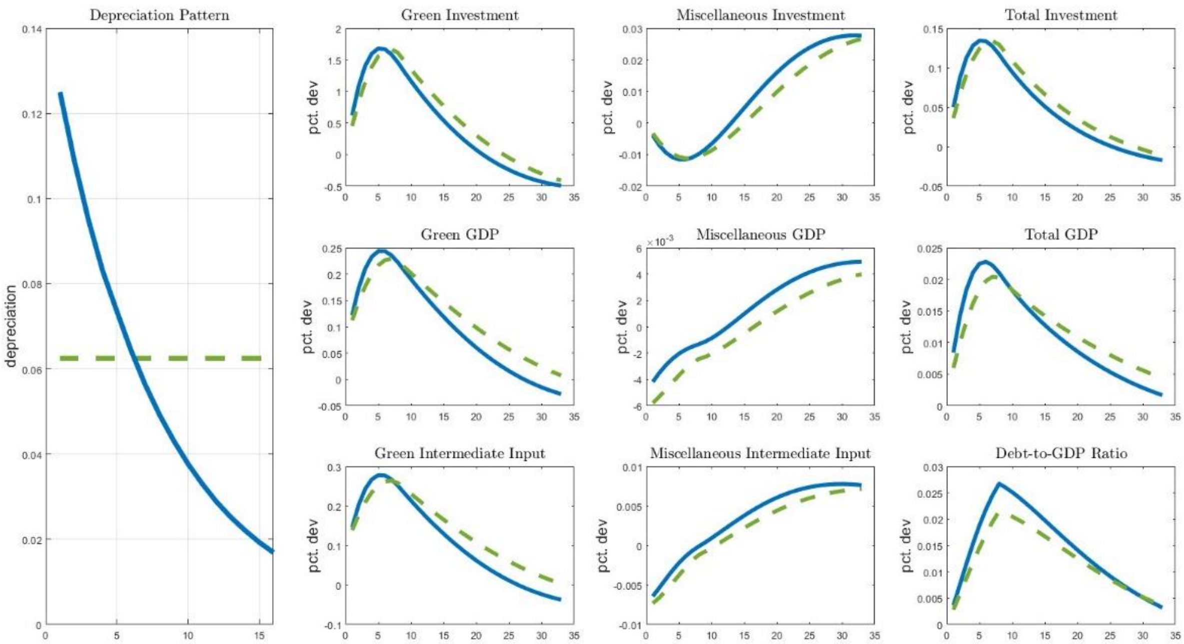
$$\begin{aligned} 1 = \nabla_{\mathrm{s,t}}^{\delta} + Q_{s,t}\left[1-\frac{\kappa^i}{2}\left(\frac{I_{s,t}}{I_{s,t-1}}-1\right)^2 - \kappa^i\left(\frac{I_{s,t}}{I_{s,t-1}}\right)\left(\frac{I_{s,t}}{I_{s,t-1}}-1\right)\right] \\ +\kappa^i \beta E_t\left\{Q_{s,t+1}\frac{\lambda_{t+1}}{\lambda_t}\left[\left(\frac{I_{s,t+1}}{I_{s,t}}\right)^2\left(\frac{I_{s,t+1}}{I_{s,t}}-1\right)\right]\right\} \end{aligned} \quad (45)$$

where

$$\nabla_{s,t}^{\delta} = \beta\hat{\delta}_{s,t} E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\tau_{t+1}^k\right] + \beta\left(1-\hat{\delta}_{s,t}\right)E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\right]\nabla_{s,t+1}^{\delta} \quad (46)$$

In contrast to the straight-line, first-order optimality condition (9), current investment now depends on the depreciation allowance's net present discounted value. The sensitivity of the super depreciation allowance impact to the depreciation pattern is explored in Figure 7, which comprises two panels. In the left panel, the straight-line 25% super depreciation pattern for the earmarked green and digital industries has been plotted alongside the alternative geometric-degressive depreciation pattern. The depreciation period in the incentivized industries is thereby 2 years (8 quarters) under both methods. The right panel shows the associated impulse response functions. As expected, the comparison reveals a slightly stronger initial investment momentum in the case of a geometric-degressive depreciation pattern (solid blue line) than in the standard case of a linear depreciation pattern (dashed green line). In the further course of time, the mirror image emerges. By and large, it is questionable whether these minor differences when comparing both depreciation methods are a sufficient *raison d'être* for a declining-balance super depreciation pattern.

Figure 7: Impulse Responses to a Biennial Straight-Line vs. Geometric-Degressive Super Depreciation Shock in the Earmarked Green and Digital Industries

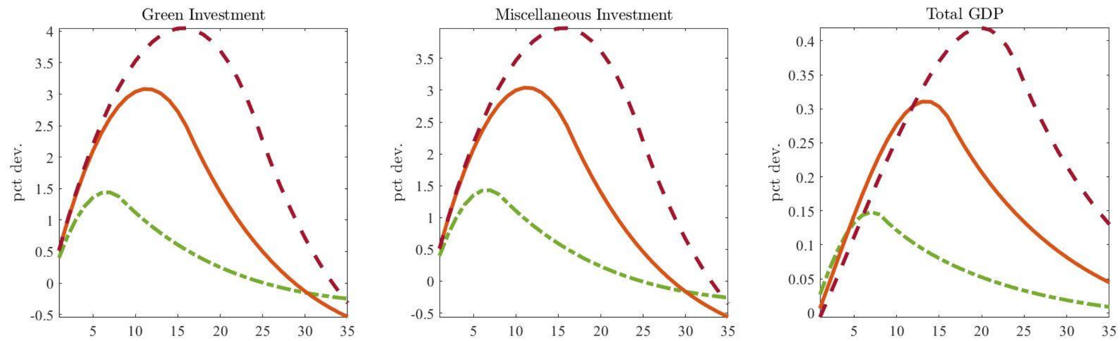


Notes: The graphs provide a comparison of a two-year linear depreciation allowance shock—from 10% initially up to the level of 25% in the targeted green and digital industries (dashed green lines)—with a geometric-degressive depreciation trajectory (solid blue lines), assuming the same total write-down period. All other parameters correspond to the baseline model calibration in Table 1.

Due to the focus on the earmarked industries, all model simulations thus far follow the policy approach of "doing more and better with less." In general, however, corporate tax policy should be neutral, and should not favor specific industries.[26] The super depreciation allowances ultimately represent a compromise. On the one hand, the policy contains elements of traditional interventionist industrial policy. On the other hand, state-directed price signals are used as a coordinating device to spur decarbonization efforts and digitalization in a process of discovery and challenge.

In the final portion of this section, we consequently expand our analysis from the narrow applicability of super depreciations on green and digital investments to a broad economic applicability.[27] In other words, a hypothetical universal policy - one that is no longer earmarked - is examined. What would such an alternative all-around design achieve with a validity of two, four, or six years? Figure 8 illustrates how a super depreciation shock from 10% initially up to 25% (for which all firms are eligible) impacts investment expenditures. The two-year, four-year, and six-year increases in the straight-line depreciation rate from 10% to 25% yield investment increases of 1.5%, 3.0%, and 4.0%, respectively.[28] At the same time, however, the numerical findings show that the desired steering effects with regard to decarbonization and the multi-dimensional digital revolution are no longer achieved. Another takeaway is that the resulting temporary budget deficits would be significantly higher.

Figure 8: Impulse Responses to a Universal Super Depreciation Shock with Alternative Maturities of the Measure



Notes: Impulse responses for a universal straight-line super depreciation shock from 10% initially up to 25% assuming alternative maturities are plotted. The depicted range of maturities comprises two years (dashed green), four years (solid red), and six years (dashed purple). All other parameters correspond to the baseline model calibration in Table 1.

The alternative design of the super depreciation allowance in Figure 8 can also be viewed from a different angle. Just as economic recovery in the immediate aftermath of the COVID-19 pandemic

[26] It has long been recognized that corporate taxes can distort incentives. For example, it can be argued that earmarked economic measures may lead to less competitive pressure, making the targeted industries less efficient (Leibenstein, 1966). Furthermore, such measures may encourage beneficiary firms to inefficiently spend resources when seeking privilege from policymakers (Krueger, 1974).
[27] In a first statement on the planned accelerated depreciation allowances, Clemens et al. (2021b) have criticized the limitations of earmarked industries. Instead, they suggest that the tax measure should be applied across the board.
[28] The expansionary effect across the board is broadly consistent with the evidence of Dorn et al. (2021), which examined the quantitative impacts of a permanent increase of the straight-line depreciation rate from 10% to 25% in a computable general equilibrium model. This resulted in a 5% increase in investment in the new steady state.

seemed to be in sight, the Russian invasion of Ukraine has created a first-order shock with potential to erase a large portion of recent economic gains. The war in Ukraine has sharply increased energy and food prices, sending shockwaves throughout the global economy. The concern is that the world may experience several years of above-average inflation and below-average growth. These risks underscore the importance of a forceful policy response. The postponed introduction of the super depreciation measure may thus be seen as an attempt of the German federal government to remain nimble and to shape the final design of the super depreciation allowance in a way that is effective in contributing to an economic recovery. The model simulations above illustrate that this ultimately boils down to the question of whether the super write-offs should primarily serve as a steering climate policy tool or as a business cycle stabilization tool in view of the significantly gloomier growth prospects resulting from the war in Ukraine.

6. Conclusions

Meeting internationally agreed-upon climate targets will require an unprecedented structural transformation of the global economy over the next few decades. This has resulted in no shortage of speechifying about green growth and calls for vigorous policy actions to decarbonize economies. In this regard, the temporary super depreciation allowance policy for green and digital investments can be perceived as a quid pro quo of significant fiscal support in exchange for structural policy targets.

Understanding the transmission channels and assessing the effectiveness of temporary tax policies aimed at decarbonization are essential for the implementation of time-limited fiscal policy measures. The pressing relevance of the question is the primary motivation for this work. The novelty stems from eye-catching green policy proposals, to which DSGE models can contribute in terms of analysis. Several results of this study have generated new insights and provided important lessons that are useful to review. First, the numerical model evaluations indicate that the temporary super depreciation measure can accelerate the change to green and digital industries and thus drive the push toward a decarbonized future. Second, the measure's effects on the green and digital industries are economically sizeable and materialize relatively quickly. Third, since the temporary measure is set to expire after two years, there is a risk that business investment may tail off at a crucial time, when post-COVID-19 recovery is levelling out at modest rates. Fourth, a super deduction may not be useful unless there are taxes to be paid. Therefore, smartly-designed instruments should allow for loss carry-forwards of the tax benefits in order to reduce future tax payments. This can be especially helpful for startups, although it still leaves them facing higher costs for their initial investments. Finally, global supply bottlenecks have created headwinds for the ongoing global economic recovery. The source of these bottlenecks are massive shifts in demand and supply triggered by the closing and reopening of economies in response to recurrent time-shifted COVID-19 waves. The immediate corollary is that the expansionary growth stimuli of the temporary super deduction measures presented above must be understood *ceteris paribus*.

In conclusion, the temporary super depreciation measure provides effective short- and medium-term green and digital knock-on effects in the green and digital industries. Due to its all-encompassing nature, however, the low-carbon transition will require a comprehensive long-term approach. The basic logic of post-Ukraine invasion energy security is to rely as little as possible on flows of fossil fuels from autocracies with aggressive ambitions. This requires the alignment of energy security with climate security. Thus, further ambitious longer-term climate policies will be needed to drive the green transition, facilitated by a broad policy package. To put it mildly, this is a work in progress. However, if such an effective and stringent policy mix is implemented, earmarked super depreciation allowances have the potential to accelerate the green and digital transition.

References

Acemoglu, D., Aghion, P., Bursztyn, L. and D. Hemous (2012) "The Environment and Directed Technical Change", *American Economic Review* 102, 131-166.

Acemoglu, D., Akcigit, U., Hanley, D. and W. Kerr (2016) "Transition to Clean Technology", *Journal of Political Economy* 124, 52-104.

Annicchiarico, B., Carattini, S., Fischer, C. and G. Heutel (2022) "Business Cycles and Environmental Policy: A Primer", *Environmental and Energy Policy and the Economy* 3, 221-253.

Armstrong, J., Black, R., Laxton, D. and D. Rose (1998) "A Robust Method for Simulating Forward-Looking Models", *Journal of Economic Dynamics and Control* 22, 489-501.

Auerbach, A.J. (1989) "Tax Reform and Adjustment Costs: The Impact on Investment and Market Value", *International Economic Review* 30, 939-962.

Bond, S.R. and M.P. Devereux (2003) "Generalised R-Based and S-Based Taxes Under Uncertainty", *Journal of Public Economics* 87, 1291-1311.

Born, B. and J. Pfeifer (2013) "Fiscal News and Macroeconomics Volatility", *Journal of Economic Dynamic and Control* 37, 2582-2601.

Born, B. and J. Pfeifer (2014) "Policy Risk and the Business Cycle", *Journal of Monetary Economics* 68, 68-85.

Bouakez, H., Rachedi, O. and E. Santoro (2022) "The Government Spending Multiplier in a Multi-Sector Economy", *American Economic Journal: Macroeconomics* (forthcoming).

Bunn, P., Oikonomou, M., Anayi, L., Mizen, P., Thwaites, G. and N, Bloom (2021) "Influences on Investment by UK Businesses: Evidence from the Decision Maker Panel", *Bank of England Quarterly Bulletin No.* 2021 Q2, 1-24.

Clemens, M., Dany-Knedlik, G., Junker, S. and W. Röger (2021a) "Ampel-Pläne zu 'Superabschreibungen' können Investitionen und Wachstum erhöhen, finanzpolitische Spielräume würden aber enger", *DIW Aktuell*, Nr. 74, 1-4.

Clemens, M., Fuest, C. and J. Wiegmann (2021b) "Promoting Investment through Accelerated Tax Depreciation", *Ifo Schnelldienst* 74, Nr. 12, 39-40.

Dorn, F., Fuest, C., Neumeier, F. und M. Stimmelmayr (2021) "Wie beeinflussen Steuerentlastungen die wirtschaftliche Entwicklung und das Steueraufkommen? Eine quantitative Analyse mit einem CGE-Modell", *Ifo Schnelldienst* 74, October, Nr. 10, 3-11.

Funke, M. and R. Terasa (2022) "Has Germany's Temporary VAT Rates Cut as Part of the COVID-19 Fiscal Stimulus Boosted Growth?", *Journal of Policy Modeling* 44, 450-473.

Furlanetto, F. and M. Seneca (2014) "New Perspectives on Depreciation Shocks as a Source of Business Cycle Fluctuations", *Macroeconomic Dynamics* 18, 1209-1233.

Gorodnichenko, Y. and M. Weber (2016) "Are Sticky Prices Costly? Evidence from the Stock Market", *American Economic Review* 106, 165-199.

Groth, C. and H. Khan (2010) "Investment Adjustment Costs: An Empirical Assessment", *Journal of Money Credit and Banking* 42, 1469-1494.

Gründler, K., Potrafke, N. and F. Ruthardt (2022) “Der Ampel-Koalitionsvertrag im Ökonomentest”, *Ifo-Schnelldienst* 75, January, 52-56.

Hinterlang, N., Moyen, S., Röhe, O. and N. Stähler (2021) “Gauging the Effects of the German COVID-19 Fiscal Stimulus Package”, *Deutsche Bundesbank Discussion Paper No.* 43/2021, Frankfurt.

House, C.L., and M.D. Shapiro (2008) “Temporary Investment Tax Incentives: Theory with Evidence from Bonus Depreciation”, *American Economic Review* 98, 737-768.

IMF (2020) *World Economic Outlook*, October 2020, Washington DC.

IMF (2022) “Euro Area Policies: 2021 Article IV Consultation with Member Countries on Common Euro Area Policies—Press Release”, *IMF Staff Country Report No.* 2022/029, Washington DC.

Ireland, P.N. (2003) “Endogenous Money or Sticky Prices”, *Journal of Monetary Economics* 50, 1623-1648.

Jones, C.I. and C. Tonetti (2020) “Nonrivalry and the Economics of Data”, *American Economic Review* 110, 2819-2858.

Juillard, M. (1996) “Dynare: A Program for the Resolution and Simulation of Dynamic Models with Forward Variables Through the Use of a Relaxation Algorithm”, *CEPREMAP Working Paper No.* 9602, Paris.

Juillard, M., Laxton, D., Pioro, H. and P. McAdam (1998) “An Algorithm Competition: First-Order Techniques Versus Newton-Based Techniques”, *Journal of Economic Dynamics and Control* 22, 1291-1318.

Krueger, A. (1974) “The Political Economy of the Rent-Seeking Society”, *American Economic Review*, 64, 291-303.

Leeper, E., Plante, M. and N. Traum (2010) “Dynamics of Fiscal Financing in the United States”, *Journal of Econometrics* 156, 304-321.

Leibenstein, H. (1966) “Allocative Efficiency vs. ‘X-Efficiency’”, *American Economic Review* 56, 392-415.

Meade, J.E. (1978) *The Structure and Reform of Direct Taxation*, Report of a committee chaired by Professor J.E. Meade, London (Allen and Unwin).

Mertens, K. and M.O. Ravn (2011) “Understanding the Aggregate Effects of Anticipated and Unanticipated Tax Policy Shocks”, *Review of Economic Dynamics* 14, 27-54.

OECD (2019) “ICT Investments in OECD Countries and Partner Economies: Trends, Policies and Evaluation”, *OECD Digital Economy Papers No.* 280, Paris.

Pindyck, R.S. (2013) “Climate Change Policy: What Do the Models Tell Us?”, *Journal of Economic Literature* 51, 860-872.

Popp, D. (2004) “ENTICE: Endogenous Technological Change in the DICE Model of Global Warming”, *Journal of Environmental Economics and Management* 48, 742-768.

Pytlarczyk, E. (2005) “An Estimated DSGE Model for the German Economy within the Euro Area”, *Deutsche Bundesbank Discussion Paper No.* 33/2005, Frankfurt.

Tian, B., Yu, B., Chen, S. and J. Ye (2020) "Tax Incentive, R&D Investment and Firm Innovation: Evidence from China", *Journal of Asian Economics* 71, 101245

Whalen, C. and F. Reichling (2017) "Estimates of the Frisch Elasticity of Labor Supply: A Review", *Eastern Economic Journal* 43, 37-42.

Winberry, T. (2021) "Lumpy Investment, Business Cycles, and Stimulus Policy", *American Economic Review* 111, 364-396.

Zangari, E. (2020) "An Economic Assessment of the Evolution of the Corporate Tax System in Italy", *Banca D'Italia Working Paper No*. 1291, Rome.

Zwick, E. and J. Mahon (2017) "Tax Policy and Heterogeneous Investment Behavior", *American Economic Review* 107, 217-248.