Investing in the Green Transition and Competition from Laggards

Johanna Saecker*   Philip Schnattinger†

[Click here for the latest version]

February 4, 2025

Abstract

We study heterogeneous firms' greening investment decisions and the role of competition between early greening investors and non-investors ("laggards") therein. Empirically, we show that firms have a higher propensity to engage in greening investment if they are more productive, less financially constrained and expect positive effects from an economy-wide transformation to climate-neutrality (*green transition*) on their competitiveness. We incorporate these facts into a dynamic heterogeneous firm model. We show that competition from non-investors keeps aggregate prices and thus idiosyncratic profits low and prevents potential early greening investors from engaging in greening investment. Incorporating expectations about a future green economy with increased competitiveness for early greening investors increases greening investment already today. Furthermore, easing financing constraints by 50% increases the share of greening firms by roughly 20 percentage points in the early stages of a green transition.

JEL codes: E22, L11, Q58
Keywords: Firm Dynamics, Green Transition

*Goethe University Frankfurt & Institute for Monetary and Financial Stability (IMFS). Contact: saecker@hof.uni-frankfurt.de

†Bank of England. Contact: philip.schnattinger@bankofengland.co.uk
We are grateful to Alexander Meyer-Gohde, Leo Kaas, Teresa Schildmann, Miriam Dietenberger and participants of the QCGBF Conference 2024, the EEA 2024, the NOeG Conference 2024 and the Goethe University PhD Macromodelling Seminar for useful comments and suggestions. We are grateful to KfW Research for giving us access to their data and especially Michael Schwartz and Elisabeth Grewenig for their support. We are grateful to CompNet for giving us access to their data.

1 Introduction

Climate change is one of the greatest challenges of our times. In order to reach net zero targets and to transform economies towards greenhouse gas neutrality, significant amounts of investment in this transition are needed. For example, the UK government estimates that an additional 50-60 billion GBP of yearly investment is needed to meet the net zero targets by 2030 (UK Government, 2021, 2023). Fiscal policy alone cannot finance the required investments in their entirety. Policymakers thus need to incentivise investment by the private sector, specifically on the firm side where emissions are an integral part of the production process. The literature has focused extensively on the impediments and gains from investing in the green transition either on an aggregate scale abstracting from the extensive margin of firm investment or on a firm level abstracting from firm interaction on this decision margin. We complement this approach by focusing on competition effects between firms when investing in their own green transition, specifically on the competitive disadvantage of being an early adopter and the ensuing macroeconomic outcomes.

In this paper, we focus on firms' greening investment decisions and the policymaker's role when incentivising greening investment in an environment where both early greening investors and non-investors compete in the same market. Since such incentives are often implemented out in a granular fashion requiring sector-specific policies and approaches, firms often operate in a situation of regulatory uncertainty. Our focus will be on outright bans (e.g. on non climate friendly production processes), which are part of the mix of instruments that policymakers have used.[1] Firms' decisions to engage in firm side investments into their green transition - we call this greening investment - thus depend on their beliefs about the likelihood of bans on brown production processes entering into effect in the foreseeable future. In this paper, we call early greening investors "green firms" and non-investors "brown firms" (or "laggards"). While some firms will invest already today (facing the necessary investment cost) and others will not, both green and brown firms compete in the same market. In our analysis, we investigate the determinants of firms' greening investment using a dataset of German firms. We then show the main competition effects in an illustrative model and finally present the main results in a quantitative model calibrated to our firm dataset.

In our empirical section, we use novel German firm survey data on greening investments of small and medium-sized enterprises (SMEs) from KfW Group's Climate Barometer (KfW Research, 2022, 2023). Since we are interested in the determinants of individual firms'

[1]While pricing policies such as the EU ETS might be the first form of policy to come to mind, outright bans such as the EU ban of new greenhouse gas emitting vehicles from 2035 onward are certainly part of the policy palette.

greening investment across the firm distribution, this is an ideal dataset to use in our analysis. We extract three findings on greening investment. We base our quantitative model on the first two and use it to rationalise the third. We find that firms with higher capital productivity invest a higher share of their total investment into greening (Finding 1). Further, we find that 52% of firms finance greening investments from their own resources (see Table 3(a)) indicating the relevance of financing constraints for this investment category. We further confirm that more financially constrained firms have a lower propensity to invest in greening (Finding 2). Finally, we find that firms which expect a positive impact of green transition policies on their future competitiveness have a higher propensity to invest in greening today (Finding 3). This highlights the role that expectations about the regulatory setting of a future green economy have on firm incentives and thus today's investment decisions. While with the second finding (the relevance of financing constraints) we confirm what a growing recent literature has been showing (Srivastava et al., 2024; European Investment Bank, 2023; Kaldorf and Shi, 2024), the relevance of firm productivity and firm expectations about the effect of policies on competitiveness are novel findings with which we contribute to the literature on the determinants of greening investment.

In order to fix ideas, we show our two main channels of competition on the macroeconomy in a small illustrative two-period model. In the model, firms decide to invest in greening in the first period. If they do not invest in greening they can only produce in the second period if the policymaker does not implement a *green policy* which bans brown production. The green policy is subject to policy uncertainty, and is enforced in the second period only with a fixed probability. An increase in the likelihood of the green policy increases the share of greening investors. Our first result is theoretical. Assuming a negative relation between prices and the amount of firms in the market (*competition effect*), we show that higher competition today decreases market prices in the economy as well as the individual firm's greening cost and thus increases the share of greening investors. With the second result we link to our empirical findings (Finding 3) in showing that the share of greening firms increases when a firm's competitiveness under a green policy shock is expected to increase.

We then build a dynamic heterogeneous firm model in which we rationalise costly engagement into greening investment as an optimal intertemporal firm decision. Firms are heterogeneous in productivity and the model features endogenous entry and exit. Every period, brown firms can decide to invest into greening investment. The latter is a one-directional decision by which firms transition into the pool of greening investors. Analogously to the small model, the policymaker sets the probability of a greening policy being enacted in the following period which forces brown firms out of production if enacted. In line with our data (Findings 1 and 2), more productive firms are more likely to invest in greening and we add stylized financing constraints with a negative dependence of greening costs on firm profits (we derive this assumption more formally in Appendix B.1). The full model is calibrated to stylized moments of our German firm data. It matches entry rates of German firms as well as the share of firms engaging in greening in the dataset and replicates the empirical green firm size distribution.

In the results section, we show the effect of competition on the macroeconomy during a green transition in different experiments. In our main experiment, we simulate the effect of the introduction of a transition policy on the production side as an exit shock by which the least productive firms in the economy are removed from the firm distribution. As a result, the price increases (this is what we call the *competition effect*), leading to an increase in average firm profits and thus a drop in the productivity of the marginal greening investor. The share of greening investors thus increases as the productivity level necessary to obtain sufficient profits has decreased. In a second experiment, we show how the policymaker can realise such a transition in our model by increasing the policy probability of a ban on brown production in the next period. In counterfactual analyses with different policy probabilities, we show how the last empirical finding (Finding 3) can be rationalised in our quantitative model. We compare a scenario where firms take into account expected improvements in their competitiveness in a future green economy (where all brown competitors have had to exit) with a scenario where firms do not expect a green policy to have positive effects on their competitiveness. When firms correctly anticipate benefits from the green policy, the share of greening firms increases. For a high policy probability ($> 50\%$), i.e. when such a green economy is likely to become reality, expectations of competitiveness improvements lead to an increase in the share of greening firms of 2-6%. In a further experiment, we analyse the relevance of financing policies on the share of greening investors. We show that a cut of greening costs by 50% increases the share of greening investors by roughly 20%-points. Last, we show that the effects on output and the increase of green investors intensifies when increasing the speed of the transition. The lower the probability of a green policy, the faster is the speed of the transition if a green policy is enacted. An instantaneous removal of all brown firms (extreme transition) produces strong reactions in the increase of greening firms and the associated loss in output.

The policy implications of our analysis concern expectations about green transition policies. First, the study can be interpreted as showing that setting expectations (e.g. via communication) about green policies can affect the share of greening investors already today. A higher share of greening investors corresponds to a lower share of emissions in the economy and a smaller distance towards reaching the set out climate goals. Second, the study shows the policymaker's trade-offs. The policymaker faces a trade-off between the climate target and the stabilisation of brown output. The policymaker can employ financial policies to reduce greening costs to increase greening investment.

Related Literature. The paper relates to three strands of the literature. First, we contribute to a nascent empirical literature on the determinants of climate investment. While we confirm the relevance of financing constraints for greening investment found by several recent (policy) studies (Srivastava et al., 2024; European Investment Bank, 2023; ECB, 2023), we add to the literature with two novel findings. We show the relevance of productivity for the intensity and share of greening investment. Furthermore, we show that firm expectations about the effects of the green transition on their competitiveness are a relevant determinant for the propensity to invest in greening. In comparison to the literature mentioned above, our dataset disposes of a wider variety of greening investment variables - binary variable, investment share as well as investment intensity. Relating to a more established literature on the determinants of energy efficiency investments, we confirm the finding that idiosyncratic firm characteristics matter (see Hrovatin et al. (2016) for an overview of different determinant categories).[2]

Second, our study is closely linked to the literature of green transition policies and heterogeneous firms. Whereas this branch of the literature focuses on CO2-reducing policies, such as cap-and-trade and emissions taxes (Anouliès, 2017; Dardati, 2016; Dardati and Saygili, 2020; Konishi and Tarui, 2015; Qiu et al., 2018), we contribute by focusing on outright bans. In line with the heterogeneous firms literature, - and to keep the model parsimonious - we conceptualise investment mainly as forgone potential output abstracting from its productive and intertemporal quality, focussing on the firm distribution instead.[3] What we add to this literature is a new transmission channel where the aggregate green transition target (here: the aggregate share of firms engaging in greening) is affected via competition between firms. The role of competition for the green transition has been investigated in micro models (Martin-Herran and Rubio, 2024), in representative agent macro models in connection with green innovation activity (Aghion et al., 2023) or in an Integrated Assessment Model (Jondeau et al., 2023), however, not in a heterogeneous firm macro model with greening

[2]Note that since energy efficiency investments make up a large part of greening investments, we also see connections to this more established literature. We add to it with a much broader scope of our dataset (e.g. several sectors, more observations) than many of these studies.

[3]Note furthermore, that in line with our dataset, but in contrast to the literature on directed technical change (Acemoglu, 2002; Fried, 2018), we consider investment efforts more broadly and do not focus only on R&D spending. Also, in contrast to the green finance literature (see e.g. Ozili (2022) for an overview), we do not focus on the determinants of green credit supply.

investment.

Third, we contribute to the literature on climate policy risk. This literature finds that the risk of climate policies being enacted in the future already affect macroeconomic outcomes today via agents' expectations and beliefs (Fried et al., 2022; Dietrich et al., 2024; Campiglio et al., 2024). In our empirical part, we show that expectations about the effects of green regulation on individual firms' competitiveness are related to the propensity to invest in greening today. In the theoretical part, we incorporate, following Fried et al. (2022), policy uncertainty as a probability of a transition policy being enacted in the next period. We show that, like this, the share of firms investing in the transition depends on the likelihood of a green policy being enacted in the next period.

In the following, we first describe the data we use and give an overview of the main greening investment facts that we want to calibrate our model to. In a small model we then show the two main effects from competition. Consequently, the quantitative model is outlined. The model dynamics are analysed in the next section. Last, we conclude.

2 Greening Investment

We present a novel dataset on German firm data showing two novel findings on the determinants of greening investment. We are able to show that a firm's share of greening investment is positively related to their capital productivity and that an increase in the firm's expected competitiveness under a future green policy is positively related to their propensity to invest in greening. We can furthermore confirm the findings from a recent literature showing that financing constraints are negatively related to the propensity to engage in greening investment.

2.1 Data and Methodology

We use cross-sectional firm survey data on climate investment from KfW's Climate Barometer (KfW Research, 2022, 2023). The latter is a yearly voluntary firm survey of private SMEs (defined as yearly turnover of $\leq$ 500 million Euro).[4] The sample is designed so as to equally represent firms from all combinations of the following categories: macro sector, size (in terms of employees), East vs. West Germany as well as receiver vs. non-receiver of subsidies from the KfW Group. We use the resulting unweighted sample of firms. We merge surveys for the years 2021 and 2022. In the survey, our central variable *greening investment* is defined as

[4] This excludes public sector firms as well as banks and non-profit organisations. They comprise sectors codes WZ2008 641, 84, 94, 97, 98 and 99. For further details see Schwartz and Gerstenberger (2023).

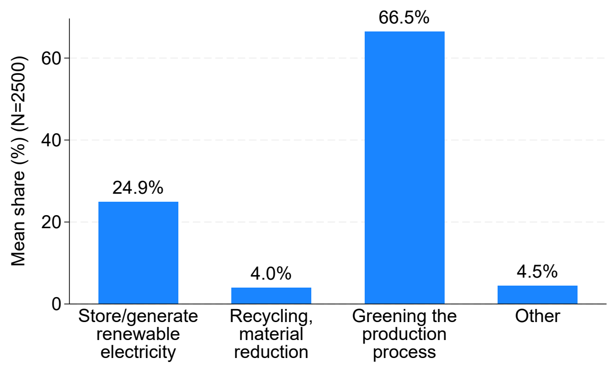


Figure 1: Destination of Firms' Greening Investment

Note: Share of investment (mean of all firms) into every category. "Greening the production process" defined as the sum of the following categories "energy efficiency in existing buildings", "energy efficiency in new builds", "energy efficiency in process or plant engineering", "climate-friendly mobility". "Other" defined as the sum of "other", "production or usage of climate-neutral hydrogen".

"[...] investments in measures to avoid or reduce greenhouse gas emissions in your company. These include investments to save energy or increase energy efficiency, measures to utilise renewable energies or investments in climate-friendly transport, such as the purchase of electric vehicles.".[5] When examining what exactly firms' greening investment comprises, firms on average invest 66% into measures which we classify as greening the production process, and the rest into other measures (see Figure 1).[6] We take this as confirmation for our proxy to measure the dimension we are interested in.

From this survey question, we construct three variables of interest. We construct *Greening Investment Intensity* as the share of greening investment relative to total assets (we define a second logged variable as the log of this ratio). Further, we construct *Greening Investment Share* as the share of greening investment relative to all investment (a log version defined respectively). *Binary Greening Investment* measures if firms have invested in greening investment during the past year or plan to do so until the end of the next year.

Based on assuming a standard production function $Y_t = f(A_t, K_t, L_t)$, where capital K_t is measured by assets, L_t is measured by the number of workers and Y_t is measured by turnover, we construct *Log Capital Productivity* $A_{K,t} = \log\left(\frac{Y_t}{K_t}\right)$ as the log of the ratio of turnover over total assets. We specify further productivity measures which we use for our robustness section in Appendix A.2. For measuring financing constraints we employ the following question: "How relevant is a lack of financial resources as an obstacle to the implementation of climate

[5] Translation, original in German.

[6] One survey question asks firms to indicate which share out of their greening investment they invest into the above categories.

investments in your company?" We construct a binary measure. Further, we use a measure for expectations of future competitiveness during the green transformation. Specifically, the survey question we employ asks: "How do you think the planned transformation of the German economy towards climate neutrality will affect the competitiveness of your company?". Firms can answer on a scale from 1 to 5 increasing in positivity of expectations. We employ the variable as a continuous variable in Section 2.2.3. Control variables are the continuous variables for firm size (measured as number of employees), investment intensity (defined as total investment/total assets), firm age as well as fixed effects for the year 2022, sectors, industries (i.e. NACE letter codes), being located in East Germany as well as energy intensity (defined as energy cost/total cost in five categories).[7] Our dataset consists of 14443 observations, although not all variables are available for all observations (see Table A3 for descriptive statistics of all variables). Firms are predominantly of small size, i.e. 67% of firms have less than 20 employees.

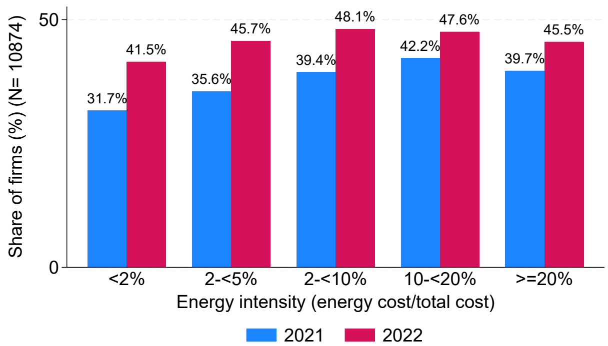
Greening investment decision. Across all firms, 36.98% invest in greening (see Table A2). Similar to European Investment Bank (2023), the propensity to invest in greening increases in firm size and is relatively similar across sectors but slightly higher in manufacturing (see Figure A1 and Table A2).[8] Furthermore, firms have a higher propensity to invest in greening in West Germany than in East Germany (see Table A2) and when being of older firm age (see Figure A1). We further confirm the relevance of energy intensity for greening investment decisions (see also European Investment Bank (2023); Srivastava et al. (2024) - the latter for its effect on expected investment). We show that firms with up to below 20% energy cost out of total cost, the greening investment propensity increases in energy intensity (see Figure 2). Firms with equal or above 20% intensity then have a slightly lower propensity to invest.[9] Following a sharp increase in energy cost in 2022, we find the share of investing firms to increase by 7.3 pp. (see Table A2) indicating that energy costs are a strong motivation for greening investment.[10] Figure 2 shows that the increase (in pp.) was strongest in the category of least energy intense firms. It might be that high energy intense firms were affected more by the energy price shock and had less resources for greening investment. Less energy intense firms, on the other hand, might have perceived the energy price shock predominantly as a signal to start investing in energy-saving greening measures.

[7] Following KfW Research (2022), we split firms into five sectors - Manufacturing, Construction, Services, Trade, Other - from the letter code sectors (see Figure A1).

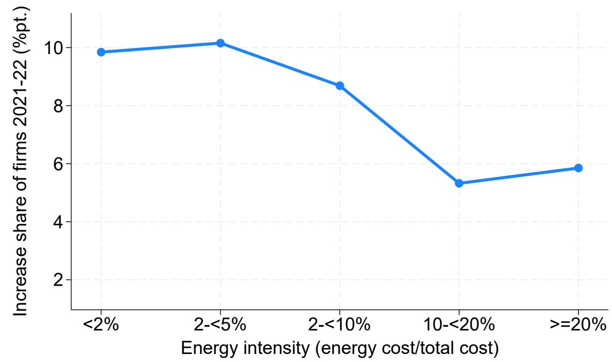
[8] More formally, this result is confirmed equally by results from logit regressions in Table 2 and Table 3.

[9] These results are confirmed to be more or less stable when controlling for firm controls in Table 2 and Table 3.

[10] Note that European Investment Bank (2023) find a comparable increase of 10 pp.



((a)) Binary greening investment across energy intensity groups and years



((b)) Change in binary greening investment between 2021 and 2022 across energy intensity

Figure 2: Binary Greening Investment and Energy Intensity

Note: The figure shows the share of firms engaging in greening investment across energy categories (energy intensity measured as share of energy cost to total cost).

2.2 Results on Greening Investment

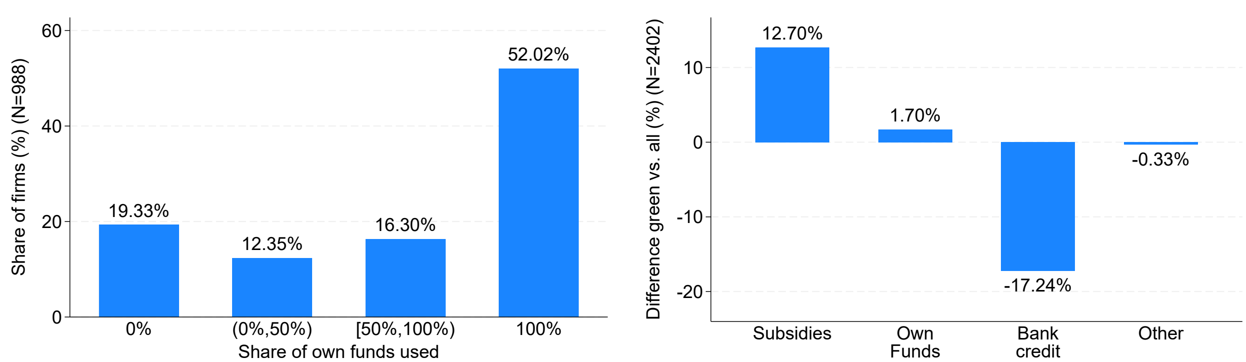
We now turn to the three empirical regularities we wish to document in our study. We show that greening investment is positively related to capital productivity, positively related to positive expectations of a firm's future competitiveness during a green transition and negatively related to the existence of financing constraints.

2.2.1 Productivity

We analyse the relation between capital productivity and greening investment using a simple linear regression model. As firm controls we include in all regressions standard variables determining firm investment decisions, namely firm size, firm age and fixed effects for firms being located in East Germany. We include sectoral and year fixed effects to control for the influence of sector and time effects. Table 1 shows that a 1% increase in capital productivity is associated with a roughly 10-13% increase in the greening investment share. Since the greening investment share relates greening investment to all investment, the result shows that greening investment is related to a higher rise in capital productivity than regular investment. The relation of productivity to greening investment intensity is even stronger (with 21-31%). The positive relation between investment and greening investment is reflected also in the positive coefficient for investment intensity (columns (1)-(2)). The relevance of capital productivity as a determinant of the investment size (both for intensity and relative to total investment) has not been shown before in the literature. We interpret that more profitable firms have more resources to allow for a longer-term planning perspective. For both measures, we see that energy intensity is generally positively related to greening investment and the effect increases with higher degrees of energy intensity. Also, the effect was higher in 2022, the year of a strong energy price increase, indicating the relevance of energy costs for the size of greening investment. We show in Table A5 (see Appendix A.3) that results are robust to the use of industry fixed effects. We furthermore show in Appendix A.2 that a positive relation holds true also for other productivity measures. Contrary to previous studies (Srivastava et al., 2024), we show a positive relation between binary greening investment and both labour productivity and TFP.

2.2.2 Financing Constraints

Figure 3(a) shows that most firms (roughly 52%) in our sample finance 100% of their greening investment with own funds.[11] Similar to (Srivastava et al., 2024), we find that firms employ less bank credit for greening investment compared to all investment but more own funds (see Figure 3(b)). The former could be related to a shortage of credit supply for greening investment (e.g. ECB (2023) find this to be a relevant barrier to climate investment) or that firms substitute bank loans with subsidies (which are used more often than for total investment).



((a)) Share of Own Funds used for Greening Investment Funding

((b)) Funding Source of Greening Investment (%-difference relative to all investment)

Figure 3: Funding Sources of Greening Investment

Note: The figure shows the funding sources of greening investment.

[11]Firms finance at the mean 65% of greening investment from own funds (see Figure A3).

	(1)	(2)	(3)	(4)	(5)	(6)
Model	Linear Regression Model					
Dependent variable	**Log Greening Investment Intensity**			**Log Greening Investment Share**		
Log Capital Productivity	0.313***	0.214***	0.217***	0.134**	0.0949*	0.0970*
	(5.70)	(3.95)	(4.05)	(2.72)	(2.03)	(2.11)
Invest. Intensity	4.043***	4.151***	4.128***			
	(13.15)	(12.95)	(12.84)			
Energy Intensity (2− < 5%)		0.369**			0.255*	
		(3.11)			(2.25)	
Energy Intensity (5− < 10%)		0.508***			0.321**	
		(3.89)			(2.64)	
Energy Intensity (10− < 20%)		0.602***			0.321*	
		(3.47)			(2.00)	
Energy Intensity (≥ 20%)		0.564**			0.377*	
		(2.99)			(2.12)	
Energy Intensity × Y2021 (continuous)			0.125**			0.0700
			(2.78)			(1.65)
Energy Intensity × Y2022 (continuous)			0.193***			0.116**
			(4.67)			(3.11)
Year 2022 FE	✓	✓		✓	✓	
Sector FE	✓			✓		
Firm Controls	✓	✓	✓	✓	✓	✓
Constant	-4.591***	-4.919***	-4.885***	-1.533***	-1.750***	-1.715***
	(-29.43)	(-36.83)	(-36.65)	(-11.12)	(-14.34)	(-14.37)
R^2	0.253	0.260	0.258	0.060	0.048	0.046
Observations	1138	1027	1027	1067	969	969

Table 1: Greening Investment Intensity/Share and Capital Productivity

Note: The table shows results from regressing log greening investment intensity (=log(greening investment/total assets)) and log greening investment (=log(greening investment/total investment)) on log capital productivity (=log(turnover/total assets)) and control variables using a linear regression model (LRM). Firm controls are firm age, firm size (employees), East Germany fixed effect. Checkmarks indicate fixed effects included. Estimates for energy intensity relative to the base category < 2%. Standard errors are robust to heteroscedasticity. t statistics in parentheses. Levels of statistical significance as follows: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

	(1)	(2)
	Binary	
Dependent variable	**Greening Investment**	
Financing Constraints	-0.0385*	-0.0425*
	(-2.31)	(-2.36)
Invest. Intensity	0.212***	0.206**
	(3.30)	(2.98)
Manufacturing	0.141***	
	(5.27)	
Services	0.0789**	
	(2.94)	
Other	0.0934*	
	(2.03)	
Trade	0.0759**	
	(2.92)	
Energy Intensity ($2- < 5\%$)		0.0726**
		(3.24)
Energy Intensity ($5- < 10\%$)		0.107***
		(4.20)
Energy Intensity ($10- < 20\%$)		0.0611*
		(1.99)
Energy Intensity ($\geq 20\%$)		0.110**
		(2.82)
Year 2022 FE	✓	✓
Firm Controls	✓	✓
Adj. R^2	0.0480	0.0453
Observations	3514	3080

Table 2: Financing Constraints and Greening Investment Propensity

Note: The table shows average marginal effects from regressing binary greening investment on a binary variable capturing the existence of financing constraints in a logit regression setup. Firm controls are firm age, firm size (employees), East Germany fixed effects. Checkmarks indicate fixed effects included. Estimates for energy intensity relative to the base category $< 2\%$; estimates for sectors relative to the construction sector. Standard errors are robust to heteroscedasticity. Adj. R^2 is McFadden's adjusted pseudo measure. t statistics in parentheses. Levels of statistical significance as follows: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 2 shows the results from using a logit model to analyse the relation between financing constraints and greening investment more formally. Remember that firms self-declare the existence of financing constraints as a barrier to their greening investment. We find that the existence of firm financing constraints is negatively related to a firm's propensity to invest in greening. This holds true across specifications at least at the 5% statistical significance level when controlling for energy intensity and the standard firm characteristics. We show in Table A6 (see Appendix A.3) that results are robust to the use of industry fixed effects and employing a tobit model. Due to the relatively small sample size for the greening investment share we cannot investigate the relative relevance of financing constraints compared to all investment more formally. Overall, we thus find that financing constraints are a barrier to greening investment, confirming findings from a growing literature on barriers to climate investments (Srivastava et al., 2024; European Investment Bank, 2023; Kaldorf and Shi, 2024) as well as a more established literature on barriers to energy efficiency investments (Thollander and Ottosson, 2008; Trianni and Cagno, 2012; Trianni et al., 2013). In our structural model in Section 4, we thus incorporate stylised financing constraints.

2.2.3 Expectations about Future Competitiveness

We analyse the relation between expectations of a firm about its future competitiveness during a green transition and the firm's greening investment decision. A simple scatterplot shows that the share of firms investing in greening increases in the firm's assessment of its competitiveness during a green transition (see Figure 4).

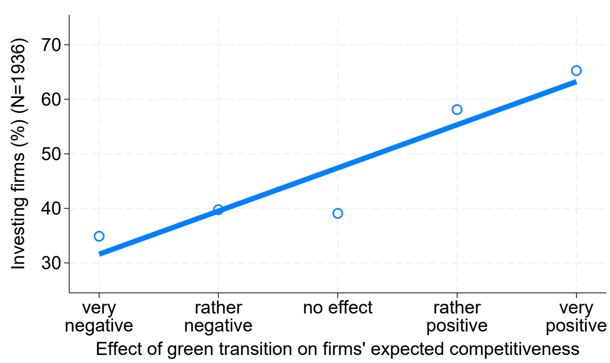


Figure 4: Share of Firms Investing in Greening and Expectations of a Firm's Competitiveness during a Green Transition

Note: The associated survey question is: "How do you think the planned transformation of the German economy towards climate neutrality will affect the competitiveness of your company?"

	(1)	(2)	(3)	(4)
Model	Logit		Linear Regression Model	
Dependent variable	**Binary Greening Investment**		**Log Greening Investment Share**	
Expected Competitiveness	0.0793*** (11.28)	0.0782*** (9.97)	0.0379 (1.06)	0.103** (2.79)
Manufacturing	0.111*** (4.29)		-0.159 (-1.32)	
Services	0.0185 (0.74)		-0.245 (-1.96)	
Other	0.0543 (1.49)		0.288 (1.64)	
Trade	0.0315 (1.32)		0.0768 (0.66)	
Energy Intensity ($2- < 5\%$)		0.0359 (1.61)		0.121 (1.07)
Energy Intensity ($5- < 10\%$)		0.0749** (3.10)		0.354** (3.07)
Energy Intensity ($10- < 20\%$)		0.0911** (3.28)		0.434** (3.19)
Energy Intensity ($\geq 20\%$)		0.0902** (2.73)		0.384* (2.14)
Firm Controls	✓	✓	✓	✓
Constant			-1.488*** (-9.05)	-1.939*** (-11.78)
R^2			0.033	0.038
Adj. R^2	0.0632	0.0616		
Observations	4202	3364	1016	877

Table 3: Expectations of Future Competitiveness and Greening Investment

Note: The table shows results from regressing binary greening investment (columns (1)-(3)) and the greening investment share (columns (4)-(5)) on an indicator of firms' negative expectations of competitiveness. The latter is a categorical variable with five options increasing in the degree of negative expectations for firm competitiveness. The survey question is "How do you think the planned transformation of the German economy towards climate neutrality will affect the competitiveness of your company?". Logit regressions show average marginal effects. Firm controls are firm age, firm size (employees), East Germany fixed effects. Estimates for energy intensity relative to the base category $< 2\%$; estimates for sectors relative to the construction sector. t statistics in parentheses. Levels of statistical significance as follows: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 3 shows results from investigating this relation more formally. We use a logit model for assessing the extensive margin of greening investment. We employ a linear regression model to assess the intensive margin of greening investment relative to all investment (i.e. the greening investment share). We control for the aforementioned firm controls as well as sectors and energy intensity. Regression results in Table 3 confirm that the more optimistic firms are about their competitiveness during a green transition, the higher is their propensity to invest in greening. The result for binary greening investment is highly statistically significant and signs of all control variables are in line with previous expectations. The result for the investment share indicates that the amount of greening investment is affected more by competitiveness concerns than total investment, albeit the coefficient displays weaker statistical significance. In sum, the analysis seems to indicate that firms' expectations about how green transition policies affect their individual firm competitiveness in the future has consequences on firm greening investment behaviour already today. This fact has not been shown before by the climate and energy efficiency literature. In terms of robustness, we show in Table A7 (see Appendix A.3) that our results are robust to controlling for the use of a tobit specification censored at zero (addressing the potential concern that data is censored from below). We also control for using industry fixed effects instead of sector fixed effects. In order to investigate potential causal mechanisms behind our findings, we build a dynamic heterogeneous firm model and propose a competition channel in Sections 3 and 4.

3 Small Model

We illustrate the firm's greening decision and the effect of competition in a simple two-period model. We show that, first, a fall in the current period's competition which brown firms (*laggards*) present increases the share of greening investors. Second, more firms engage in greening investment if they face lower competition in a future green economy. In a quantitative model (see Section 4) that is calibrated to the German firm data, we quantify the effects from our policy experiments.

3.1 Model Exposition

In this simple model, firms live for two periods only. Knowing that the policymaker implements a greening policy with probability κ in the second period which forces non-greeners to exit, the firm makes a greening decision in the first period.

In the first period ($t = 1$), firms draw idiosyncratic productivity z_1 from a distribution $H(z)$. If the resulting firm value V is below zero firms exit at the beginning of the second period.

This gives us a productivity cut-off value $\tilde{z}_P$ (defined by $V(\tilde{z}_P) = 0$), so that firms produce if $z_1 \geq \tilde{z}_P$. Firms produce at fixed cost f and receive profits $\pi_1(z_1, p)$, where the aggregate price is p. Furthermore, firms need to decide if they engage in greening investment at cost $c(.) > 0$ or if they do not - in which case there is no cost. Firms with more own funds have better conditions for financing the necessary greening investment - either by using these funds to finance greening investment (which is what we see in the data in the previous section) or to secure better financing conditions for external financing (in Appendix B.1 we show this more formally). In our model, firm own funds can be proxied by profits. We thus incorporate a cost function $c(\pi_1)$ with a negative relation between profits and greening cost $\partial c/\partial \pi_1 < 0$.

In the second period ($t = 2$), the respective low-productivity firms with $z_1 < \tilde{z}_P$ exit and do not contribute to second period output. Remaining firms draw a new productivity z_2. With probability $\kappa > 0$, a transition policy is enacted mandating all firms to use a green production process in the second period. Firms that invested in the first period will produce. Firms which did not, cannot produce and exit the economy. In case of a green policy enactment there would be a shock to the number of firms and the resulting price level. Both variables would change to new values, namely p_g for the price level and N_g for the number of firms.

The degree of competition in the economy is reflected by the number of firms N producing in the economy. We assume that the aggregate price p negatively depends on the degree of competition, i.e. $\partial p/\partial N < 0$ (as well as $\partial p_g/\partial N_g < 0$). Consequently, the degree of competition has a negative impact on the profit π_t of a firm, $\partial \pi_t/\partial N < 0$ ($\partial \pi_2/\partial N_g < 0$).

The firm value of green investors (see (1)) consists of profits minus greening costs in the first period. With the probability $1 - \kappa$ of a green policy not entering into force the firm receives expected profits in the second period. With the probability κ of a green policy being enacted, the firm receives expected profits depending on a different price p_g. In this case, all brown firms have to exit instantaneously, lowering the amount of firms in the economy N_g leading to a new price p_g. The firm value of the brown non-investor (see (2)) consists of profits in the first period and expected profits in the second period only in case of no green policy implementation.

$$V_I = \pi_1(z_1, p(N)) - c(\pi_1(z_1, p(N))) + \kappa\, \mathbb{E}\, \pi_2(z_2, p_g(N_g)) + (1 - \kappa)\, \mathbb{E}\, \pi_2(z_2, p(N)) \tag{1}$$

$$V_{NI} = \pi_1(z_1, p(N)) + (1 - \kappa)\, \mathbb{E}\, \pi_2(z_2, p(N)) \tag{2}$$

A firm's investment choice thus depends both on idiosyncratic firm productivity (z_1 and z_2) and competition (N and N_g), i.e. the amount of competitors in the economy. Firms engage in greening investment if $V_I \geq V_{NI}$. After simplifying, the investment condition reads as in

Explanation	Functional Form	
Production function	$y = p\ z$	
Investment cost function	$c(\pi) = \frac{c}{p\ z}$	
Profit function	$\pi = p\ z - f$	
Demand side	$p = N^{\frac{1}{1-\sigma}}$	
Productivity distribution	$\text{H(z)} = \begin{cases} \dfrac{1}{z_{max} - z_{min}}, & \text{if } z_{min} \leq z \leq z_{max} \\ 0, & \text{otherwise} \end{cases}$	
Explanation	**Parameter**	**Values**
Cost of production	f	1
Elasticity of substitution parameter	σ	3
Cost function parameter	c	2

Table 4: Small Model Assumptions: Parameters and Functional Forms

(3).

$$\kappa\ \mathbb{E}\ \pi_2(z_2, p_g(N_g)) \geq c(\pi_1(z_1, p(N))) \tag{3}$$

On the left hand side, the benefits of investing are the surplus profits received when investing and a green policy shock hits relative to the alternative of zero profits in the case of no investing. Note that these expected surplus profits depend on competition and prices in an economy with only green firms ($p_g(N_g)$). On the right hand side, the costs of investing are the greening cost depending on the price and competition in the economy in the first period. A firm thus decides to invest if the benefits are at least as high as the costs. The exit conditions are $V_I < 0$ and $V_{NI} < 0$. Conditional on other variables being exogenous, the investment cutoff $\tilde{z}_I$, i.e. the lowest productivity level at which the firm fulfills the greening investment condition, is derived using (3) and is given by equation (4). The production cutoff $\tilde{z}_P$, namely, the lowest productivity level at which the firm has a high enough firm value to produce, can be derived from the brown non-investor's exit decision and is given by (5).

$$\kappa\ \mathbb{E}\ \pi_2(z_2, p_g) = c(\pi_1(\tilde{z}_I, p)) \tag{4}$$

$$\pi_1(\tilde{z}_P, p) + (1 - \kappa)\ \pi_2(z_2, p) = 0 \tag{5}$$

3.2 The Competition Effect

Assuming the functional forms and parameters given in Table 4, we investigate the effect of competition on the share of investors.

Proposition 1: *For a given expectation of a future green policy realisation κ, the incentive to green is stronger, i.e. the investment cutoff $\tilde{z}_I$ is lower, if there is less competition today.*

Proof. Show that $\frac{\partial \tilde{z}_I}{\partial N} > 0$. Using condition (4), we define function F

$$F(N_g, N, \tilde{z}_I) = \kappa\, (p_g(N_g)\, \tilde{z}_I - f) - \frac{c}{p(N)\, \tilde{z}_I} \tag{6}$$

and since $\sigma > 1$

$$\frac{\partial \tilde{z}_I}{\partial N} = -\frac{\partial F}{\partial N}\left(\frac{\partial F}{\partial \tilde{z}_I}\right)^{-1} = \frac{1}{\sigma - 1}\frac{c}{\tilde{z}_I} N^{\frac{\sigma}{1-\sigma}} \left(\kappa p_g + \frac{c}{p\tilde{z}_I^2}\right)^{-1} > 0 \qquad q.e.d. \tag{7}$$

Proposition 2: *For a given expectation of a future green policy realisation κ, the incentive to green is stronger, i.e. the investment cutoff $\tilde{z}_I$ is lower, if less competition is expected in the case of a green policy realisation.*

Proof. Show that $\frac{\partial \tilde{z}_I}{\partial N_g} > 0$. We use function F to show that

$$\frac{\partial \tilde{z}_I}{\partial N_g} = -\frac{\partial F}{\partial N_g}\left(\frac{\partial F}{\partial \tilde{z}_I}\right)^{-1} = \frac{1}{\sigma - 1} N_g^{\frac{-\sigma}{1-\sigma}} \kappa \tilde{z}_I \left(\kappa p_g + \frac{c}{p\tilde{z}_I^2}\right)^{-1} > 0 \qquad q.e.d. \tag{8}$$

We illustrate these findings in Figure 5 which shows the competition effect (Figure 5(b), Figure 5(c)) as well as the effect of a change in the green policy probability (Figure 5(a)) in the small model on the greening investment cutoff. For a given productivity level, firms engage in greening investment if benefits (blue line) are higher than the costs (red line). All firms with productivity levels higher than (i.e. right from) those at the intersection of both curves engage in greening investment. If the cutoff value of both curves moves, so does the amount of greening firms in the economy. Figure 5(a) shows that a higher probability of a green policy shock being enacted ($\kappa \uparrow$) shifts the greening investment cutoff downwards and thus increases the share of greening investors. The level of the policy shock expectation shows with which probability green policies will be enacted in the near future. An increase in this likelihood changes firms' expectations thus giving a higher weight to the scenario of a green economy where all brown firms will exit the economy. The surplus benefit of greening investment rises and consequently more firms invest in greening today.

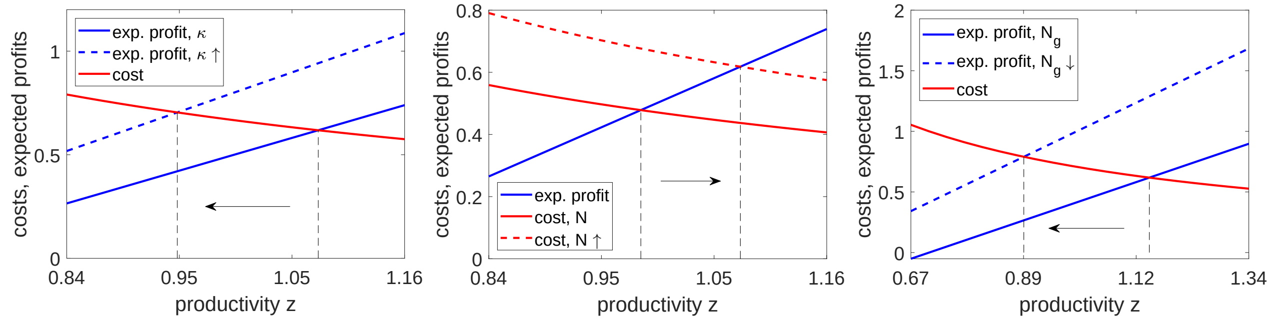
Figure 5(b) shows how an increase in competition today ($N \uparrow$) increases the investment cutoff and decreases the number of greening investors. An increase in competition decreases the aggregate price level; for a given productivity level, decreases profits in the first period π_1 and increases costs of greening investment (see the right-hand side of (3)). Thus the share of greening investors falls. This second graph highlights the main point of our study. If there is an initially high degree of competition from brown firms that potential green investors face, there is a negative effect on the amount of greening firms in the economy. In the small model version, we only show the effect of high competition between brown firms ("laggards") and potential greeners that works via financing constraints. In the full quantitative model, we extend the firm's greening decision and confirm that this result holds.

Last, Figure 5(c) focuses on the role of expectations about a green economy, i.e. once a green policy has been implemented. Note that in the small as well as the quantitative model, we exclusively focus on the situation *before* the implementation of such a green economy. The latter thus only enters the firm's greening decision in the form of expectations. Figure 5(c) highlights two aspects. First, it describes expectations about a green economy. If the green policy shock is implemented, all brown firms are forced to exit the economy. This improves the competitiveness of all remaining green firms and increases the price level (*competition effect*). The green economy equilibrium is thus characterised by higher expected profits (since firms know that $p_g > p$), so that the left-hand side term $\mathbb{E}\,\pi_2$ is higher than it would be under the first-period price level p and contributes to a high surplus benefit of greening investment. This is how the competition effect increases expected surplus benefits of greening investment (via high expected profits, in contrast to a high κ in Figure 5(a)) and affects the benefit-side of the greening investment decision. Second, in the small model, we rationalise the positive relation between expectations of future competitiveness and today's greening investment (Finding 3) which we uncovered in Section 2.2.3. Lower expected competition in the case of a green policy shock ($N_g \downarrow$) increases expected profits in the policy case and thus the benefit from today's greening investment.

4 Quantitative Model

In the following, we outline the quantitative dynamic heterogeneous firms model which we calibrate to our firm data and use to quantify the effect of expectations and financing policies. Since we aim to capture the heterogeneity between profitable and unprofitable firms as well as greening and non-greening firms, we use a baseline heterogeneous firm model (Hopenhayn, 1992; Hopenhayn and Rogerson, 1993) as a foundation.[12] We extend the model with a binary greening decision - the central decision margin of our interest -, and stylized financing costs which affect the cost of greening investment. Last, the policymaker can implement a green transition policy - a feature, we use to analyse how the transition unfolds.

[12]Note that we use a model with persistent heterogeneity since we are interested in long-term greening investment decisions which persistently alter the firm's economic situation - compared to models with non-persistent heterogeneity.



((a)) Policy probability ($\kappa \uparrow$) ((b)) Competition today ($N \uparrow$) ((c)) Green policy ($N_g \downarrow$)

Figure 5: Investment Decision in the Small Model

Note: This figure illustrates comparative statics in the greening investment decision in (3). Figure 5(a), shows the effect of an increase in the green policy probability κ on the greening investment decision margins. Figures 5(b), 5(c) show the effect of an increase in competition today and a decrease of competition in the case of a green policy shock on the greening investment decision margin. Productivity on the x-axis is normalised relative to the mean.

4.1 Profit Maximisation

Firms aim to maximise their present discounted value of future profits by choosing inputs into production and optimal entry and exit. All firms choose labour l. Brown firms also choose a one-directional binary investment decision into greening their production process (see Section 4.3). Higher labour input increases current output, while increasing greening investment serves to avoid future cost when a greener production process is mandated under a possible green policy.

Firms maximise current period profits $\pi(z)$ given by (9) by choosing labour input $l(z)$ optimally, given the production function in (10). Output is denoted by $y(z)$, the labour share by α and idiosyncratic productivity by z. In order to produce, firms need to pay a fixed production cost f valued in labour units. The wage w is constant.

$$\max_{l} \pi(z) = p\, y(z) - w\, l - fw \tag{9}$$

$$y(z) = \exp(z)\, l^{\alpha} \tag{10}$$

Optimal labour input is the result of equating the marginal benefit of labour input $p\, \partial y(l)/\partial l$ to the marginal cost of labour w.

$$p\, \alpha \exp(z)\, l^{\alpha-1} = w \tag{11}$$

4.2 Green Policy

We focus on a situation of green policy risk in the style of Fried et al. (2022). Each period, with probability κ, the policymaker introduces a green policy mandating a green production process from next period on. Should the policy be mandated, all firms which will not have invested in greening their production process with the one-shot greening investment would receive profits of zero in the period and would have to exit the economy. This results in a new equilibrium with a new price p_g. Two remarks are in order. First, note that, since we are interested in studying today's greening decisions, we only focus on cases where this equilibrium never occurs. Expectations about the economy in such a green equilibrium, however, determine firms' greening decisions already today. Second, note that we thus model an extreme case of a green policy shock which, once it materialises, drives all brown firms out of the economy. This has the effect that there is no competition from brown firms towards green firms any more since the economy then only consists of green firms.

4.3 Investment Decision

Every period, non-transitioned, i.e. brown, firms can choose to engage in one-shot greening investment $g \in \{0, 1\}$ at cost $c(\pi)$. Firms choose g to maximise the present discounted value of profits. Once they do so, they transition into the pool of firms which have adapted their production process, i.e. green firms. This is a one-directional decision and every firm permanently remains in the group of green firms until it exits the economy.

In line with the empirical greening fact from Section 2.2.2 we incorporate firm financing constraints into our model. Due to model tractability, we do so in a stylized way analogous to the small model (see Section 3). We assume that the size of greening investment depends negatively on profits. In the Appendix B.1 we show how higher firm net worth (which collapses to firm profits in our parsimonious model) is negatively related to external funding costs in an extended version of our firm problem which includes capital, debt and financing constraints. Since more productive firms have higher profits, our parsimonious approach implies the well-known fact that more productive (proxying for bigger and older) firms face less financing constraints. Thus, in (13) we have $\partial c(.)/\partial\pi < 0, \partial^2 c(.)/\partial\pi^2 > 0$.

The value function for brown firms of the current period follows (12). In every period, brown firms decide on their greening investment g by maximising (12). In the first case, if the firm does not invest in greening the firm value is described by (14). This firm receives profits today. In the following period this firm only receives profits if no greening policy is enacted, i.e. with probability (1-κ), and again faces the choice of investing in greening or not. In the second case, if the firm invests in greening the firm value is described by (13). The investing firm receives profits and pays greening costs once. In the following period, in case of no policy shock, the firm's value function is described by (15). This is the green firm's value function in every state after the firm transitioned. Last, (16) is the value function in the case of a green policy being enacted. In our model, (16) describes an equilibrium that never occurs in the current period but only enters into the firm's intertemporal decision in expectation. In this equilibrium, all brown firms exit the economy and thus the aggregate price in this economy is $p_g > p$. Note that - in line with our empirical section - our model implies that more profitable firms are more likely to invest in greening.

$$V_B(z) = \max_g g\, W_1 + (1-g)\, W_2, \qquad g \in \{0,1\} \tag{12}$$

$$W_1 \equiv \pi(z) - c(\pi(z)) + \frac{1}{r}\, \mathbb{E}_{z'|z}\big[(1-\kappa)\, V_G(z') + \kappa\, V_{G,\kappa}(z')\big] \tag{13}$$

$$W_2 \equiv \pi(z) + \frac{1}{r}\, \mathbb{E}_{z'|z}\big[(1-\kappa)\, V_B(z')\big] \tag{14}$$

$$V_G(z) = \pi(z) + \frac{1}{r}\, \mathbb{E}_{z'|z}\big[V_G(z')\big] \tag{15}$$

$$V_{G,\kappa}(z) = \pi(z) + \frac{1}{r}\, \mathbb{E}_{z'|z}\big[V_{G,\kappa}(z')\big] \tag{16}$$

4.4 Timing

The timing of the model is as follows.

1. All firms make exit and stay choices. The marginal green and brown producer's productivity values z_s^G, z_s^B are determined.
2. New firms enter into production based on expected firm value.[13] The marginal entrant's productivity value z_s^E is determined.
3. All firms draw productivity.
4. All firms make static labour choices.
5. Brown firms make intertemporal investment choices. The marginal investor's productivity value z_s^I is determined.
6. Aggregation and household decision are made.
7. All firms receive profits.

[13] In the stationary equilibrium, as many firms are entering as were exiting in the first step.

4.5 Productivity, Entry, Exit and the Firm Distribution

Idiosyncratic firm productivity follows an AR(1) process in logs, where $\varepsilon_z \sim \mathcal{N}(0, \sigma_z)$ and $\rho_z > 0$.

$$\log(z') = \rho_z \log(z) + \varepsilon_z \tag{17}$$

At the beginning of each period, firms exit if the expected discounted firm value is smaller than zero. The exit conditions for the green and brown firm are (18) and (19). They define the production cut-offs for green and brown firms z_s^G, z_s^B. For green firms, z_s^G is defined as the lowest productivity value for which (18) holds with equality. Analogously for brown firms.

$$\mathbb{E}_{z'|z}\big[V_G(z')\big] < 0 \tag{18}$$

$$\mathbb{E}_{z'|z}\big[V_B(z')\big] < 0 \tag{19}$$

There is an unbounded set of possible entrants. In timing step 2, firms draw an initial productivity level z_0 from the probability distribution $\nu(z_0)$ and pay a fixed entry cost f_e valued in labour units. Firms enter if the expected value of entering $V^E(z_0)$, namely the expected value of the firm based on the expected production and investment decisions of the firm given the idiosyncratic productivity shock hitting in the timing step 3, equals the entry cost. The marginal entrant has productivity z_s^E and determines the entry condition equation (20). If an entrant's productivity is $z_0 < z_s^E$, the firms choose to immediately exit again. Firms enter into the pool of brown firms initially, but can make greening investment decisions in the same period. Entrants are equal to incumbents in every subsequent period (see the firm values for the next period in (21)).

$$V^E(z_s^E) - w f_e = 0 \tag{20}$$

$$V^E(z_0) = \max_g g\, W_1^E + (1-g)\, W_2^E, \qquad g \in \{0,1\} \tag{21}$$

$$W_1^E \equiv \pi(z_0) - c(\pi(z_0)) + \frac{1}{r}\, \mathbb{E}_{z'|z_0}\big[(1-\kappa)\, V_G(z') + \kappa\, V_{G,\kappa}(z')\big] \tag{22}$$

$$W_2^E \equiv \pi(z_0) + \frac{1}{r}\, \mathbb{E}_{z'|z_0}\big[(1-\kappa)\, V_B(z')\big] \tag{23}$$

4.6 Household

Households maximise the present discounted value of utility in (24) subject to the aggregate budget constraint (25). The choice of labour L is static. The choice of consumption C is intertemporal. The budget constraint states that the spending on consumption plus the spending on new entrants MV^E and bonds B must not exceed the income from labour wL

plus aggregate firm profits Π plus earnings from bond holdings. Households own all firms. Household decisions are made just before profits are received. Note that $u(.)$ is a continuous, twice differentiable function which fulfills the Inada conditions and $f_L > 0$.

$$U(C) = \max\,[u(C) - f(L)] + \beta\,\mathbb{E}\,U(C') \tag{24}$$

$$p\,C + M\,V^E + B' = wL + \Pi + rB \tag{25}$$

In a stationary equilibrium, the parameter w is determined by the first-order conditions for labour $w = f_L$. Since prices are constant in a stationary equilibrium and households and firms discount with the same factor, i.e. $\beta = 1/r$, the first-order condition for consumption, $u_C = \beta\mathbb{E}[r\ u_{C'}\ p/p']$, reduces to $u_C = u_{C'}$. Consumption is constant. We further assume aggregate demand to be fixed, i.e. $\bar{D} = p\,C$, where $C = Y$. Labour supply is consequently given as in (26). Aggregates are defined in Appendix B.2.

$$L^s = L = \frac{1}{w}\left(\bar{D} + MV^E - \Pi\right) \tag{26}$$

4.7 Equilibrium

Definition. A *stationary equilibrium* contains aggregate prices $p \geq 0$, a mass of entrants $M \geq 0$, value functions V_B, V_G, policy functions for exit $X_G(z), X_B(z)$ and for greening decisions $\gamma(z)$ as well as the measures of green incumbents μ_G, brown incumbents μ_B and entrants μ^E, so that

1. the labour market clears: $L^s(\mu_G, \mu_B, M; p) = L^d(\mu_G, \mu_B, M)$
2. $V_G, V_B, X_G(z), X_B(z), \gamma(z)$ and $w = f_Z$ solve the firm problem in (12)-(16), and where $V_{G,\kappa}$ solves the firm problem in a green equilibrium outlined in Appendix B.3[14]
3. the entry condition $V^E \geq wf_e$ is fulfilled with equality for $M > 0$
4. the measures of incumbents evolve according to the laws of motion:
   $\mu'_G = (1 - X_G)\;\gamma\;\mu_B + (1 - X_G)\;\mu_G + M\;\gamma\;\mu^E$
   $\mu'_B = (1 - X_B)\;(1 - \gamma)\;\mu_B + M\;(1 - \gamma)\;\mu^E$

5 Calibration

We calibrate key parameters to match moments of our firm data. The remaining parameters are either normalised or set to standard values (see Table 5).

[14]Note that this equilibrium is never reached in our analysis, but enters into our problem in expectation.

First, we set the discount factor β to receive an annual real interest rate of 4%. The curvature of the labour input in the production function is set to 0.66 - a value which is standard in the real business cycle literature. Second, we set the fixed cost of production to an arbitrary value and choose the fixed entry cost as a fraction of production so as to match the entry rate from German firm data. We use sectoral data for firm entry rates from the Federal Statistical Office of Germany and weigh each sector with the firm share in our firm dataset on greening investment.[15] This allows us to match the model's entry rate closely to this weighted empirical entry rate (see Table 6). We choose the functional form for the cost function to be $c(.) = \frac{c_1}{(p\ y)^{c_2}}$ and match the cost parameter c_1 to imply the share of green investors to match the one in the data (see Table 6) for a given value of c_2 and the lowest policy parameter in our grid ($\kappa = 0.05$). Since we analyse the beginning of a green transition, we thus assign the data to the lowest possible policy probability.

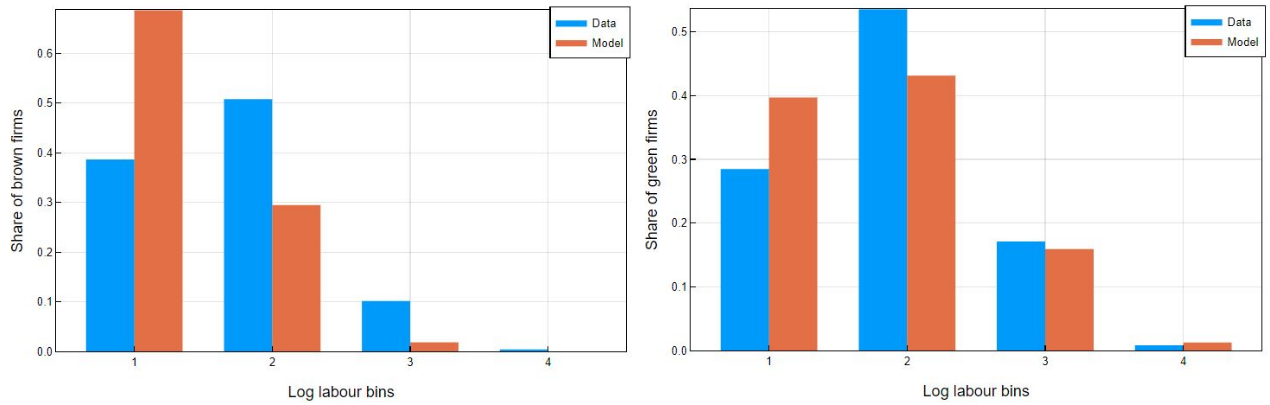
Explanation	**Parameter**	**Values**
Standard parameters		
Discount factor	β	0.96
Risk-free rate	r	$1/\beta$
Labour share	α	0.66
Standard deviation of the productivity process	σ_z	0.1
Mean of the productivity process	μ_z	0
Autocorrelation productivity process	ρ_z	0.85
Matching firm data		
Fixed cost of production	f	30
Fixed entry cost	f_e	$0.48 \times f$
Greening investment cost parameter	c_1	87.8
Greening investment cost parameter	c_2	0.1
Normalised parameters		
Number of productivity grid points	N_z	200
Wage	w	2
Aggregate demand	$\bar{D}$	400

Table 5: Full Model: Calibration

Description	**Moment**	**Data**	**Model**
Share of green investors	N_i/N	0.3698	0.3684
Entry rate	M/N	0.0678	0.0614

Table 6: Full Model: Targeted Moments

[15]For the Federal Statistical Office of Germany, see the webportal DESTATIS: https://www.destatis.de/EN/Home/_node.html.



((a)) Brown firm size distribution: data and model ((b)) Green firm size distribution: data and model

Figure 6: Brown and Green Firm Distributions: Model and Data

Note: The figure shows the brown and green firm size distributions comparing our dataset to the model results. The bins are constructed over equally spaced intervals of log employees.

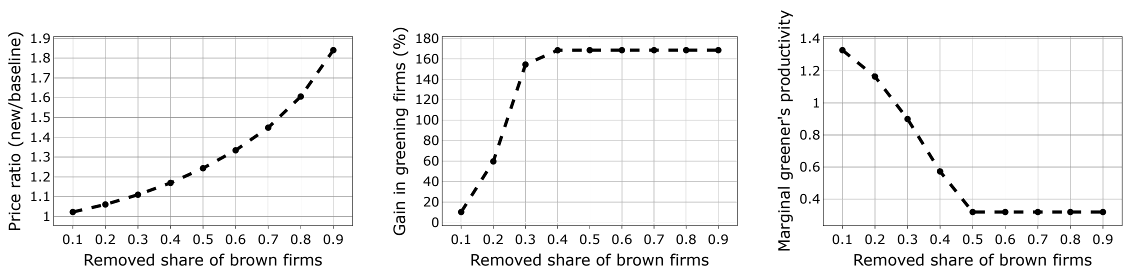
Furthermore, together with the greening parameters, we choose the parameters of the productivity process - mean μ_z, standard deviation σ_z and autocorrelation ρ_z - to match the firm distribution of green and brown firms in the data. We construct both size distributions over four bins of equally spaced intervals over log employees of green and brown firms separately. Figure 6 shows the brown and green firm size distributions in both model and data. The shape of the green fim size distribution is matched rather well with the majority of firms located in the first two quartiles and a peak in the second quartile. For the brown firm distribution the mass is generally matched with the overall mass in the first two quartiles. Third, we normalise the remaining parameters as given in Table 5.

6 Results

In this section, we show how competition from brown firms hinders the green transition in the quantitative model. Further, we show how expectations about future competitiveness positively influence the green transition. Last, we highlight the role of financing constraints and show the non-linearity of effects for different transition speeds.

6.1 Competition from Brown Firms hinders the Green Transition

In our heterogeneous firm model, we focus on analysing the effect of a green transition on the firm side and its implications for the number of greening firms. We conceptualise the transition by thinking that throughout the transition process, all firms will eventually either become green (by making greening investment) or have to exit the economy until there are only green firms left (*green economy*). In order to disentangle the influence of the competition effect during a green transition, we conduct an experiment that isolates today's reduction in the number of firms from additional effects on firm value. We fix the green policy probability at $\kappa = 0.05$ and sequentially remove different shares of the brown firm distribution - from left to right - thus simulating the changes in greening firms that only come from the competition effect during a green transition process. Figure 7 shows that with increasingly removing larger shares of the firm distribution, the aggregate price in the economy increases (see Figure 7(a)). Due to both an increase in individual firm profits as well as a decrease in greening costs, the number of greening firms increases (see Figure 7(b)). The marginal greener's productivity shows how the cutoff of the greening decision in the firm distribution falls simultaneously (see Figure 7(c)).



((a)) Price increase relative to baseline (ratio)

((b)) Increase in the number of greening firms (%)

((c)) Productivity of the marginal green investor

Figure 7: Competition Effect in the Quantitative Model: Brown Firm Exit

Note: This figure shows the change in prices (Figure 7(a)) (as a ratio of new/baseline), the increase in greening firms (Figure 7(b)) (in % relative to the initial amount of greening firms) and productivity of the marginal greener (Figure 7(c)) from an experiment where different shares of the brown firm distribution are removed (starting from left to right), thus simulating the exit of brown firms (starting with the least productive) during a green transition.

6.2 Positive Expectations about Competitiveness in a future Green Economy increase Greening Investment

In this section, we first show how the policymaker realises a green transition by increasing the likelihood of a green policy shock happening (κ). We then present our main second result, namely that we can replicate the remaining finding (Finding 3) from the empirical section.

Policy Experiment Setup. Table 7 shows aggregate and firm-specific moments under a subset of policy shock values, where all values are normalised to one except for the share of green firms. With an increase in the green policy probability, the firm value of the least productive firm drops below zero and the respective firms exit the economy (analogously to the small model in section 3). This leads to an upward shift of the production cutoffs, a decrease in the number of brown firms and a drop in brown output. With an increase in the productivity cut-off, less productive firms are driven out of the economy and average productivity should increase. At the same time, the greening investment cutoff falls. The overall effect on brown productivity is thus ambiguous, but we see that it falls slightly. A higher policy probability decreases the benefit of not-investing in the second term of equation (12), i.e. the non-investor's gain in case of no policy, whereas the effect on the investor's firm value is less clear. It thus makes non-investing less likely.[16] The greening investment productivity cutoff thus falls, increasing the share of green firms and green output. The average green productivity increases as well.

Policy probability	$\kappa = 0.05$	$\kappa = 0.35$	$\kappa = 0.55$	$\kappa = 0.75$
Share of green firms	0.3684	0.8325	0.8531	0.8717
Average green productivity	1	2.8357	3.0895	3.3678
Average brown productivity	1	0.3153	0.2932	0.2724
Number of green firms	1	3.0065	3.2962	3.6152
Number of brown firms	1	0.3529	0.3311	0.3104
Green output	1	2.5964	2.8209	3.0719
Brown output	1	0.2614	0.2410	0.2223

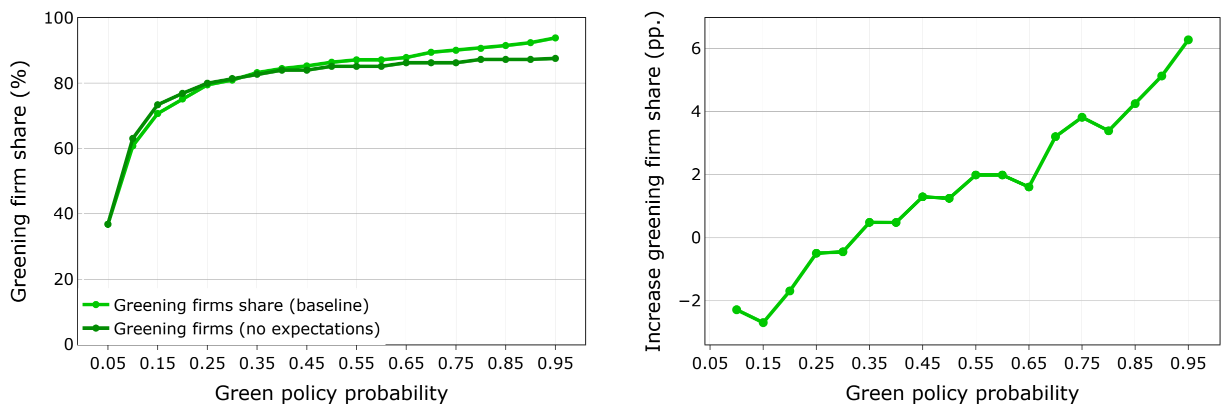
Table 7: Full Model: Aggregate Moments at Different Levels of the Green Policy Probability

Note: This table shows aggregate moments from comparing stationary equilibria with different green policy shock probabilites. Note that all variables are normalised to 1 for $\kappa = 0.05$ except for the share of green firms.

Expectations about the Green Economy. In the following, we show that an increase in a firm's future expected competitiveness in a green economy increases the greening investment share today - for high values of the green policy probability. In this experiment we thus replicate the qualitative results from our empirical section on expectations about future competitiveness (see Section 2.2.3). In an alternative scenario to the standard policy experiment outlined above (the dark green line/"no expectations" in Figure 8(a)), we replace $V_{G,\kappa}$ by V_G in (13). This means that potential greening firms do not expect a green economy without competition from brown firms after the policy shock has happened. However, firms now expect firm value determined in an economy with all brown firms, i.e. more competition

[16] Here you equally see the main difference between the investment decision in the small model and the quantitative model. While in the decision in the small model, we were able to cancel the terms with $(1 - \kappa)$, this is not possible in the quantitative model where we are more specific about what happens to both types of firms in the case of no green policy shock.

than in the green economy. We thus model a scenario where firms expect less favourable conditions concerning their competitiveness. When comparing the difference between the baseline (= lower competition) with the alternative scenario (= more competition), we find in Figure 8(a) the greatest impact of a change in expectations about future competitiveness on the right of the graph. These are scenarios where the greening policy probability is high. A high greening policy probability weighs the term on expectations about the green economy equilibrium in the potential greening firm's value function more. Figure 8(b) shows that the



((a)) Greening firm share (%)

((b)) Greening firm share difference (%-points)

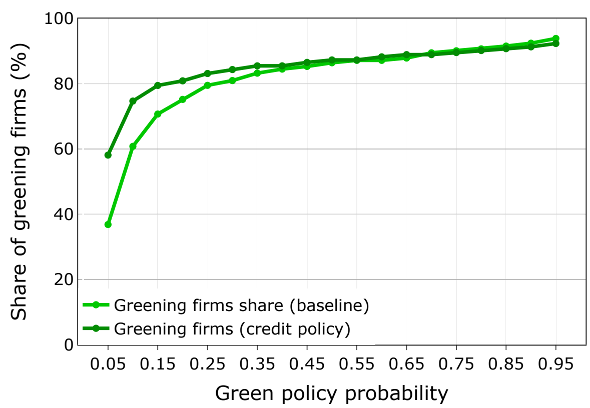
Figure 8: The Influence of Positive Expectations about a Green Equilibrium on the Greening Firm Share

Note: Figure 8(a) shows the share of greening firms in the baseline case compared to an alternative case without positive expectations about firm competitiveness in a green equilibrium. In the alternative case expected firm value in a green economy ($V_{G,\kappa}$) is replaced by the firm value in the baseline economy (V_G) in the brown firm's value function (13). We thus show the difference in the share of greening firms (Figure 8(b)) when comparing an economy without positive expectations about green firm competitiveness in a green economy with an economy with positive expectations (= baseline). Note that in the green economy, all brown firms have to exit, reducing the competition for green firms (previously coming from brown firms) and improving the remaining green firms' competitiveness.

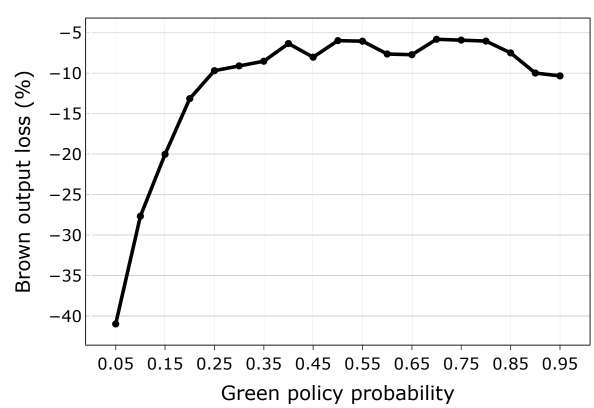
more relevant expectations become in the firm's greening decision, the higher is the percentage point increase of the greening firm share coming from the difference in expectations. Quantitatively, we find that for a green policy probability of more than 50%, the increase in the greening firm share due to positive expectations about firm competitiveness in a green economy lies between roughly 2-6%.

6.3 Easing Financing Constraints raises Greening Investment

In the following, we show results from lowering financing constraints for potential greening investors and the effect it has on the share of greening firms. In this experiment, greening costs are reduced by 50%. We compare the share of green firms and the loss in brown output across different green policy probabilities. A decrease in greening costs decreases costs of greening investment and thus increases today's firm value of potential investors. This lowers the productivity cutoff of greening investment and thus increases the share of greening investors. Figure 9(a) shows that this effect is most dominant at the beginning of the transition, i.e. with low green policy probabilities. Greening costs in our model are thus a barrier especially at the beginning of the transition. An increase in greening firms of initially roughly 20%-points comes at the cost of a loss in brown output of roughly 40%. For higher values of the policy probability, the brown output loss stabilises at a still very high level of 5-10%. We see strongly non-linear reactions. The trade-off between the loss in brown output and the increase in green firms is strongest for low policy probabilities.



((a)) Share of greening firms (%)



((b)) Brown output loss

Figure 9: The Influence of Financing Constraints on Greening Firm Share and Brown Output

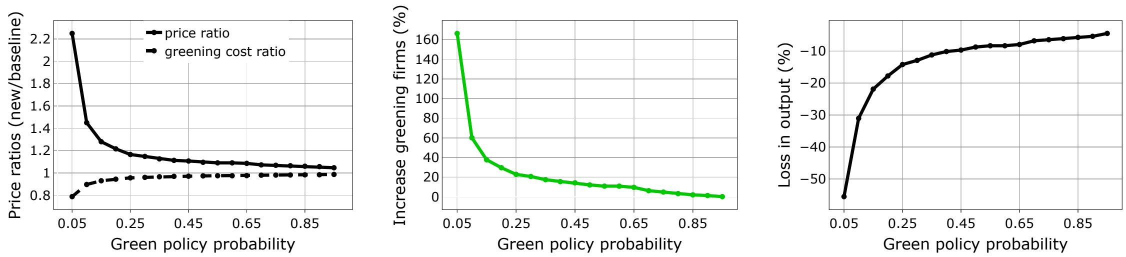
Note: The figure shows the share of greening firms (Figure 9(a)) and the brown output loss (Figure 9(b)) over different policy probabilities from an experiment of reducing greening costs by 50% for all firms. The output loss is computed as the difference between the equilibrium with 50% less greening costs and the baseline case relative to the baseline case.

6.4 The Speed of the Transition

In this section, we suggest how to think about the effect of the speed of the transition on the economy with the use of the quantitative model. In this experiment we simulate an instantaneous radical green transition where all brown firms are forced to exit the economy immediately. We conduct this experiment for different degrees of the green policy probability, i.e. different probabilities with which firms expect a transition to happen. We then compare the effect of this exit on key variables with the *baseline* state of the economy before the experiment - for the fixed green policy probability. We thus compare an economy with both brown and green firms (high degree of competition) with an economy with only green firms (low degree of competition).

This experiment offers several insights. First, it shows the workings of the competition effect in another experiment. Figure 10 shows that the price level in the economy increases following the outlined experiment (see Figure 10(a)). The price level is negatively related to the number of firms and output in our model. Following a forced exit of all brown firms, both the number of firms and output fall, leading to an increase in prices. The remaining firms thus experience an increase in profits. Due to a negative relation of greening cost and firm profits (see Section 4.3), greening costs for individual firms fall. Figure 10(a) shows how greening costs are permanently lower than in the baseline. Figure 10(b) shows the resulting change in the amount of greening firms relative to the initial amount of green firms.

Second, the effect of competition is non-uniform across different stages of the transition. The green policy probability in our model reflects firms' expectations about the implementation of future transition policies. And firms react based on these probabilities, i.e. expectations. The continuum over different probabilities of the green transition policy being enacted in the following period, can thus be interpreted as different stages of the transition process. For a low green policy probability, agents do not expect a green transition policy being enacted in the following period. If such a policy is enacted, it thus represents an extreme case of a fast transition. This results in enormous costs and gains. The loss in output is 55% and the rise in greening firms is roughly 60%. Such a transition seems not to be a realistic scenario. For a high policy probability, on the contrary, agents already expect a green transition policy being enacted in the following period with almost certainty. The transition has already taken place and a subsequent enactment of the green policy represents one of the last steps in a slow transition. However, our model still predicts sizeable losses in output of around 3% in the last probability value and increases in the share of greening firms of similar amount.



((a)) Price and green cost ratio (relative to baseline) ((b)) Increase greening firm share (%) ((c)) Loss in output (%)

Figure 10: Competition Effect in the Full Model: Extreme Transition

Note: This figure shows the change in prices (Figure 10(a)) (in %), greening cost (Figure 10(b)) (in %) and output lost (in %) (Figure 10(c)) from an experiment where all brown firms are forced to exit the economy relative to an economy with both green and brown firms when keeping the green policy probability fixed.

7 Conclusion

We have analysed the role of competition between green and brown firms for heterogeneous firms' investment into greening the production process. In our empirical analysis, using a novel dataset on German firm data, we found three motivational facts. The more productive and less financially constrained firms are the higher their propensity to invest into greening. These two facts are used to motivate our quantitative model. The third empirical fact shows that the propensity of firms to green is higher for firms with positive expectations about their future competitiveness in a green economy. The third fact was rationalised in our quantitative model. We built a heterogeneous firm model with endogenous entry and exit in which a firm's binary decision to engage in greening investment positively depends on productivity. We showed, that in our model a decrease in competition (i.e. the number of firms producing) increases the price, firm profits, lowers greening costs and thus increases the incentive to engage in greening investment. Furthermore, we showed that when incorporating positive expectations about a firm's future competitiveness, the share of greening investors is higher. More specifically, for a high probability of a green economy in the next period, the share of investing firms was shown to increase by 2-6% when taking positive expectations into account.

References

Acemoglu, D. (2002): "Directed technical change," *The Review of Economic Studies*, 69, 781–809.

Aghion, P., R. Bénabou, R. Martin, and A. Roulet (2023): "Environmental preferences and technological choices: Is market competition clean or dirty?" *American Economic Review: Insights*, 5, 1–19.

Anouliès, L. (2017): "Heterogeneous firms and the environment: a cap-and-trade program," *Journal of Environmental Economics and Management*, 84, 84–101.

Campiglio, E., F. Lamperti, and R. Terranova (2024): "Believe me when I say green! Heterogeneous expectations and climate policy uncertainty," *Journal of Economic Dynamics and Control*, 165, 104900.

Dardati, E. (2016): "Pollution permit systems and firm dynamics: how does the allocation scheme matter?" *International Economic Review*, 57, 305–328.

Dardati, E. and M. Saygili (2020): "Aggregate impacts of cap-and-trade programs with heterogeneous firms," *Energy Economics*, 92, 104924.

Dietrich, A. M., G. J. Müller, and R. S. Schoenle (2024): "Big news: Climate-disaster expectations and the business cycle," *Journal of Economic Behavior & Organization*, 227, 106719.

ECB (2023): "Economic Bulletin," 6, available at https://www.ecb.europa.eu/press/economic-bulletin/html/eb202306.en.html.

European Investment Bank (2023): "What drives firms' investment in climate action? Evidence from the 2022-2023 EIB Investment Survey," Tech. rep., Europen Investment Bank.

Fried, S. (2018): "Climate policy and innovation: A quantitative macroeconomic analysis," *American Economic Journal: Macroeconomics*, 10, 90–118.

Fried, S., K. Novan, and W. B. Peterman (2022): "Climate policy transition risk and the macroeconomy," *European Economic Review*, 147, 104174.

Hopenhayn, H. and R. Rogerson (1993): "Job turnover and policy evaluation: A general equilibrium analysis," *Journal of Political Economy*, 101, 915–938.

Hopenhayn, H. A. (1992): "Entry, exit, and firm dynamics in long run equilibrium," *Econometrica: Journal of the Econometric Society*, 1127–1150.

Hrovatin, N., N. Dolšak, and J. Zorić (2016): "Factors impacting investments in energy efficiency and clean technologies: empirical evidence from Slovenian manufacturing firms," *Journal of Cleaner Production*, 127, 475–486.

Jondeau, E., G. Levieuge, J.-G. Sahuc, and G. Vermandel (2023): "Environmental Subsidies to Mitigate Net-Zero Transition Costs," *Banque de France Working Paper*, 910.

Kaldorf, M. and M. Shi (2024): "Do firm credit constraints impair climate policy?" *SSRN Working Paper*, available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4720512.

KfW Research (2022): "KfW-Klimabarometer 2022," Tech. rep., KfW Research, available at https://www.kfw.de/PDF/Download-Center/Konzernthemen/Research/PDF-Dokumente-KfW-Klimabarometer/KfW-Klimabarometer-2022.pdf.

——— (2023): "KfW-Klimabarometer 2023," Tech. rep., KfW Research, available at https://www.kfw.de/PDF/Download-Center/Konzernthemen/Research/PDF-Dokumente-KfW-Klimabarometer/KfW-Klimabarometer-2023.pdf.

Konishi, Y. and N. Tarui (2015): "Emissions trading, firm heterogeneity, and intra-industry reallocations in the long run," *Journal of the Association of Environmental and Resource Economists*, 2, 1–42.

Martin-Herran, G. and S. J. Rubio (2024): "Cournot Competition and Green Innovation in a Dynamic Oligopoly," *SSRN Working Paper*, available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4792421.

Ozili, P. K. (2022): "Green finance research around the world: A review of literature," *International Journal of Green Economics*, 16, 56–75.

Qiu, L. D., M. Zhou, and X. Wei (2018): "Regulation, innovation, and firm selection: The porter hypothesis under monopolistic competition," *Journal of Environmental Economics and Management*, 92, 638–658.

Schwartz, M. and J. Gerstenberger (2023): "KfW-Mittelstandspanel 2023 Tabellenband," Tech. rep., available at https://www.kfw.de/PDF/Download-Center/Konzernthemen/Research/PDF-Dokumente-KfW-Mittelstandspanel/KfW-Mittelstandspanel-2023-Tabellenband.pdf.

Srivastava, P., N. Bloom, P. Bunn, P. Mizen, G. Thwaites, and I. Yotzov (2024): "Firm climate investment: A glass half-full," *Bank of England Staff Working Paper No. 1095*.

Thollander, P. and M. Ottosson (2008): "An energy efficient Swedish pulp and paper industry–exploring barriers to and driving forces for cost-effective energy efficiency investments," *Energy Efficiency*, 1, 21–34.

Trianni, A. and E. Cagno (2012): "Dealing with barriers to energy efficiency and SMEs: Some empirical evidences," *Energy*, 37, 494–504.

Trianni, A., E. Cagno, P. Thollander, and S. Backlund (2013): "Barriers to industrial energy efficiency in foundries: a European comparison," *Journal of Cleaner Production*, 40, 161–176.

UK Government (2021): "Net Zero Strategy: Build Back Greener," Tech. rep., available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf.

——— (2023): "Mobilising Green Investment - 2023 Green Finance Strategy," Tech. rep., available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf.

Appendix for

"Investing in the Green Transition and Competition from Laggards"

Johanna Saecker Philip Schnattinger

February 4, 2025

Contents

Appendix

A Empirical Analysis

A.1 Data Cleaning

We use four macro sectors from the KfW Climate Barometer, which are defined as follows:

Macro sector	WZ-codes
Manufacturing	10-33, 58, 95
Construction	41-43
Trade	45-47
Services	37-39, 49-53, 55, 56, 59-66, 68-75, 77-82, 85-88, 90-93, 96
Other	1-3, 5-9, 35-36

Table A1: Definition of Macro Sectors

Note: The underlying data uses the German industry classification WZ2008 which is almost identical to NACE Rev.2 2-digit industry codes. For the specific differences see https://www.destatis.de/DE/Methoden/Klassifikationen/Gueter-Wirtschaftsklassifikationen/Downloads/klassifikation-wz-2008-3100100089004-aktuell.pdf?__blob=publicationFile, p.17

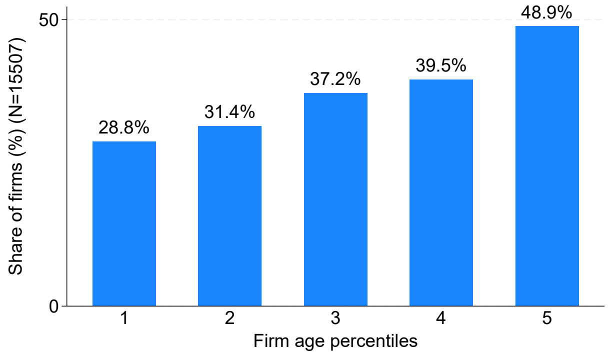
A.2 Additional Empirical Results

A.2.1 Descriptives Binary Greening Investment

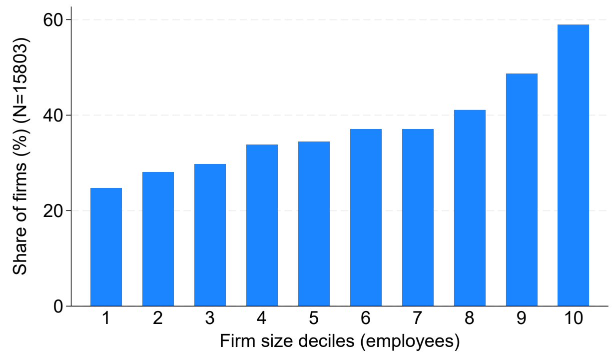
	Share of firms investing in greening in each category
All firms	36.98 %
Years	
2021	34.4 %
2022	41.7 %
Region	
West Germany	39.9 %
East Germany	30.8 %

Table A2: Binary Greening Investment: Descriptives

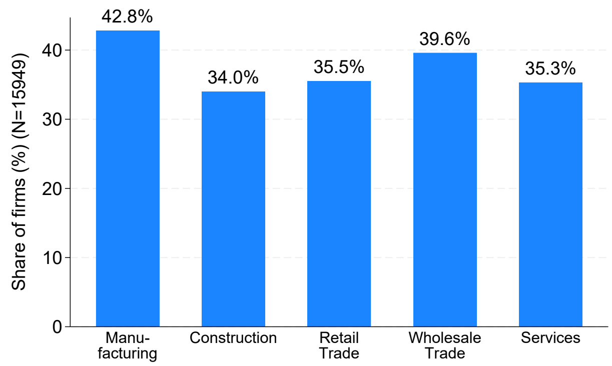
Note: The table shows the share of firms (in percent) investing in greening in each of the five categories. Example: In 2021, 34.4% were investing in greening, 65.6% were not.



((a)) Share of firms engaging in greening investment across firm age quintiles



((b)) Share of firms engaging in greening investment across firm size deciles



((c)) Share of firms engaging in greening investment across sectors

Figure A1: Descriptives of Binary Greening Investment

Note: The figure shows binary greening investment across the following firm characteristics: age, size (in employees) and sectors.

A.2.2 Descriptives Greening Investment Share

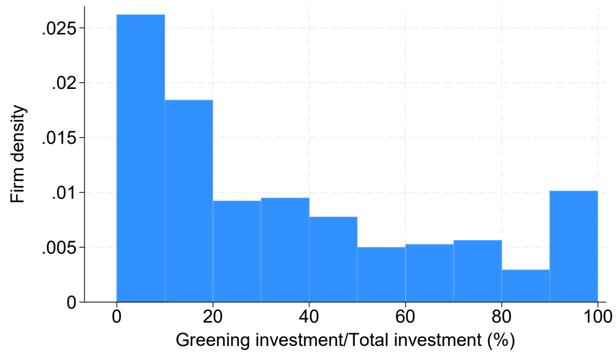


Figure A2: Histogram: Greening Investment Share

Note: The figure shows a histogram of the variable Greening Investment Share (in percent) (= greening investment/total investment × 100).

A.2.3 Other Descriptives

Variable	Count	Mean	Standard Deviation	Minimum	Maximum
Greening Investment Intensity	1370	0.048	0.092	0	1
Greening Investment Share	1907	0.368	0.315	5.81e-05	1
Log Greening Investment Intensity	1335	-4.127	1.636	-10.560	0
Log Greening Investment Share	1907	-1.558	1.293	-9.753	0
Log Capital Productivity	5549	0.423	0.992	-6.838	6.883
TFP	2368	12.332	2.167	3.833	18.041
Investment Intensity	3779	0.105	0.140	1.50e-07	1
Firm Age	14044	37.128	38.577	0	694
Firm Size (employees)	14314	34.350	97.124	0	4752
Expected Competitiveness	4375	2.847	1.026	1	5
Financing Constraints	12732	0.467	0.499	0	1

Table A3: Descriptive Statistics of Main Variables

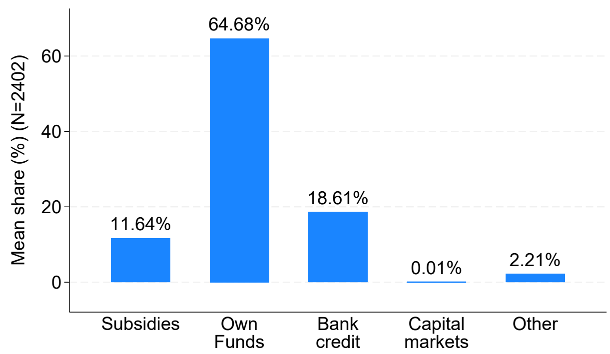


Figure A3: Funding Source of Greening Investment (%-shares) (mean across firms)

A.2.4 Productivity

Based on assuming a standard production function $Y_t = f(A_t, K_t, L_t)$, where capital K_t is measured by assets, L_t is measured by the number of workers and Y_t is measured by turnover, we construct two more productivity measures. First, we construct labour productivity $A_{L,t} = \frac{Y_t}{L_t}$ as the log of the ratio of turnover over employees. Second, we construct a measure of sectoral total factor productivity (TFP), i.e. A_t, using industry-wide estimates for the output elasticity of capital and labour from CompNet (2020). We construct TFP for firm i in sector j as $TFP_{ij} = log(turnover_i) - \alpha_j \, log(totalassets_i) - \beta_j \, log(employees_i)$, where α_j, β_j are 2-digit industry-wide estimates for the output elasticity of capital and labour from OLS estimation of revenue-based translog production functions at the 2-digit industry level provided by CompNet (2020). Industries are 2-digit NACE code industries.

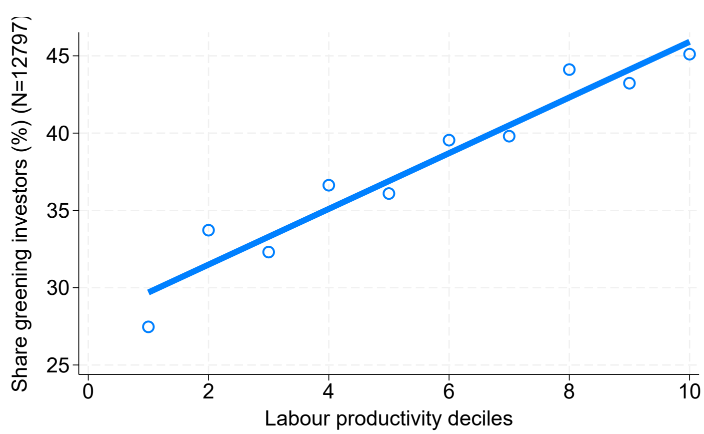


Figure A4: Share of Greening Investors over Labour Productivity (deciles)

Note: Figure A4, shows the share of firms engaging in greening investment over labour productivity (log(turnover/employees)) deciles.

Using conventional measure of labour productivity. Figure A4 shows in a simple scatterplot that labour productivity is strictly positively correlated with the share of firms investing in greening. Using the more general binary greening investment to analyse TFP, Table A4 shows that an increase of TFP by 1% is associated with a probability increase of 2-3%-points of engaging in greening investment. Furthermore, bigger, older and more energy intense firms are more likely to invest, as are firms located in West Germany.

	(1)	(2)	(3)	(4)	(5)	(6)
Model	Logit	Logit	Logit	Tobit	Tobit	Tobit
Dependent variable	**Binary Greening Investment**					
TFP	0.0221***	0.0187**	0.0244***	0.0524***	0.0464***	0.0624***
	(3.92)	(2.79)	(3.99)	(5.08)	(3.85)	(5.31)
Energy Intensity			0.0553*			0.129*
$(2- < 5\%)$			(2.05)			(2.20)
Energy Intensity			0.112***			0.240***
$(5- < 10\%)$			(3.71)			(3.73)
Energy Intensity			0.119**			0.250**
$(10- < 20\%)$			(3.10)			(3.14)
Energy Intensity			0.137**			0.290**
$(\geq 20\%)$			(3.12)			(3.26)
Sector FE		✓			✓	
Year 2022 FE	✓	✓	✓	✓	✓	✓
Firm controls	✓	✓	✓	✓	✓	✓
Adj. R^2	0.0584	0.0565	0.0657	0.0386	0.0394	0.0446
Observations	2317	2317	2013	2317	2317	2013

Table A4: Binary Greening Investment and TFP

Note: The table shows average marginal effects of regressing a binary greening investment measure on TFP (constructed using industry-wide estimates for output elasticity of capital and labour from CompNet) and control variables using logit and tobit model specification. Firm controls are firm age, firm size (employees), east Germany fixed effect. Checkmarks indicate fixed effects included. Estimates for energy intensity relative to the base category $< 2\%$. Adj. R^2 is McFadden's adjusted pseudo measure. t statistics in parentheses. Levels of statistical significance as follows: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

A.3 Robustness Checks

	(1)	(2)
Model	Linear Regression Model	
Dependent Variable	**Log Greening Investment Intensity**	**Log Greening Investment Share**
Log Capital Productivity	0.246***	0.0933
	(3.95)	(1.68)
Invest. Intensity	4.207***	
	(12.52)	
Year 2022 FE	✓	✓
Industry FE	✓	✓
Firm controls	✓	✓
Constant	-4.247***	-1.226***
	(-15.26)	(-5.95)
R^2	0.325	0.136
Observations	1084	1016

Table A5: Greening Investment Intensity/Share and Capital Productivity (Robustness: Industry FE instead of Sector FE)

Note: The table shows results from regressing log greening investment intensity (=log(greening investment/total assets)) and log greening investment (=log(greening investment/total investment)) on capital productivity (=log(turnover/total assets)) and control variables using a linear regression model (LRM). Firm controls are firm age, firm size (employees), east Germany fixed effect. Industries are German WZ2008 industry codes (almost identical to NACE Rev.2 2-digit industry codes). Checkmarks indicate fixed effects included. Estimates for energy intensity relative to the base category $< 2\%$. Standard errors are robust to heteroscedasticity. t statistics in parentheses. Levels of statistical significance as follows: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

	(1)	(2)	(3)	(4)
Model	Logit	Tobit	Tobit	Tobit
Dependent Variable	**Binary Greening Investment**			
Financing Constraints	-0.0466**	-0.0471**	-0.0398*	-0.0438*
	(-2.71)	(-2.73)	(-2.38)	(-2.43)
Invest. Intensity	0.230***	0.217***	0.200**	0.193**
	(3.47)	(3.45)	(3.26)	(2.94)
Energy Intensity				0.0739**
$(2- < 5\%)$				(3.29)
Energy Intensity				0.108***
$(5- < 10\%)$				(4.21)
Energy Intensity				0.0603
$(10- < 20\%)$				(1.94)
Energy Intensity				0.110**
$(\geq 20\%)$				(2.84)
Year 2022 FE	✓	✓	✓	✓
Industry FE	✓	✓		
Sector FE			✓	
Firm controls	✓	✓	✓	✓
Adj. R^2	0.0382	0.0730	0.0485	0.0460
Observations	3323	3338	3514	3080

Table A6: Financing Constraints and Greening Investment Propensity

Note: The table shows average marginal effects from regressing binary greening investment on a binary variable capturing the existence of financing constraints in a logit regression setup. Firm controls are firm age, firm size (employees), east Germany fixed effect. Checkmarks indicate fixed effects included. Estimates for energy intensity relative to the base category $< 2\%$. Standard errors are robust to heteroscedasticity. Adj. R^2 is McFadden's adjusted pseudo measure. t statistics in parentheses. Levels of statistical significance as follows: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Model	(1) Tobit	(2) Tobit	(3) Tobit	(4) LRM
Dependent Variable		**Binary Greening Investment**		**Log Greening Investment Share**
Expected Competitiveness	0.176*** (11.02)	0.164*** (9.65)	0.177*** (10.96)	0.0469 (1.22)
Manufacturing	0.267*** (4.59)			
Services	0.0746 (1.27)			
Other	0.104 (1.22)			
Trade	0.0732 (1.29)			
Energy Intensity ($2- < 5\%$)		0.0841 (1.71)		
Energy Intensity ($5- < 10\%$)		0.164** (3.13)		
Energy Intensity ($10- < 20\%$)		0.188** (3.16)		
Energy Intensity ($\geq 20\%$)		0.199** (2.83)		
Industry FE			✓	✓
Firm controls	✓	✓	✓	✓
Constant				-1.374*** (-5.15)
Observations	4202	3364	4079	985
R^2				0.083
Adj. R^2	0.0387	0.0373	0.0583	

Table A7: Expectations of Future Competitiveness and Greening Investment

Note: The table shows results from regressing binary greening investment (columns (1)-(3)) and the greening investment share (columns (4)-(5)) on an indicator of firms' negative expectations of competitiveness. The latter is a categorical variable with five options increasing in the degree of negative expectations for firm competitiveness. The survey question is "How do you think the planned transformation of the German economy towards climate neutrality will affect the competitiveness of your company?". Logit regressions show average marginal effects. Firm controls are firm age, firm size (employees), east Germany fixed effect. Checkmarks indicate fixed effects included. Adj. R^2 is McFadden's adjusted pseudo measure. Estimates for energy intensity relative to the base category $< 2\%$; sector estimates are relative to the construction sector. t statistics in parentheses. Levels of statistical significance as follows: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

B Quantitative Model

B.1 Financing Constraints

In this section we show how the intuition for stylized financing constraints can be derived when augmenting the firm problem with capital k and borrowing b. In addition to the assumptions from the main paper, firms make capital choices and can borrow at price q. Financial frictions are introduced with a standard borrowing constraint (31), following Jo and Senga (2019) and dividends D cannot be negative. The discount factor of capital is δ, the Lagrange multiplier of the borrowing constraint $\lambda > 0$ and the leverage factor of borrowing is θ. The inter-temporal firm problem now comprises idiosyncratic states z, k, b and the firm value is denoted V.

We shown that there is a negative relationship between the firm's cash-on-hand (which collapses to profits in our quantitative model in the main section) and the cost of financing.

$$V(z,k,b) = \max_{l,\,k',\,b'} \Big\{ p\,y - w\,l - fw - qb + (1-\delta)k + b' - k' + \beta \mathbb{E} V(z',k',b') \Big\} \tag{27}$$

$$\text{s.t.} \tag{28}$$

$$D \geq 0 \tag{29}$$

$$y = \exp(z)\, l^{\alpha} k^{\gamma}, \quad \alpha + \gamma \leq 1 \tag{30}$$

$$b' \leq \theta k', \quad \theta \in [0,1] \tag{31}$$

The first order conditions with respect to labour, capital and borrowing are found as follows.

$$p\,\alpha \exp(z)\, l^{\alpha-1} = w \tag{32}$$

$$\beta \mathbb{E}\big[p\, \partial y(z',k')/\partial k' + (1-\delta) - \theta\lambda\big] = 1 \tag{33}$$

$$q = \lambda + \beta \tag{34}$$

We define cash-on-hand m as follows. Note that for a given productivity level, labour is determined as well and cash-on-hand $m(k,b)$ depends on capital and borrowing.

$$m(z,k,b) = p\,y - w\,l - fw - qb + (1-\delta)k \tag{35}$$

Following Jo and Senga (2019), we determine a threshold level $\bar{m}$ above which firms have enough cash-on-hand to be unconstrained and below which firms are constrained. Constrained firms do not pay dividends so that the threshold is found by focusing on optimal capital choices k'^{*} and substituting the binding borrowing constraint into the budget constraint.

$$0 = m + \theta k' - k' \tag{36}$$

$$\bar{m}(k) = (1-\theta)k'^{*} \tag{37}$$

For a constrained firm at given productivity (see (38)) it thus holds that cash-on-hand lies below the threshold level and debt financing costs q are higher than for an unconstrained firm (see (39)). The constrained firm's additional cost of financing arises due to the binding borrowing constraint (which implies that $\lambda = 0$). The additional wedge in the cost of borrowing that a constrained firm faces (relative to an unconstrained firm) is thus the additional cost that comes precisely from the constrained firm's status. Note further, that the more constrained a firm is, the higher the Lagrange multiplier on borrowing λ and the higher the financing costs.

$$\text{constrained firm}: \qquad m < \bar{m} \quad \Rightarrow \quad q = \lambda + \beta \tag{38}$$

$$\text{unconstrained firm}: \qquad m > \bar{m} \quad \Rightarrow \quad q = \beta \tag{39}$$

In our model in the main paper, cash-on-hand is represented by profits alone (and cash-on-hand collapses to profits without this section's extensions). We have thus shown that there is a negative relationship between the firm's period-resources (cash-on-hand or profits) and the cost of financing when financing constraints matter.

B.2 Aggregation

We denote as $H_G(z)$ and $H_B(z)$ the distribution of green and brown firms.

Aggregate costs comprise costs by new investors - coming both from the group of incumbents (first summand of (40)) as well as entrants (second summand of (40)).[1]

$$Cost = \int_{z_s^I}^{\infty} c(\pi(z))\; dH_B(z) + M \int_{z_s^I}^{\infty} c(\pi(z))\; d\nu(z) \tag{40}$$

[1]Note that all aggregation happens at step 6 when this period's investment and production decisions have been made.

Aggregate labour demand comprises variable and fixed labour demand of incumbent investors and non-investors as well as entrants' labour demand and fixed entry costs.

$$L^d = \int_{z_s^G}^{\infty} [l(z) + f] \, dH_G(z) + \int_{z_s^B}^{\infty} [l(z) + f] \, dH_B(z) \; + M \int_{z_s^E}^{\infty} l(z) \, d\nu(z) + M f_e \tag{41}$$

Aggregate output comprises output by investors and non-investors as well as entrants' output.

$$Y = \int_{z_s^G}^{\infty} y(z) \, dH_G(z) + \int_{z_s^B}^{\infty} y(z) \, dH_B(z) + M \int_{z_s^E}^{\infty} y(z) \, d\nu(z) \tag{42}$$

Aggregate profits Π are found as follows in terms of aggregate variables.

$$\Pi = pY - wL^d(\mu_G, \mu_B, M) - Cost \tag{43}$$

B.3 Green Equilibrium

Definition. A *green stationary equilibrium* contains aggregate price $p_g \geq 0$, a mass of entrants $M^g \geq 0$, a value function $V_{G,\kappa}$, a policy function for exit $X_G^g(z)$ as well as the measures of incumbents μ_G^g, and entrants μ_g^E, so that

1. the labour market clears: $L^s(\mu_G^g, M_g; p_g) = L^d(\mu_G^g, M_g)$
2. $V_{G,\kappa}$, $X_G^g(z)$ and $w = f_Z$ solves the firm problem in (16)
3. the measure of green incumbents evolves according to the law of motion: $\mu_G^{g\,\prime} = (1 - X_G^g)\, \mu_G^g + M^g \, \mu^E$
4. the entry condition $V_g^E \geq w f_e$ is fulfilled with equality for $M_g > 0$, where it holds that: $V_g^E(z_0) = \pi(z_0) + \frac{1}{r}\, \mathbb{E}_{z'|z_0}\left[V_{G,\kappa}(z')\right]$

References

CompNet (2020): "User Guide for the 7th Vintage CompNet Dataset," Tech. rep., The Competitiveness Research Network, available at https://www.comp-net.org/fileadmin/_compnet/user_upload/Documents/7th_Vintage/7th_Vintage_User_Guide.pdf.

Jo, I. H. and T. Senga (2019): "Aggregate consequences of credit subsidy policies: Firm dynamics and misallocation," *Review of Economic Dynamics*, 32, 68–93.