Investing in the green transition and competition from laggards

Johanna Saecker[*] Philip Schnattinger[†]

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Abstract

We study heterogeneous firms' decision-making for investment into greening their production process. Empirically, we find that an increase in labour productivity by 1% is associated with a probability increase of 2-3% of engaging in greening investment. Thus more productive and profitable firms invest more in greening. We incorporate this stylized fact into a heterogeneous firm model where a firm's decision to engage in greening investment depends positively on idiosyncratic firm productivity. We show that the decision also depends negatively on the degree of competition in the market and positively on the probability of policymakers mandating a green production process in the future. All three decision margins are rationalised in a parsimonious small model. Comparing stationary equilibria in the full model under perfect competition, we verify that a higher probability of a green policy mandate increases the share of firms engaging in greening investment and that competition from non-investors decreases the share of firms engaging in greening investment.

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

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1 Introduction

The green transition[1] requires firms to invest in the reduction of carbon emissions originating in the production process[2]. We call this *greening investment*[3]. In this paper, we study the decision-making problem of firms' greening investment. We find a negative effect on the share of firms investing in greening stemming from competition with non-investors (*laggards*). This is due to a price channel where competition from laggards decreases the aggregate price level and prevents the marginal firm from engaging in greening investment. We will explore the implications of this channel for the policy-maker's optimal green transition policy in a stationary equilibrium as well as along a transition path. To our knowledge, we are the first to combine a heterogeneous firm model for the green transition with the question in how far competition from laggards of greening policies affects desired outcomes.

In our empirical section, we use UK firm data to uncover basic firm facts of greening investment. We merge data about firms' CO2-reduction spending from the Business Insights and Conditions Survey (BICS) of UK firms with firm data from the Annual Business Survey (ABS) to retrieve a dataset of 27,011 firms. Our main fact is that across all firms we find that an increase of labour productivity by 1% is associated with a probability increase of 2-3%-points of engaging in greening investment. We incorporate this fact in a small two-period model in which firms decide to invest in greening in the first period and where production in the second period depends on a green policy shock entering into effect with a certain probability. If the policymaker mandates greening investment in the second period only first period investors can produce. We show that an increase in firms' expectation of a green policy shock increases the share of firms investing. Lower competition today decreases market prices in the economy, as well as the cost of greening investment and thus increases the share of investors. Similarly, lower expected competition tomorrow, increases expected profits tomorrow and thus the share of investors.

We furthermore build a dynamic firm model in the spirit of Hopenhayn and Roger-

[1] Note that we use the terms "green transition" and "transition" - towards an economy which does not emit greenhouse gases - interchangeably in this article. In the model we assume that firms will transition into the pool of transitioned firms by making a one-time greening investment.

[2] For example, the UK government estimates an additional need of yearly 50-60 billion GBP of capital investment to meet the net zero targets outlined until 2030, for which strong involvement from the private sector will be needed (UK Government, 2021, 2023).

[3] Concretely, this might include the insulation of buildings, supplementing heating and cooling systems, electrifying vehicle fleets or switching essential parts of the production process to GHG-neutral versions.

son (1993), in which we rationalise costly engagement into greening investment as an optimal intertemporal firm decision. We conceptualise future policies mandating a green production process for all firms (*green policy*) as an uncertainty shock that firms are subject to throughout the transition. In every period, firms can invest in a one-time greening investment in order to transition. However, due to the MIT-shock, in our model, if the policy materialises, non-investing firms are subject to an immediate transition cost which causes some firms to exit. The full model will be calibrated to match the UK firm data. In a stationary equilibrium, we verify the empirical fact that a higher probability of a green policy realisation increases the share of firms engaging in greening investment and we show that competition from laggards decreases the equilibrium market price and prevents the marginal firm from engaging in greening investment.

Related Literature The paper relates to four strands of the literature. First, our study is closely linked to the literature of regulation during the green transition. While a dominant strand of this literature focuses on CO2-reduction policies such as cap-and-trade systems or carbon taxes (Anouliès, 2017; Annicchiarico and Di Dio, 2015; Annicchiarico and Diluiso, 2019; Hassler et al., 2021), we contribute by focussing on mandates for engaging in greening investment[4] with firms' own funds[5]. Exploring the transition along a policy path, we will thus be able to explore the dynamic effect of future policy mandates on firms' decision-making.

Second, we contribute to the literature on regulatory uncertainty in the form of an MIT shock (Boppart et al., 2018). Building on the fact that private sector investment during the green transition is accompanied by a high degree of regulatory uncertainy (Berg et al., 2023), we conceptualise our policy mandates as an MIT shock and investigate how optimal green investment policy should be devised in an environment with regulatory uncertainty. We thus contribute to this literature on MIT shocks by analysing green transition policies in conjunction with these shocks.

Third, we add to the heterogeneous firms literature concerned with environmental questions (Anouliès, 2017; Dardati, 2016; Dardati and Saygili, 2020; Konishi and Tarui, 2015; Qiu et al., 2018). Whereas one branch of the literature focuses on CO2-reducing poli-

[4]Note that 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.

[5]In contrast to the green finance literature (see e.g. Ozili (2022) for an overview), we thus abstract from outside financing. In our model, firms face a cost function for investment that is proportional to the firm's current and future expected profitability.

cies, such as cap-and-trade and emissions taxes (Anouliès, 2017; Dardati and Saygili, 2020; Konishi and Tarui, 2015), we contribute by focussing on another form of regulation. In addition, we add a new transmission channel in this literature, namely via a competition effect.

Fourth, our study is most closely linked to a nascent literature linking questions of environmental regulation with competition effects. Jondeau et al. (2023) build an Integrated Assessment Model with an abatement sector selling abatement services to other producers. While, their key mechanism equally works via a competition effect that is affected by subsidies, it plays out only in the small and growing abatement sector, whereas we focus on the role of the competition effect in affecting the required engagement of all firms to invest in greening their production process.

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 main competition effect central to our analysis. Consequently, the full model and the two experiments are outlined. Next, the policy-maker's optimal strategy will be analysed. Last, we conclude.

2 Greening investment

Using UK firm data, we show that an increase of labour productivity by 1% is associated with a probability increase of 2-3%-points of engaging in greening investment.

2.1 Data

We collect the data from the Business Insights and Conditions Survey (BICS) and merge it with data from the Annual Business Survey (ABS). The BICS is a fortnightly voluntary survey of UK businesses sampled from the inter-departmental business register. We use an unweighted sample of firms. Firms can answer multiple times. If this is the case, we keep only the firm's most recent non-missing answer to our question of interest (see below). The ABS is a survey of financial data from UK businesses' end-year accounts. We use ABS waves 2018 to 2020 and keep the most recent observation for every firm.

From the BICS we use the question "Which of the following actions, if any, have you taken to reduce your business's carbon emissions?" which was asked 10 times from 2021 until February 2023 (see appendix for details). We construct two greening investment dummy variables, cinvt1 and cinvt2, according to table 1. Each dummy was recorded as "1" if the firm reported engaging in at least one of the activities indicated with a cross in the respective column. The

BICS answers	Investment	cinvt1	cinvt2
No actions have been taken to reduce emissions	none	0	0
Not sure[6]	n.a.	n.a.	n.a.
Adjusting heating and cooling systems	low	x	
Going paperless	low	x	
Electrifying your vehicle fleet	high	x	x
Installing a smart meter	low	x	
Installing charging points	low	x	
Installing your own renewable electricity or heating	high	x	x
Insulating your buildings	high	x	x
Introducing a cycle to work scheme	low	x	
Switching to LED bulbs	low	x	
Other	low	x	
Does not have emissions	n.a.	n.a.	n.a.

Table 1: Construction of green investment dummies cinvt1 and cinvt2
Variables are one if firm reported engaging in at least one of the activities indicated by a cross, zero if first answer was chosen, and missing otherwise.

dummy was recorded as "0" if the firm reported to not have taken any actions, and missing otherwise, i.e. no answer was chosen or only one of the options indicated with "n.a.". Variable cinvt1 contains all possible firm investment whereas cinvt2 only contains high cost investments. Furthermore, we construct two measures of labour productivity llprod_bics and llprod_abs. The former uses BICS data on turnover, and employment (in number of employees) and is the logarithm of turnover over employees. The latter uses ABS data on approx. general value added (GVA) at basic prices over employment.

Our dataset consists of 27,014 observations. The final dataset for our first productivity measure llprod_bics consists of 27,011 observations and of 10,234 for our second productivity measure llprod_abs. There are three firms which only report the latter but not the former. Firms in our dataset are from the following sectors (letter codes in brackets)[7]: Manufacturing (C), Water Supply and Sewage (E), Construction (F), Wholesale and Retail Trade (G), Transportation and Storage (H), Accommodation and Food Service Activities (I), Information and Communication (J), Real Estate (L), Professional, Scientific and Technical Activities (M), Administrative Activities (N), Education (P), Human Health and Social Work (Q), Arts, Entertainment and other services (RS). There is a positive correlation between productivity and firm size (number of employees) only for the sectors M, J, I, H, G, F, E, C. Firms engaging in greening investment are more productive across productivity

[7]Note that we use short versions of the official sector description names. The full descriptions can be found in the appendix in table A1.

Variable		firm size quartiles (employees)			llprod1_bics		llprod3_abs	
		Q1	Q2	Q3				
statistic		N	N	N	N	mean	N	mean
cinvt1	1	5,655	7,197	7,719	20568	4.3862	8752	3.7715
	0	3,458	1,718	1,267	6443	4.1065	1482	3.5145
Total		9,113	8,915	8,986	27011	4.3195	10234	3.7343
cinvt2	1	1,579	2,660	3,406	7645	4.5625	3888	3.8002
	0	7,534	6,255	5,580	19366	4.2236	6346	3.6939
Total		9,113	8,915	8,986	27011	4.3195	10234	3.7343

Table 2: Summary statistics

Note: firm size quantiles in terms of employees are as follows: Q1: 1-23 employees, Q2: 24-84 employees, Q3: 85-269,351 employees.

measures and greening investment measures. For both greening measures, the share of firms investing increases with firm size. The share of firms engaging in low investments is higher than those not in all sectors, whereas it is the converse for high investments in all sectors. The shares, however, differ across sectors.

2.2 Firm facts

Across all observations (table 4), there is a positive relationship between productivity and greening investment for both investment variables and productivity measures. An increase of labour productivity by 1% is associated with a probability increase of 2-3%-points of engaging in greening investment. Looking at individual sectors (table 3), there is a positive correlation between productivity and high greening investment for the sectors of Trade (G), Transportation (H) and Administrative Support (N). A labour productivity increase of 1% is associated with a 1-7%-points higher probability of engaging in greening investment. In sectors H and N, the probability of engagement is higher for low investment than high investment actions.

Across all observations (table 4), an increase in firm size is associated with an increase in probability of engaging in greening investment. Across all sectors (table 3), where significant, an increase in firm size within the sector is associated with a higher marginal effect on the probability of engaging in greening investment. However, for the BICS probability variable, the additional increase in probability of climate engagement when moving from one to the next size category are higher for the high cost greening investment variable - which might depend more on firm size.

sector code	C	E	F	G	H	I
sector name	Manufact.	Water	Construct.	Trade	Transport	Accommod.
llprod1_bics	0.0179***	0.0580*	0.0381***	0.0122**	0.0576***	0.00635
	(3.42)	(2.50)	(4.32)	(2.75)	(5.05)	(0.61)
size group 2	0.100***	0.274***	0.271***	0.156***	0.172***	0.0582**
	(7.32)	(3.98)	(11.53)	(10.48)	(5.33)	(2.90)
size group 3	0.144***	0.328***	0.314***	0.201***	0.227***	0.129***
	(11.33)	(5.03)	(13.70)	(14.08)	(7.31)	(6.86)
N	4210	241	2170	4730	1185	2520

J	L	M	N	P	Q	RS
Information	Real Estate	Scientific Act.	Admin.	Education	Health	Entertainm.
0.0140	0.000122	0.0365***	0.0454***	0.00802	-0.0341	-0.00752
(1.65)	(0.01)	(5.37)	(7.54)	(0.70)	(-1.24)	(-0.77)
0.201***	0.134*	0.227***	0.177***	0.180***	0.0593	0.171***
(7.28)	(2.24)	(12.23)	(8.26)	(4.51)	(1.59)	(5.87)
0.290***	0.182**	0.279***	0.206***	0.316***	0.148***	0.250***
(10.94)	(3.16)	(15.33)	(9.65)	(9.60)	(4.24)	(9.26)
1809	332	3863	2984	723	857	1387

t statistics in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3: Sectoral logit regressions for investment (cinvt1)

Logit regressions of productivity and firm size dummies on cinvt1, for each sector separately. Table shows average marginal effects of firm size and productivity on the probability of investment (cinvt1).

The relevance of productivity on greening investment seems to be most relevant in sectors Manufacturing (C), Trade (G) and Arts and Entertainment (RS).

	(1) cinvt1	(2) cinvt1	(3) cinvt1	(4) cinvt2	(5) cinvt2	(6) cinvt2
llprod1_bics	0.0286***	0.0258***	0.0242***	0.0341***	0.0390***	0.0266***
	(13.04)	(13.02)	(11.31)	(12.96)	(17.26)	(10.56)
E	-0.125***		-0.132***	0.0176		0.0216
	(-4.28)		(-4.55)	(0.55)		(0.72)
F	-0.124***		-0.0782***	-0.0197		0.0292*
	(-11.27)		(-7.41)	(-1.59)		(2.38)
G	-0.0670***		-0.0375***	-0.0630***		-0.0281**
	(-8.17)		(-4.45)	(-6.41)		(-2.91)
H	-0.134***		-0.128***	-0.0781***		-0.0617***
	(-9.62)		(-9.09)	(-5.19)		(-4.28)
I	-0.0245**		-0.00372	-0.111***		-0.0900***
	(-2.66)		(-0.39)	(-8.95)		(-7.57)
J	-0.196***		-0.149***	-0.199***		-0.161***
	(-15.85)		(-12.27)	(-17.29)		(-13.75)
L	-0.106***		-0.0650**	-0.0874***		-0.0462
	(-4.40)		(-2.86)	(-3.35)		(-1.76)
M	-0.189***		-0.136***	-0.185***		-0.143***
	(-20.33)		(-14.60)	(-18.97)		(-14.58)
N	-0.171***		-0.170***	-0.133***		-0.118***
	(-16.70)		(-16.29)	(-12.06)		(-11.13)
P	-0.0240		-0.0313*	-0.0295		-0.0379*
	(-1.64)		(-2.01)	(-1.48)		(-2.10)
Q	-0.0991***		-0.0876***	-0.166***		-0.145***
	(-6.39)		(-5.52)	(-10.32)		(-9.28)
RS	-0.0675***		-0.0378**	-0.0889***		-0.0587***
	(-5.52)		(-3.17)	(-5.91)		(-3.99)
size group 2		0.180***	0.165***		0.117***	0.108***
		(27.25)	(25.08)		(18.75)	(17.19)
size group 3		0.233***	0.222***		0.198***	0.189***
		(37.08)	(35.20)		(30.42)	(28.83)
N	27,011	27,011	27,011	27,011	27,011	27,011

t statistics in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4: Logit regressions for investment (cinvt1 & cinvt2)
Logit regressions with productivity, sectoral dummies and firm size dummies. Average marginal effects.

3 A Small model

We illustrate our key mechanisms in a simple two-period model. We show that a fall in expected as well as current period's competition increases the share of green investors; equally does an increase in the probability of a green policy enactment. In this simple model, firms decide whether to invest in adopting green production processes during the first period. They are subject to a green policy shock in the second period which makes regulation more stringent with probability κ. After the shock, only those firms produce that invested in greening their production process during the first period. We assume that competition from N other firms has a negative consequence on the profit π of a firm, $\frac{\partial \pi}{\partial N} < 0$, whereas increases in productivity z has a positive, $\frac{\partial \pi}{\partial z} > 0$ Firms have idiosyncratic productivity drawn from a distribution $H(z)$. Greening investment $c(\pi_1)$ has a negative impact on profits, $\frac{\partial c}{\partial \pi} < 0$ and, conditional on a green policy realisation of probability κ, determines firms' ability to produce in the second period. Firm value is determined as follows depending on firms investing or not.

Firm value (with greening investment):

$$\pi_1(z, N_1) + \kappa\ \pi_2(z, N_2) + (1 - \kappa)\ \pi_2(z, N_2) - \ c(\pi_1(z, N_1)) \tag{1}$$

Firm value (no greening investment):

$$\pi_1(z, N_1) + (1 - \kappa)\ \pi_2(z, N_2) \tag{2}$$

Firms' investment choice depends both on idiosynractic firm productivity z (constant across periods) and competition, i.e. the amount of competitors in each period (N_1, N_2). Firms engage in greening investment if profits under a green policy realisation are higher than investment costs (equation (3)). Consequently, firms are less likely to invest if they expect a green policy realisation to be unlikely or if investment costs are small.

$$\kappa\ \pi_2(z, N_2) > c(\pi_1(z, N_1)) \tag{3}$$

Conditional on other variables being exogenous, the investment cutoff $\tilde{z}$, i.e. the productivity level at which the firm is indifferent between engaging into climate investment or not, is thus given by equation (4).

$$\kappa\ \pi_2(\tilde{z}, N_2) = c(\pi_1(\tilde{z}, N_1)) \tag{4}$$

Assuming the functional forms and parameters given in table 5, we next show the effect of a decrease in competition in both periods.

Explanation	Functional Form	
Production function	$y = p\ z$	
Cost function	$c(\pi) = \frac{c}{p\ z}$	
Profit function	$\pi = p\ z - f$	
Demand side	$p = N^{\frac{1}{1-\sigma}}$	
Productivity distribution	$z \sim$ Pareto(1.5) over $[z_{min}, \infty)$	
Explanation	**Parameter**	**Values**
Cost of production	f	1
Elasticity of substitution parameter	σ	3
Cost function parameter	c	2

Table 5: Small model assumptions: parameters and functional forms

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

Proof. Show that $\frac{\partial \tilde{z}}{\partial N_1} > 0$. Using equation (4), we define function F

$$F(N_1, N_2, \tilde{z}) = \kappa\ (p_2(N_2)\ \tilde{z} - f) - \frac{c}{p_1(N_1)\ \tilde{z}} \tag{5}$$

and since $\sigma > 1$

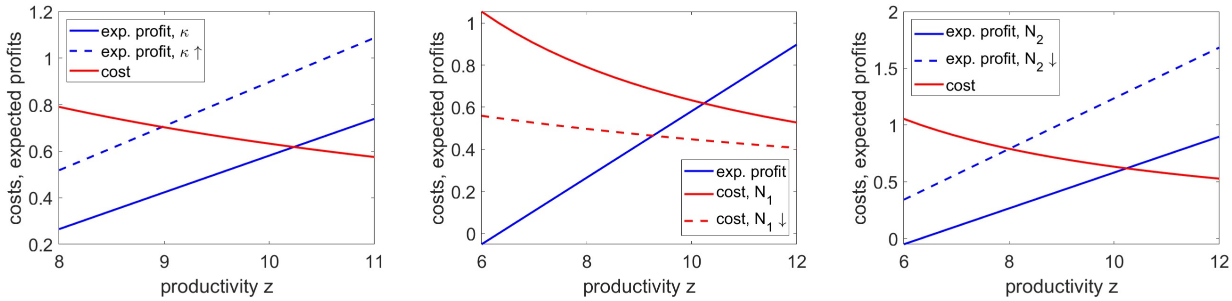
$$\frac{\partial \tilde{z}}{\partial N_1} = -\frac{\partial F}{\partial N_1}\left(\frac{\partial F}{\partial \tilde{z}}\right)^{-1} = \frac{1}{\sigma - 1}\frac{c}{N_1^{\frac{-\sigma}{1-\sigma}}\tilde{z}}\left(\kappa p_2 + \frac{c}{p_1 \tilde{z}^2}\right)^{-1} > 0 \qquad q.e.d. \tag{6}$$

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

Proof. Show that $\frac{\partial \tilde{z}}{\partial N_2} > 0$. We use function F to show that

$$\frac{\partial \tilde{z}}{\partial N_2} = -\frac{\partial F}{\partial N_2}\left(\frac{\partial F}{\partial \tilde{z}}\right)^{-1} = \frac{1}{\sigma - 1}N_2^{\frac{-\sigma}{1-\sigma}}\kappa\tilde{z}\left(\kappa p_2 + \frac{c}{p_1 \tilde{z}^2}\right)^{-1} > 0 \qquad q.e.d. \tag{7}$$

Figure 1 shows the competition effect (figure 1(b), figure 1(c)) as well as the effect of a change in the green policy probability (figure 1(a)) in the small model for different productivity levels. For a given productivity level, firms engage in greening investment if gains (blue line) are higher than costs (red line). All firms with productivity levels higher than those at the intersection of both curves engage in greening investment. A higher probability of green



((a)) Policy probability ($\kappa \uparrow$) ((b)) Competition today ($N_1 \downarrow$) ((c)) Compet. tomorrow ($N_2 \downarrow$)

Figure 1: Investment decision in the small model

Figure 1(a), shows the effect of an increase in the green policy probability κ on the the investment decision margins. Figures 1(b), 1(c) show the effect of a decrease in competition today and tomorrow.

policy shocks ($\kappa \uparrow$) increases expected profits from greening investment and thus increases the share of green investors (figure 1(a)). Lower competition today ($N_1 \downarrow$) increases the market price, lowers firm costs from greening investment and thus increases the share of green investors (figure 1(b)). Lower expected competition tomorrow ($N_2 \downarrow$) increases tomorrow's expected profits and thus the benefit from today's greening investment (figure 1(c)).

4 The Full Model

In the dynamic model, we, first, verify our mechanism comparing stationary equilibria, and, second, show the adjustment process of the economy along a green transition policy path (MIT-shock) in a sequential equilibrium from one stationary equilibrium to another. We will thus be able to explore the dynamic implications of how competition from laggards prevents investment from potential investors and pin down an optimal policy path.

Our model is a firm dynamics model in the spirit of Hopenhayn (1992). Firms aim to maximise their present discounted value of future profits by choosing inputs into production and optimal entry and exit. Among the inputs to choose from there is labour l_i and investment into greening the production process g_i. Higher labour input increases current output, while increasing greening investment serves to avoid future cost when a greener production process is mandated (*green policy*).

4.1 Profit maximisation

Firms maximise current period profits π_i given by equation (8) by choosing prices p_i and labour input l_i optimally, given the production function in equation (9). Output is denoted by y_i, the labour share by α and idiosyncratic productivity by z_i. In order to produce, firms need to pay a fixed production cost f valued in labour units. The wage w is constant.

$$\max_{l_i,p_i} \pi_i = p_i y_i - w l_i - f w \tag{8}$$

$$y_i = \exp(z_i) l_i^{\alpha} \tag{9}$$

Optimal price

The optimal price in equation (10) is found as markup $\mathcal{M}$ times marginal cost mc_i. The markup differs depending on our assumption about how differentiated goods enter the household's utility function (see appendix A.2.1 for derivations).

$$p(z_i) = \mathcal{M}\, mc_i \tag{10}$$

$$\text{perfect competition:} \qquad \mathcal{M} = \mu = 1 \tag{11}$$

$$\text{CES:} \qquad \mathcal{M} = \mathcal{M} = \frac{\sigma}{\sigma - 1} \tag{12}$$

$$\text{translog:} \qquad \mathcal{M}(N) = \left(1 + \frac{1}{\gamma N}\right) \tag{13}$$

Marginal cost

Cost minimisation gives the marginal cost of an additional goods unit as in equation (14).

$$mc_i = \frac{w}{MPL_i} = \frac{w}{\alpha \exp(z_i) {l_i}^{\alpha-1}} \tag{14}$$

Optimal labour input

Optimal labour input is the result of equating the marginal benefit of labour input $p_i y(l_i)$ to the marginal cost of labour w.

$$p_i \alpha \exp(z_i) {l_i}^{\alpha-1} = w \tag{15}$$

Competition effect

The current price level is a function of the markup $\mathcal{M}$. The more firms there are, the lower markups and thus the aggregate price level (competition effect). Using a translog expenditure function, the inverse relationship between firm numbers and markups is explicitly incorporated into the formula for markups (see equation (13)) (see appendix A.2.1 for derivations).

4.2 Green policy

Each period, the green technology will be mandated from that period onward for production with probability κ. At this point firms not having implemented the technology will have to face a present discounted cost c_g for not investing. When $c_g \geq v'_{i,\kappa}$ firms that have not invested exit.

4.3 Investment decision

Firms choose greening investment $g_i \in \{0,1\}$ to maximise the present discounted value of profits. Firms need to make a greening investment $c(\pi)$ once in order to enter the pool of firms which have adapted their production process. Investment is a one-directional decision, i.e. firms can only "switch" the state of g_i from zero to one once [8]. Every firm which has invested into the green technology in any of the previous periods permanently continues with the state variable $g_i = 1$. The size of the investment costs depends on profits and it holds that $\partial c/\partial \pi > 0, \partial^2 c/\partial \pi^2 > 0$. The parameter ζ is a scaling parameter for different investment needs (e.g. for different sectors).

The value function [9] for firms in the pool of non-investors follows equation (16). Note that this includes newly entered firms as well as incumbents. These firms had not invested yesterday and if the firm chooses not do so again this period a green policy shock next period has a negative consequence on firm value. In case of non-investment and no green policy, the firm is in exactly the same position again tomorrow (see v'_i in second argument of (16)).

$$\max_{g_i'} v_i = \Big\{ \pi_i - g_i' \zeta c(\pi_i) + \frac{1}{r} E[(1-\kappa) v'_{i,g} + \kappa v'_{i,g,\kappa} | z_{i,g} > z_{s,g}], \\ \pi_i + \frac{1}{r} E[(1-\kappa) v'_i + \kappa (v'_{i,\kappa} - c_g) | z_i > z_s] \Big\} \tag{16}$$

Value function equation (17) describes firms that have not invested last period, face a green policy shock today and enter into the pool of investing firms.

$$v_{i,\kappa} = \pi_i + \frac{1}{r} E[(1-\kappa) v'_{i,g} + \kappa v'_{i,g,\kappa} | z_{i,g} > z_{s,g}] \tag{17}$$

[8] We can think of it as a matrix of zero's and one's over firm productivity permanently recording which firm has already invested. The transition manifests as the amount of one's in the matrix growing, i.e. ever more firms switching from zero to one.

[9] Firm value functions v_i are indexed by additionally g if firms decided to invest last period and by κ if the firm faces a green policy shock in the current period.

Value function equation (18) describes firms that have invested last period. Their value function is not influenced by green policy shocks anymore.

$$v_{i,g} = v_{i,g,\kappa} = \pi_i + \frac{1}{r} E[v'_{i,g,\kappa} | z_{i,g} > z_{s,g}] \tag{18}$$

Note that the decision to invest specifies a productivity cutoff value $z_{s,g}$ above which firms will invest and below which they will not. Further, r is the risk-free rate.

4.4 Timing

We adopt the naming convention of Hopenhayn and Rogerson (1993) where all choice variables within the period are denoted without prime except for the intertemporal forward-looking investment decision variable.

1. States at beginning of period: z_{-1}, g, $\mu_{-1}(z_{-1}, g)$, which gives N_{-1}, N_{n-1}, N_{i-1}.
2. All firms (whether transitioned or not) make exit/stay choices based on yesterday's state variables (z_{s-1} is determined).
3. An exit shock forces each remaining firm to exit with probability δ.
4. *The distribution of incumbents $\mu_{-1}(z_{-1}, g)$ with both transitioned and non-transitioned firms is cut, firm mass shrinks.*
5. New firms from $\nu(z_{-1})$ enter into production (as non-transitioned) based on expected firm value[10] (${z_s}^E_{-1}$ is determined).
6. All firms draw productivity z.
7. *The aggregate state of the economy is described by firm distribution $\mu(z, g)$ and $M\nu(z)$. N is determined here (it determines firms' production and investment choices).*
8. All firms make static labour and price choices. They depend on N.
9. Non-transitioned firms (incumbents and entrants) make intertemporal investment choices g'.
10. *The total amount of firms in the economy is still N. Now, N_i and N_n can be determined.*
11. Aggregation and household decision.
12. All firms receive profits.

[10]In the stationary equilibrium: as many firms are entering as were exiting in the first step. In the transitional equilibrium: no restriction.

13. New firms are added to the distribution $\mu(z, g')$.

4.5 Productivity, entry and exit

Law of motion for productivity

Idiosyncratic firm productivity follows an AR(1) process in logs, where $\varepsilon_z \sim \mathcal{N}(0, \sigma_z)$ and $\rho_z > 0$. Note that $0 < \delta < 1$ is the amount of firms hit by an exit shock every period.

$$\log(z') = \rho_z \log(z) + \varepsilon_z \tag{19}$$

Exit

At the beginning of each period, firms exit if the expected discounted firm value is smaller than zero. The exit condition (here, for the beginning of next period) thus is

$$v_x < 0, \quad \text{where} \quad x \in \{i, \{i, g\}, \{i, g, p\}, \{i, p\}\} \tag{20}$$

Entry

There is an unbounded set of possible entrants. In timing step 5, firms draw a productivity level z_i from the probability distribution $\nu(z_i)$ and pay a fixed entry cost f_e valued in labour units. Firms enter if the expected value of entering $v_i{}^E({z_s}^E)$, namely the expected firm value based on the firm's expected production and investment decisions given the idiosyncratic productivity shock hitting in timing step 6, equals the entry cost. If $z_i < {z_s}^E$, firms choose to immediately exit again. The marginal entrant has productivity ${z_s}^E$ and determines the entry condition equation (21). Like in Hopenhayn and Rogerson (1993), we assume that entrants do not have to pay fixed production costs (giving us a profit function π^E different from equation (8)). Entering firms immediately enter into the pool of non-investors, but however, are subject to the idiosyncratic productivity shock in the same period, and can then make investment decisions. Also, entrants will be equal to incumbents in every following period (see next period's value functions in 22).

$$v_i^E({z_s}^E) - w f_e = 0 \tag{21}$$

$$\begin{aligned} \max_{g_i'} v_i^E = E\Bigg\{ & {\pi^E}_i - g_i'\zeta c({\pi^E}_i) + \frac{1}{r}\left[(1-\kappa)v'_{i,g} + \kappa v'_{i,g,p} \middle| z'_{i,g} > z'_{s,g}\right], \\ & \pi_i + \frac{1}{r}\left[(1-\kappa)v'_i + \kappa(v'_{i,p} - c_g) \middle| z'_i > z'_s\right]\Bigg\} \end{aligned} \tag{22}$$

Firm distribution

Note that (timing step 7.) each firm is characterized by a pair (z_i, g_i) and the mass of all incumbent firms by the distribution $\mu(z_i, g_i)$ over such pairs. Note that N is the total number of firms once exit and entry have taken place. N includes both incumbents (first summand) and entrants (second summand). Once investment decisions are made, denote the number of transitioned firms N_i and the number of firms that have not done so N_n, so that (26) holds (timing step 10.). In a stationary equilibrium, we restrict the number of entering firms to be equal to the number of exiting firms as to keep N constant in equilibrium. Note that $g_i' = 1$ includes both firms which invested in this period as well as in previous periods.

$$N = \int_{z_s-1}^{\infty} \mu(z_i, g_i = 0)\, dz_i + \int_{z_s-1}^{\infty} \mu(z_i, g_i = 1)\, dz_i + M \int_{z_s{}^E-1}^{\infty} \nu(z_i)\, dz_i \tag{23}$$

$$N_i = \int_{z_s-1}^{\infty} [\mu(z_i, g_i)|g_i' = 1]\, dz_i + M \int_{z_s{}^E-1}^{\infty} [\nu(z_i)|g_i' = 1]\, dz_i \tag{24}$$

$$N_n = \int_{z_s-1}^{\infty} [\mu(z_i, g_i)|g_i' = 0]\, dz_i + M \int_{z_s{}^E-1}^{\infty} [\nu(z_i)|g_i' = 0]\, dz_i \tag{25}$$

$$N = N_n + N_i \tag{26}$$

4.6 Household

Households maximise the present discounted value of utility equation (27) subject to the aggregate constraint equation (28). Mv^E is the spending on new entrants, C covers consumption and $wL + \Pi$ income from labour L, and aggregate firm profits Π. Note that B is investment in all firms except entrants, where we assume $B = B' = 0$ in equilibrium. Timing-wise, household decisions are made just before profits are received. Note that $u(.)$ is a continuous, twice differentiable function which fulfills the Inada conditions and $f_L > 0$.

$$U = \max_{C_t,\, L_t,\, B_{t+1}} E_t \sum_{t=0}^{\infty} \beta^t \Big\{ u(C_t) - f(L_t) \Big\} \tag{27}$$

$$PC + M\ v^E + B = wL + \Pi + rB' \tag{28}$$

$$w = f_L \tag{29}$$

$$u_C = \beta r E u_{C'} \frac{P}{P'} \tag{30}$$

In a stationary equilibrium, the parameter w will thus be determined as in (29) and following (30) (and as aggregate prices are constant) it needs to hold that household discounting is determined as $\beta = 1/r$, i.e. household and firm discounting need to be the same. We further assume aggregate demand to be fixed, i.e. $C = Y(P) = \bar{Y}$.

$$L^s = L = \frac{1}{w}\left(P\,\bar{Y} + Mv^E - \Pi\right) \tag{31}$$

4.7 Aggregation

Aggregate [11] costs comprise costs by incumbents which did not invest yesterday but do so today ($\mu(z_i, g_i = 0|g_i' = 1)$) as well as entrants which invest today.

$$Cost = \int_{z_s-1}^{\infty} c(\pi_i(z_i))\; d\mu(z_i, g_i = 0|g_i' = 1) + M\int_{z_s{}^E-1}^{\infty} [c(\pi_i(z_i))|g_i' = 1]\; d\nu(z_i) \tag{32}$$

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 [12].

$$\begin{aligned} L^d = \int_{z_s-1}^{\infty} [l(z_i) + f]\; d\mu(z_i, g_i|g_i' = 0) + \int_{z_s-1}^{\infty} [l(z_i) + f]\; d\mu(z_i, g_i|g_i' = 1) + \\ M\int_{z_s{}^E-1}^{\infty} l(z_i)\; d\nu(z_i) + Mf_e \end{aligned} \tag{33}$$

Aggregate output comprises output by investors and non-investors as well as entrants' output. Note that, in contrast to Hopenhayn and Rogerson (1993), we do not consider "net output" (net of fixed production costs) since all our fixed costs are measured in labour units.

$$Y = \int_{z_s-1}^{\infty} y(z_i)\; d\mu(z_i, g_i|g_i' = 0) + \int_{z_s-1}^{\infty} y(z_i)\; d\mu(z_i, g_i|g_i' = 1) + M\int_{z_s-1}^{\infty} y(z_i)\; d\nu(z_i) \tag{34}$$

Under perfect competition, the aggregate price is reduced to being a parameter independent of idiosyncratic firm decisions. Under the Dixit-Stiglitz setup (and the translog setup), we assume a fixed aggregate demand $\bar{Y}$ and retrieve the corresponding aggregate price P.

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

$$\Pi = P\bar{Y} - wL^d(\mu, M) - Cost \tag{35}$$

4.8 Equilibrium

In our first experiment, the economy is in steady state with a fixed probability κ of a green policy shock. We solve for the stationary equilibrium with μ being a stationary distribution.

[11] Note that all aggregation happens at step 11 when this period's investment and production decisions have been made.

[12] We do not distinguish for investors and non-investors in entrants as the distribution $\nu(.)$ which we are using does not require it.

This assumption necessitates that as many firms enter as exited in the beginning of each period. The solution algorithm searches for the price P that is consistent with this equilibrium.

Definition. A *stationary equilibrium*[13] contains aggregate prices $P \geq 0$, a mass of entrants $M \geq 0$ as well as a measure of incumbents μ, so that

1. $L^s(\mu, M; P) = L^d(\mu, M)$
2. $T(\mu, M; P) = \mu$
3. $v^E \leq w f_e$, with equality if $M > 0$

Note that, equal to Hopenhayn and Rogerson (1993), in the stationary equilibrium, we need to make the assumption that the operator $T(.)$ is linearly homogenous in μ and M jointly.

In our second experiment, we solve for a transitional equilibrium following an MIT-shock in the spirit of Boppart et al. (2018). Given a path of the green policy parameter $\{\kappa_t\}_{t=0}^{\infty}$, this models the transition of the economy from one steady state to another. The solution algorithm searches for the consistent price path $\{P_t\}_{t=0}^{\infty}$ for this transition. This transition path will result in an accompanying path for the amount of entering firms $\{M_t\}_{t=0}^{\infty}$ and exiting firms along the path.

Definition. A *sequential equilibrium* contains a sequence of aggregate prices $\{P_t\}_{t=0}^{\infty}$, a sequence of entrants $\{M_t\}_{t=0}^{\infty}$, where $M_t \geq 0 \ \forall t$, as well as a sequence of distributions $\{\mu_t\}_{t=0}^{\infty}$ such that

1. ${L^s}_t(\mu_t, M_t; P_t) = {L^d}_t(\mu_t, M_t)$
2. $T_t(\mu_t, M_t; P_t) = \mu_t$
3. ${v^E}_t \leq w f_e$, with equality if $M_t > 0$

5 Calibration

5.1 Fixed parameters

In table 6 we show the parameters that we need to calibrate. The cost function is $c(.) = \frac{c_1}{(p_i y_i)^{c_2}}$.

[13] This is defined analogously to Hopenhayn and Rogerson (1993).

Explanation	Parameter	values
Wage	w	10
Aggregate demand	$\bar{Y}$	100
Risk-free rate	r	1/0.96
Labour share	α	0.66
Cost function scaler	ς	0.1
Fixed cost of production	f	30
Fixed entry cost	f_e	20
Standard deviation of the productivity process	σ_z	0.11
Autocorrelation productivity process	ρ_z	0.85
Parameter determining the cost of greening investment	c_1	500
Parameter determining the decline the investment cost in firm value	c_2	0.1

Table 6: Full model: calibration

The table shows the calibration of the full model for the case of perfect competition.

5.2 Parameters calibrated to UK firm data

[To be completed]

6 Analysis

Comparing stationary equilibria under perfect competition with different probabilities of a green policy realisation, we replicate the finding from the small model that the share of firms engaging in greening investment increases in the green policy probability (see figure 2).

Meanwhile, the full model also shows in figure 3 that competition from non-investing firms decreases the equilibrium price in the market. This effect is greater, the more non-greened firms produce. Ultimately, this competition reduces the ability of firms on the margin to green their production process. This is illustrated with figure 4, which shows the share of additional firms that would green their production process at the price, which would exist if only greening firms were to produce.

Obviously, any policy change involves an adjustment process. We will explore this adjustment process with an MIT shock, to illustrate how competition from non-greening firms reduces the ability of firms that would be greening in the long-run to adjust their current production process until non-greening firms at the destruction margin have been cleansed.

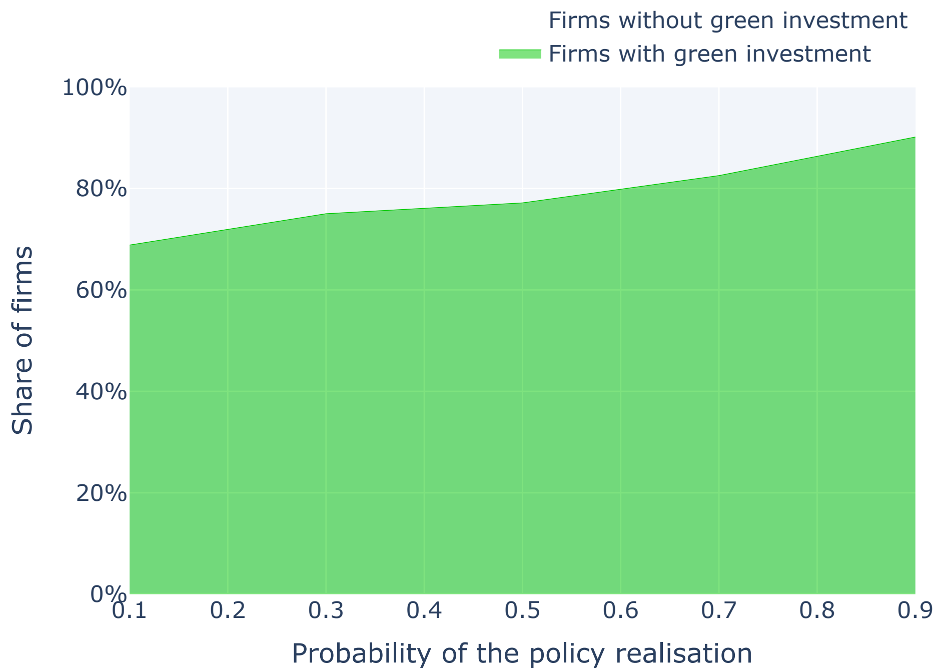


Figure 2: Share of firms engaging in greening investment

Figure 2, shows the share of firms engaging in greening investment vs. those which do not for a given probability of a green policy realisation.

Figure 3: Share of firms engaging in greening investment

Figure 3, shows how more firms producing without a greened production process makes green firms less profitable through their competition.

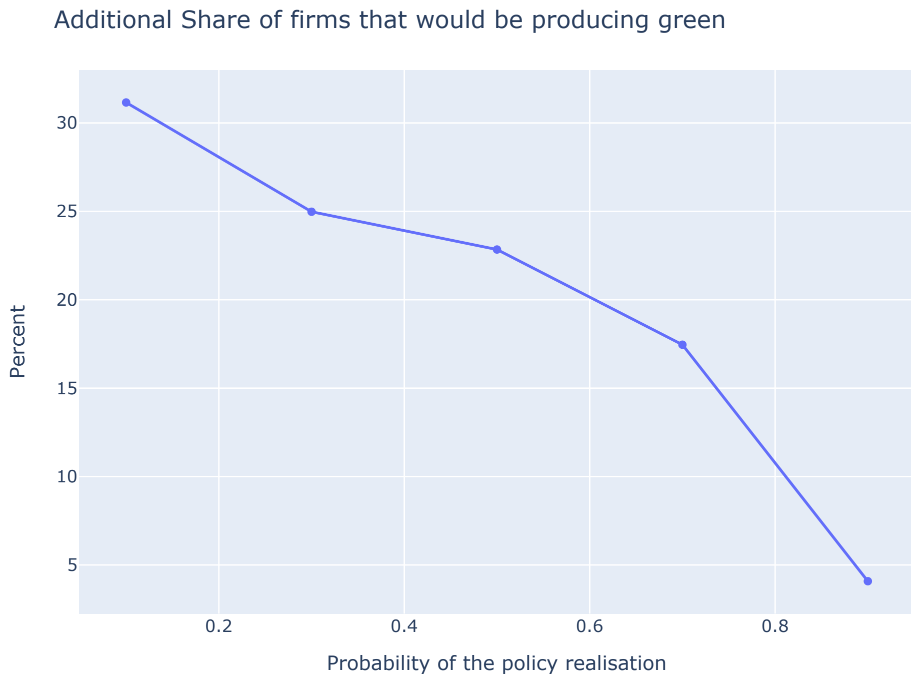


Figure 4: Share of firms engaging in greening investment

Figure 4, shows the percent increase in the share of firms that would be producing green if competition from non-greening firms were removed.

7 Optimal Green Policy

[To be completed]

8 Conclusion

We have analysed the role of competition for heterogeneous firms' investment into greening the production process. In our empirical analysis using UK firm data on investment into CO2 we found that the more productive and profitable firms invest into greening. Based on this fact, we built a heterogeneous firm model in the spirit of Hopenhayn (1992) 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 and thus the incentive to engage in greening investment. Furthermore, the probability of a green policy realisation mandating a green production process in the future positively affects firms' incentives to green. Results were in an initial stage retrieved in a model with perfect competition when comparing stationary equilibria.

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Appendix for
"Investing in the green transition and competition from laggards"

Johanna Saecker   Philip Schnattinger

February 29, 2024

Contents

A Appendix

A.1 Empirical analysis

A.1.1 Data

Sector classifications

The sectors are classified according to the UK SIC2007 classification described on the website of the ONS.

Letter code	Sector description
A	Agriculture, Forestry and Fishing
B	Mining and Quarrying
C	Manufacturing
D	Electricity, Gas, Steam and Air Conditioning Supply
E	Water Supply; Sewerage, Waste Management and Remediation Activities
F	Construction
G	Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles
H	Transportation and Storage
I	Accommodation and Food Service Activities
J	Information and Communication
K	Financial and Insurance Activities
L	Real Estate Activities
M	Professional, Scientific and Technical Activities
N	Administrative and Support Service Activities
O	Public Administration and Defence; Compulsory Social Security
P	Education
Q	Human Health and Social Work Activities
R	Arts, Entertainment and Recreation
S	Other Service Activities
T	Activities of Households as Employers; Undifferentiated Goods-and Services-Producing Activities of Households for Own Use
U	Activities of Extraterritorial Organisations and Bodies

Table A1: Sector classification according to UK SIC2007.

BICS questions

Waves	27	28	33	41	45	49	53
Dates	08.04.	22.04.	01.07.	21.10.	16.10.	10.02.	07.04.
Years	2021					2022	
No actions have been taken to reduce emissions	x	x	x	x	x	x	x
Not sure	-	x	x	x	x	x	x
Adjusting heating and cooling systems	x	x	x	x	x	x	x
Going paperless	-	-	-	-	-	-	x
Electrifying your vehicle fleet	x	x	x	x	x	x	x
Installing a smart meter	x	x	x	x	x	x	x
Installing charging points	x	x	x	x	x	x	x
Installing your own renewabl electricity or heating	x	x	x	x	x	x	x
Insulating your buildings	x	x	x	x	x	x	x
Introducing a cycle to work scheme	x	x	x	x	x	x	x
Switching to LED bulbs	x	x	x	x	x	x	x
Other	-	-	-	-	-	-	-
Does not have emissions	-	-	x	-	-	-	-

Table A2: Possible firm answers to BICS-question “Which of the following actions, if any, have you taken to reduce your business’s carbon emissions?”

Waves	59	66	71
Dates	30.06.	06.10.	15.12.
Years	2022		
No actions have been taken to reduce emissions	x	x	x
Not sure	x	x	x
Adjusting heating and cooling systems	x	x	x
Going paperless	x	x	x
Electrifying your vehicle fleet	x	x	x
Installing a smart meter	x	x	x
Installing charging points	x	x	x
Installing your own renewabl electricity or heating	x	x	x
Insulating your buildings	x	x	x
Introducing a cycle to work scheme	x	x	x
Switching to LED bulbs	x	x	x
Other	x	x	x
Does not have emissions	-	-	-

Table A3: Possible firm answers to BICS-question "Which of the following actions, if any, have you taken to reduce your business's carbon emissions?"

Sectors

	Firm size (employees, quantiles)			
sector	Q1	Q2	Q3	Total
C	752	1,650	1,809	4,211
E	47	95	99	241
F	915	720	535.0	2,170
G	1,650	1,613	1,467	4,730
H	300	473	412	1,185
I	863	873	784	2,520
J	786	529	495	1,810
L	146	95	91	332
M	1,812	1,051	1,001	3,864
N	869	873	1,242	2,984
P	165	181	377	723
Q	244	351	262	857
RS	564	411	412	1,387
Total	9,113	8,915	8,986	27,014

Table A4: Number of firms in each sector according to firm size (three quantiles of number of employees)

sector	cinvt1 0	cinvt1 1	Total	cinvt2 0	cinvt2 1	Total
C	551	3660	4211	2567	1644	4211
E	60	181	241	142	99	241
F	538	1632	2170	1360	810	2170
G	887	3843	4730	3126	1604	4730
H	319	866	1185	829	356	1185
I	472	2048	2520	1942	578	2520
J	599	1211	1810	1487	323	1810
L	84	248	332	240	92	332
M	1275	2589	3864	3139	725	3864
N	985	1999	2984	2312	672	2984
P	132	591	723	496	227	723
Q	216	641	857	691	166	857
RS	325	1062	1387	1038	349	1387
Total	6443	20571	27014	19369	7645	27014

Table A5: Number of firms in each investment category according to sector

A.1.2 Regression specifications

First, we run the following logit regressions separately for every sector.

$$Cinvt1_i = \beta_1 Lprod_i + \sum_{s \in \mathcal{S}} \beta_2^s Size_s + \varepsilon_i \tag{36}$$

where $cinvt1$ is the binary investment variable, $Size_s$ is the categorical firm size variable (3 quantiles in terms of number of employees) constructed for every sector anew and $\mathcal{S}$ is the set of all size categories. $Lprod$ is a measure of log labour productivity.

Second, we run logit regressions with productivity and investment using sectoral dummies.

$$Cinvt1_i = \beta_1 Lprod_i + \sum_{n \in \mathcal{N}} \beta_2^n Sect_n + \varepsilon_i \tag{37}$$

where variables are the same as above and $\mathcal{N}$ is the set of all sectors and Sec_n is the sector dummy for sector n taking value 1 if a firm is member of this sector. We also check for size dummies as well as sector-size dummies.

In both setups, in the robustness checks we substitute $Cinvt1$ with $Cinvt2$.

A.2 Full Model

A.2.1 Demand side: Translog expenditure function

The translog unit expenditure function is as in equation (38) and follows Feenstra (2003). The term "unit expenditure" here refers to the fact that the household's total goods expenditure, $e_t = P_t Y_t$ with $Y_t = 1$.

$$\ln e_t = \ln P_t = a_0 + \sum_{i=1}^{N_t} a_i \ln p_i + \frac{1}{2}\sum_{i=1}^{N_t}\sum_{j=1}^{N_t} b_{ij} \ln p_i \ln p_j, \quad \text{with} \quad b_{ij} = b_{ij} \tag{38}$$

Note that $\tilde{N}$ is the universe of available goods, whereas N_t is the amount of goods being produced in a given period, so that $\tilde{N} \geq N_t, \forall t$.

With the parameterisation from Feenstra (2003) which lets all goods enter symmetrically, the following assumptions need to hold.

$$a_i = \frac{1}{N_t}, \quad b_{ii} = -\frac{\gamma(N_t - 1)}{N_t}, \quad b_{ij} = \frac{\gamma}{N_t} \text{ for } i \neq j, \text{with } i, j = 1, ..., N_t \tag{39}$$

$$a_0 = \alpha_0 + \frac{1}{2}\frac{\tilde{N} - N_t}{\gamma N_t \tilde{N}} \tag{40}$$

This parameterisation makes the function homogeneous of degree one (as they fulfill the restrictions of $\sum_{i=1}^{N} a_i = 1$ and $\sum_{i=1}^{N} b_{ij} = 0$). A price increase of the individual good by a factor increases the aggregate price level by the same. Note that $\gamma > 0$ so that the price elasticity of demand exceeds unity.

Expenditure share

For the unit expenditure function take the derivative with respect to the price of each good to receive the expenditure shares $s_{i,t} = \frac{p_{i,t} y_{i,t}}{P_t Y_t}$ (Bergin and Feenstra, 2000, 2001; Lewis and Stevens, 2012).

$$s_{i,t} = \frac{\partial \ln f(p_{1,t}, p_{2,t}, ..., p_{N,t})}{\partial \ln p_{i,t}} = \alpha_i + \sum_{j=1}^{N} b_{ij} \ln p_{j,t} \tag{41}$$

Following Bilbiie et al. (2012) we consider the symmetric case in this paper, where all goods produced are the same.

$$s_{i,t} = \alpha_i + \sum_{j=1, j\neq i}^{N} b_{ij} \ln p_{j,t} + b_{ii} \ln p_{i,t} \tag{42}$$

$$s_{i,t} = \frac{1}{N_t} + (N_t - 1)\frac{\gamma}{N_t} \ln p_{j,t} - \frac{\gamma(N_t - 1)}{N_t} \ln p_{i,t} \tag{43}$$

$$s_{i,t} = \frac{1}{N_t} \tag{44}$$

The share of the total goods expenditure ($P_t Y_t$) spent on each good is symmetric and the same across goods (in the symmetric case).

Demand for goods variety

Household demand for indivdiual goods is found using Shephard's lemma, where the second equality follows since the unit expenditure function does not depend on Y_t. Under symmetry, household demand is found as in equation (46) (Lewis and Stevens, 2012).

$$y_{i,t} = \frac{\partial P_t Y_t}{\partial p_{i,t}} = Y_t \frac{\partial P_t}{\partial p_{i,t}} = s_{i,t} \frac{P_t Y_t}{p_{i,t}} \tag{45}$$

$$y_{i,t} = \frac{Y_t}{\rho_{i,t} N_t} \tag{46}$$

If competition increases and thus the number of goods produced in the economy, households demand less of each individual good.

Price elasticity of demand

The symmetric price elasticity of demand $\zeta(N_t) = -\frac{\partial y_{i,t}}{\partial p_{i,t}} \frac{p_{i,t}}{y_{i,t}} = -\frac{\partial \ln y_{i,t}}{\partial \ln p_{i,t}}$ follows as below (Feenstra, 2003). Use equation (43) to find the second equality.

$$\zeta(N_t) = 1 - \frac{\partial \ln s_{i,t}}{\partial \ln p_{i,t}} = 1 + \frac{\gamma(N_t - 1)}{s_i N_t} \tag{47}$$

Using equation (44) as well as the approximation of large N_t, we find the following expression of the price elasticity of demand like in Lewis and Stevens (2012). The natural result that an increase in competition increases the price elasticity of demand for the idiosyncratic good becomes obvious.

$$\zeta(N_t) = 1 + \gamma N_t \tag{48}$$

Markup

Using equation (48), the markup can be found as follows (compare Bilbiie et al. (2012)). An increase in competition decreases firms' markups.

$$\mu_t(N_t) = \frac{\zeta(N_t)}{\zeta(N_t) - 1} = 1 + \frac{1}{\gamma N_t} \tag{49}$$

Real price

Under symmetry, the price index P_t as well as the real idiosyncratic goods price ρ_t is derived from the unit expenditure function.

$$\ln P_t = \alpha_0 + \frac{1}{2}\frac{\tilde{N} - N_t}{\gamma N_t \tilde{N}} + N_t \frac{1}{N_t} \ln p_{i,t} + \underbrace{\frac{1}{2}\frac{N_t(N_t-1)\gamma}{N_t} \ln p_{i,t} \ln p_{i,t}}_{\text{for } b_{ij}} - \underbrace{\frac{1}{2}\frac{\gamma(N_t-1)N_t}{N_t} \ln p_{i,t} \ln p_{i,t}}_{\text{for } b_{ii}} \tag{50}$$

$$\frac{P_t}{p_{i,t}} = \exp\left(\frac{1}{2}\frac{\tilde{N} - N_t}{\gamma N_t \tilde{N}}\right) \tag{51}$$

$$\rho_t(N_t) = \frac{p_{i,t}}{P_t} = \exp\left(-\frac{1}{2}\frac{\tilde{N} - N_t}{\gamma N_t \tilde{N}}\right) \tag{52}$$

The real idiosyncratic goods price ρ is a positive function of the number of goods produced in the economy.

A.2.2 Steady state - Firm dynamics

$$\mu = (\mu E x \Pi_z + M \Pi_{ZLR})(I - gpol)$$

$$\mu_g = \mu_g E x g \Pi_z + \mu gpol$$

$$\mu = E \Pi_{ZLR}(I - gpol)(I - \Pi_z(I - gpol))^{-1}$$

$$\mu_g = \mu gpol (I - \Pi_z)^{-1}$$

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