Clean Energy Investment and Credit Rationing

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Motivation

- Climate Change is one of the greatest challenges in the 21st century.
- Decoupling of economic activity and the use of finite resources is imperative for the transition towards a low-carbon economy.
- Required additional annual investment to meet 2°C target: between $650 to $900 billion[1], 2% of GDP[2].

[1] IEA, 2012; McCollum et al., 2014; McKinsey&Co, 2010; WEF, 2013; [2] UNEP, 2011

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- Required additional annual investment to meet 2°C target: between $650 to $900 billion[1], 2% of GDP[2].
- Main barriers impeding the transition towards low-carbon economy:
  - Negative environmental externalities (GHG emissions).
  - Positive externalities from clean innovation (spillovers).
- Potential market failures on financial markets are typically not considered:
  - Largely caused by information asymmetries.
  - Risk of socially not optimal allocation (Akerlof, 1970; Stiglitz & Weiss, 1981).

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However:

- Clean energy investments rely highly on services provided by capital markets:
  - Capital costs dominate cost structure (Evans et al., 2009; Wiser et al., 1997).
  - Project finance structure (Pollio, 1998; McCrone et al., 2015).
- Information asymmetries between lenders and borrowers strong for:
  - Borrowers using relatively new technologies (Campiglio, 2016).
  - Young firms with limited prior relationship with lender (Berger & Udell, 2002; Bharath et al., 2011; Jiménez & Saurina, 2004).

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- Empirical evidence: financial sector development and access to external financing, in particular debt, are core drivers of low-carbon investments (e.g., Best, 2017; Butler and Neuhoff, 2008; Carpenter and Petersen, 2002).

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- Empirical evidence: financial sector development and access to external financing, in particular debt, are core drivers of low-carbon investments (e.g., Best, 2017; Butler and Neuhoff, 2008; Carpenter and Petersen, 2002).

$\Rightarrow$ Financial markets highly relevant for clean energy investments.

Main contribution:

- A first theoretical analysis of the impact of information asymmetries on financial markets on low-carbon investment.
- Discussion of different policy interventions to resolve this issue.

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Approach:

- Theoretical principal-agent model with information asymmetries between borrowers and lenders (e.g., Janda, 2011; Philippon and Skreta, 2012).

Model Framework

Setup

Dirty sector:

- Two types of producers, $d \in \{\underline{d}, \overline{d}\}$,
- differ w.r.t. emissions associated with output, $e_{\overline{d}} < e_{\underline{d}}$,
- with identical output, y_D.

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Clean sector:

- Two types of risk-neutral producers (borrowers), $c \in \{\underline{c}, \overline{c}\}$,
- differ w.r.t. success probabilities, $0 < \delta_{\underline{c}} < \delta_{\overline{c}} < 1$,
- with identical output, y_C,
- requiring a bank loan, normalised to 1.

Overview of clean & dirty projects: private perspective

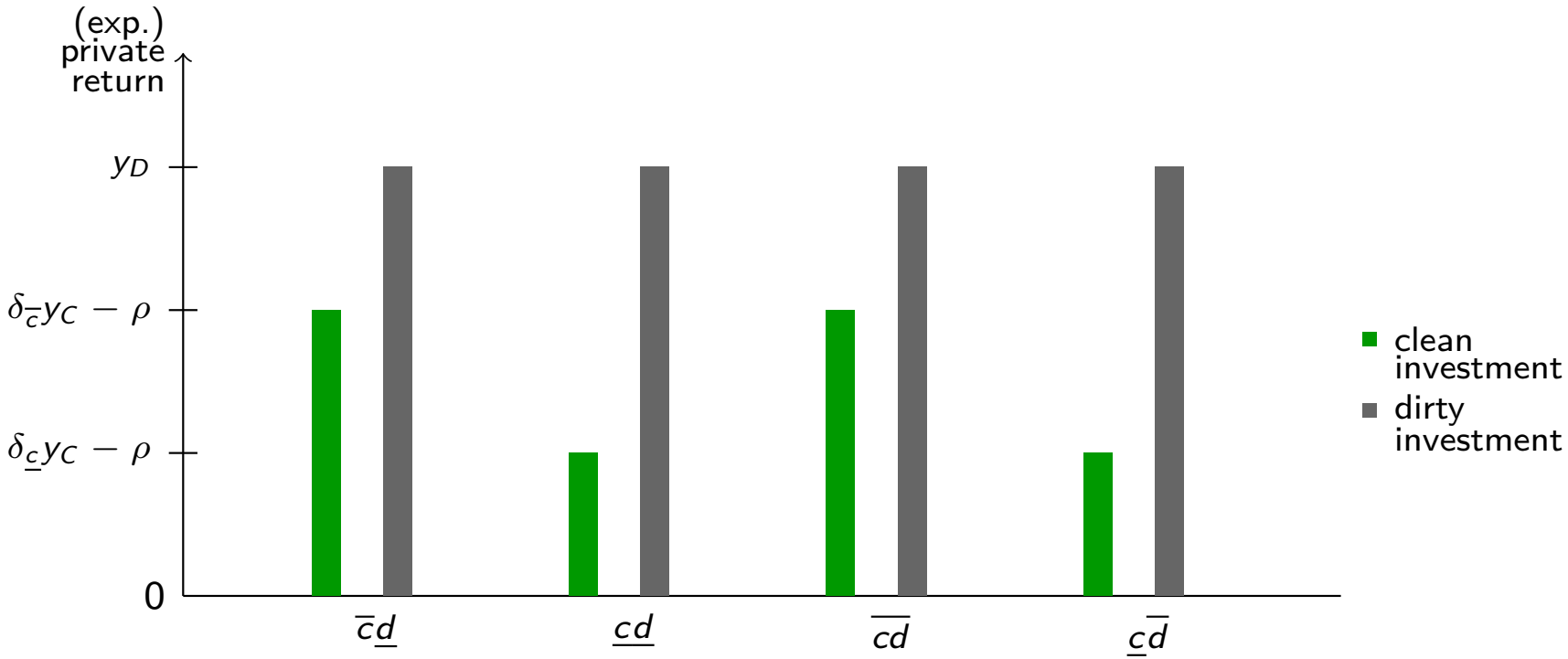
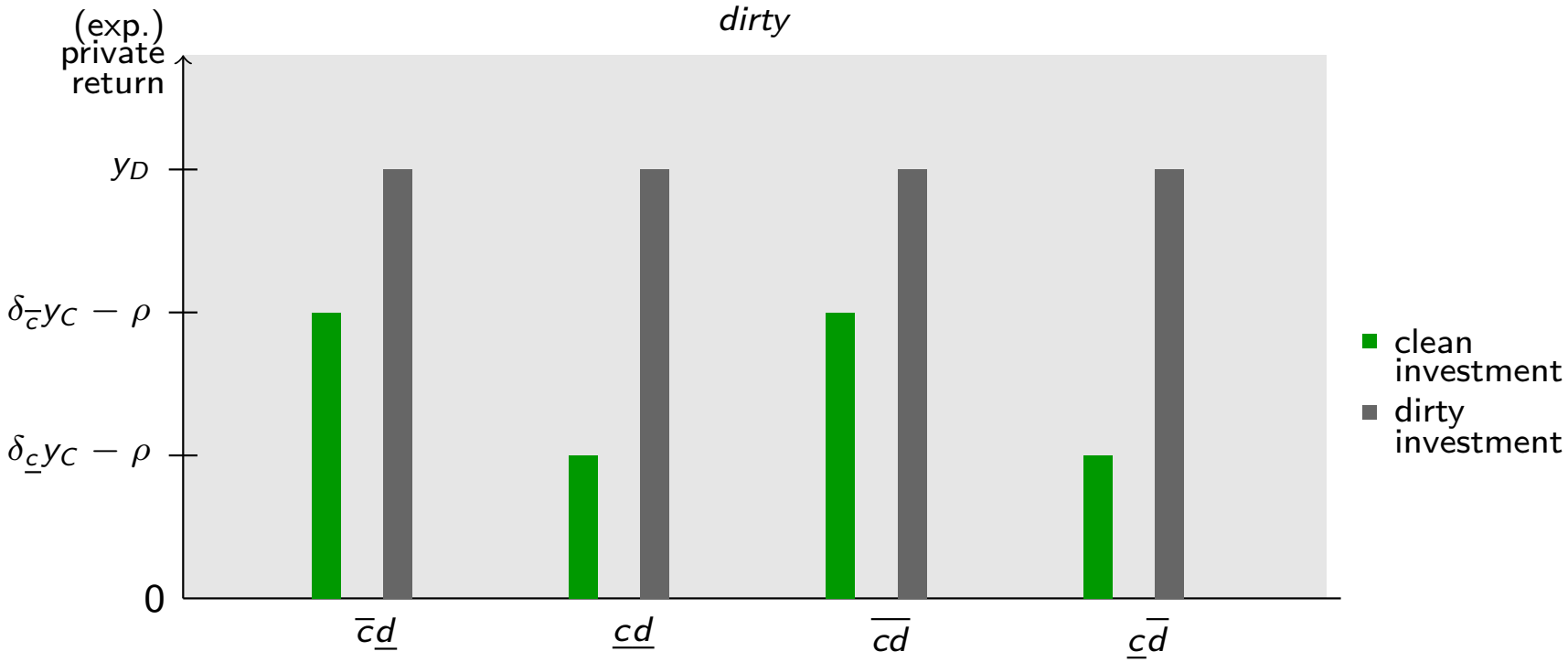


Figure 1: Expected private returns to projects by firm type.

Assumption: $y_D > y_D - c_e e_{\overline{d}} > \delta_c y_C - \rho > y_D - c_e e_{\underline{d}} \geq o \qquad c \in \{\underline{c}, \overline{c}\}$

Base case I: Laissez-faire allocation



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Overview of clean & dirty project: social perspective

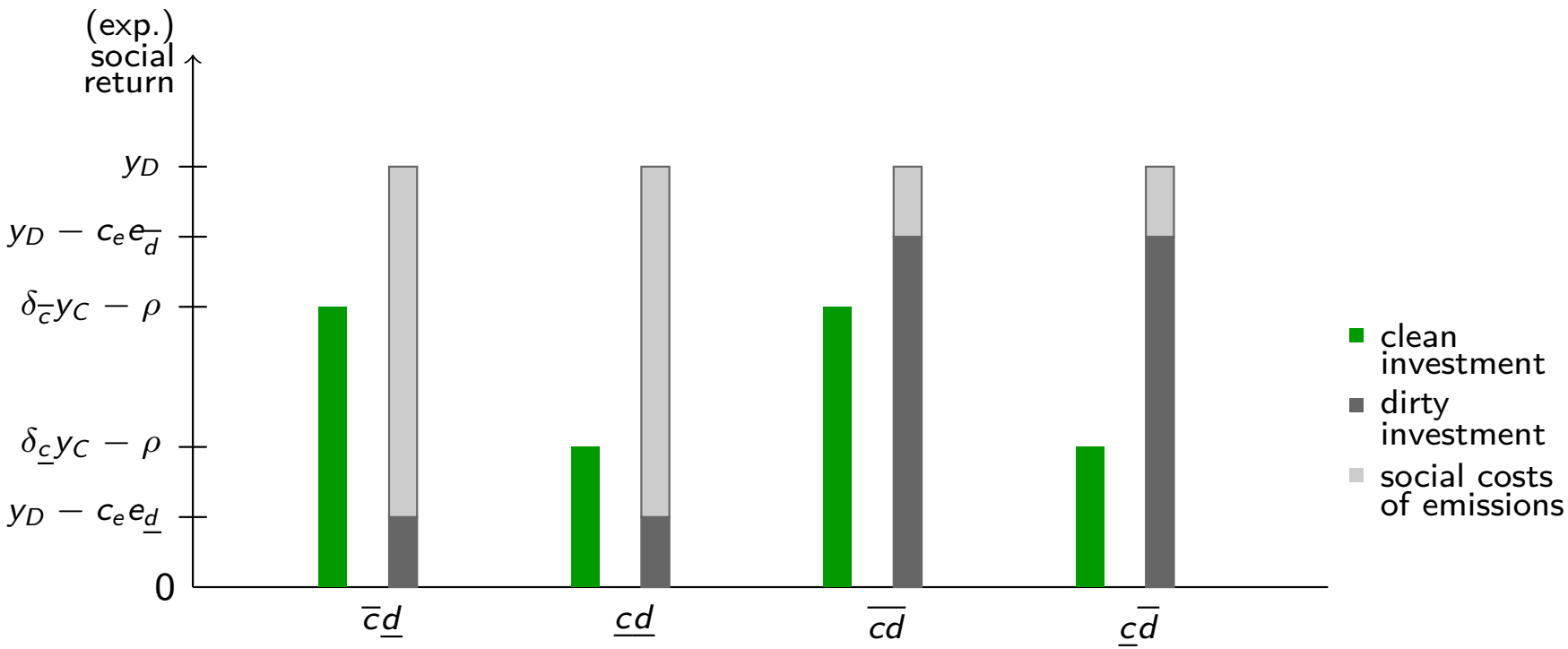
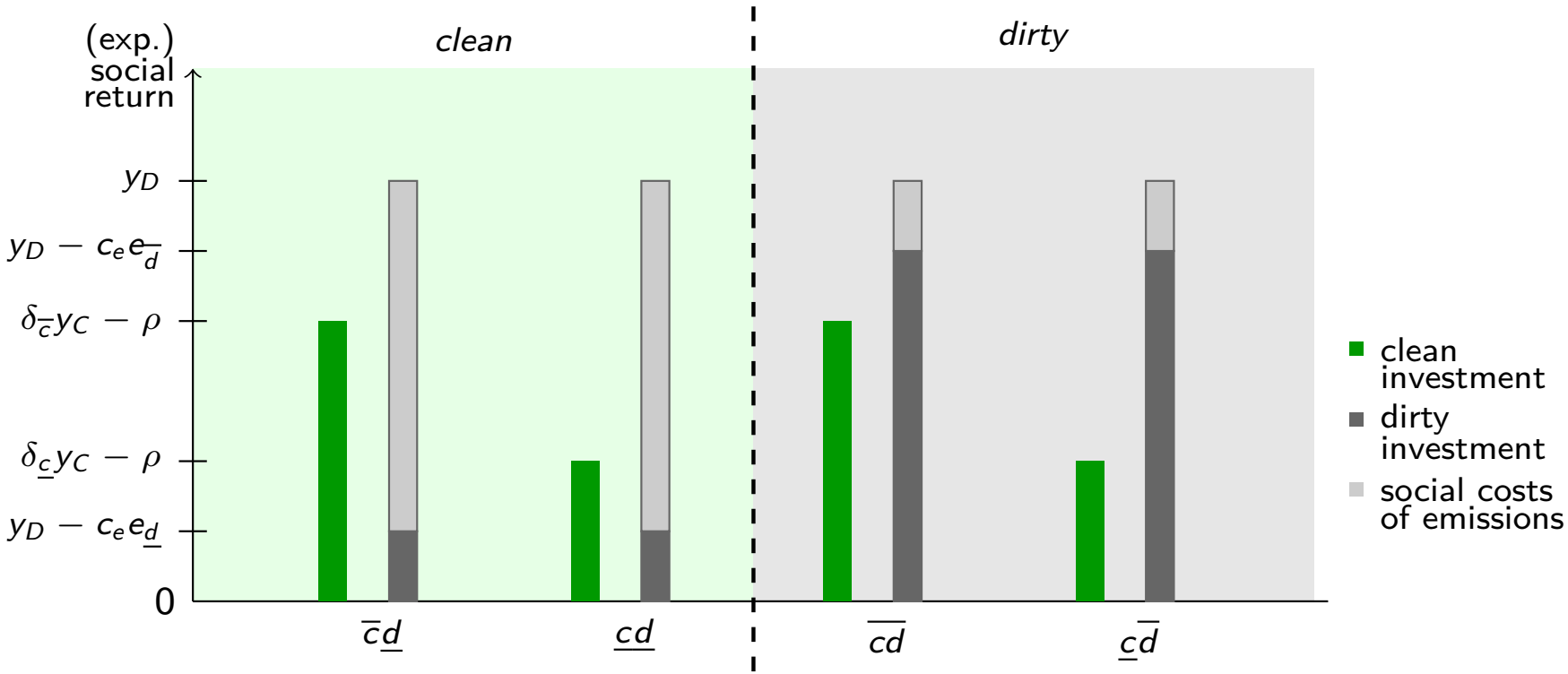


Figure 2: Expected social returns to projects by firm type.

Assumption: $y_D > y_D - c_e e_{\overline{d}} > \delta_c y_C - \rho > y_D - c_e e_{\underline{d}} \geq o \qquad c \in \{\underline{c}, \overline{c}\}$

Base case II: Socially optimal allocation



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Loan market:

- Lender (bank) receives funds at unit costs ρ.
- Information asymmetry between firms (borrowers) and lender (and the government).
- Loan contracts comprise π_k & R_k, with $k \in \{\underline{c}\underline{d}, \underline{c}\overline{d}, \overline{c}\underline{d}, \overline{c}\overline{d}\}$, where
  - π_k is the probability of receiving the loan and
  - R_k is the loan repayment (1+interest rate).

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  - π_k is the probability of receiving the loan and
  - R_k is the loan repayment (1+interest rate).
- The expected profit of a borrower of type cd, who applies for a contract designed for a borrower k is:

$$P_{cd,k} = \pi_k \left[\delta_c \left(y_C - R_k\right) - y_D\right]. \tag{1}$$

- The lender's expected profit for a loan to a borrower of type k is:

$$B_k = \pi_k \left[\delta_c R_k - \rho\right]. \tag{2}$$

$\Rightarrow$ Bank maximises profits from lending subject to the (potential) borrowers' participation constraint ($P_{cd,k} > 0$) and incentive compatibility constraints (each borrower chooses the contract designed for him, i.e. $cd = k$).

Economy with emission tax

Introduction of Emission Tax

- Government sets an emission tax $\tau = c_e$.
- Altered expected profits of firms (borrowers):

$$P_{cd,k} = \pi_k \left[\delta_c \left(y_C - R_k\right) - \left(y_D - \tau e_d\right)\right]. \tag{3}$$

$\rightarrow$ relative return of clean investments $\uparrow$.

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  $\rightarrow$ relative return of clean investments $\uparrow$.
- Type $c\underline{d}$ firms attempt to switch to the clean sector.
- Type $c\overline{d}$ firms remain in the dirty sector ($PC_{c\overline{d}}$ cannot be fulfilled).

The bank's (reduced) maximisation problem is:

$$\max_{\pi_{\underline{cd}}, R_{\underline{cd}}, \pi_{\overline{c}\underline{d}}, R_{\overline{c}\underline{d}}} \quad B = \theta_d \left[\theta_c B_{\underline{cd}} + (1-\theta_c) B_{\overline{c}\underline{d}}\right]$$

$$= \theta_d \left[\theta_c \pi_{\underline{c}} \left[\delta_{\underline{c}} R_{\underline{cd}} - \rho\right] + (1-\theta_c) \pi_{\overline{c}} \left[\delta_{\overline{c}} R_{\overline{c}\underline{d}} - \rho\right]\right]$$

subject to

$$\begin{aligned}
(PC \text{ of type } \underline{cd}) \quad & \pi_{\underline{cd}} \left[\delta_c \left(y_C - R_{\underline{cd}}\right) - \left(y_D - \tau e_{\underline{d}}\right)\right] \geq 0 \\
(IC \text{ of type } \overline{c}\underline{d}) \quad & \pi_{\overline{c}\underline{d}} \left[\delta_{\overline{c}} \left(y_C - R_{\overline{c}\underline{d}}\right) - \left(y_D - \tau e_{\underline{d}}\right)\right] \geq \pi_{\underline{cd}} \left[\delta_{\overline{c}} \left(y_C - R_{\underline{cd}}\right) - \left(y_D - \tau e_{\underline{d}}\right)\right] \\
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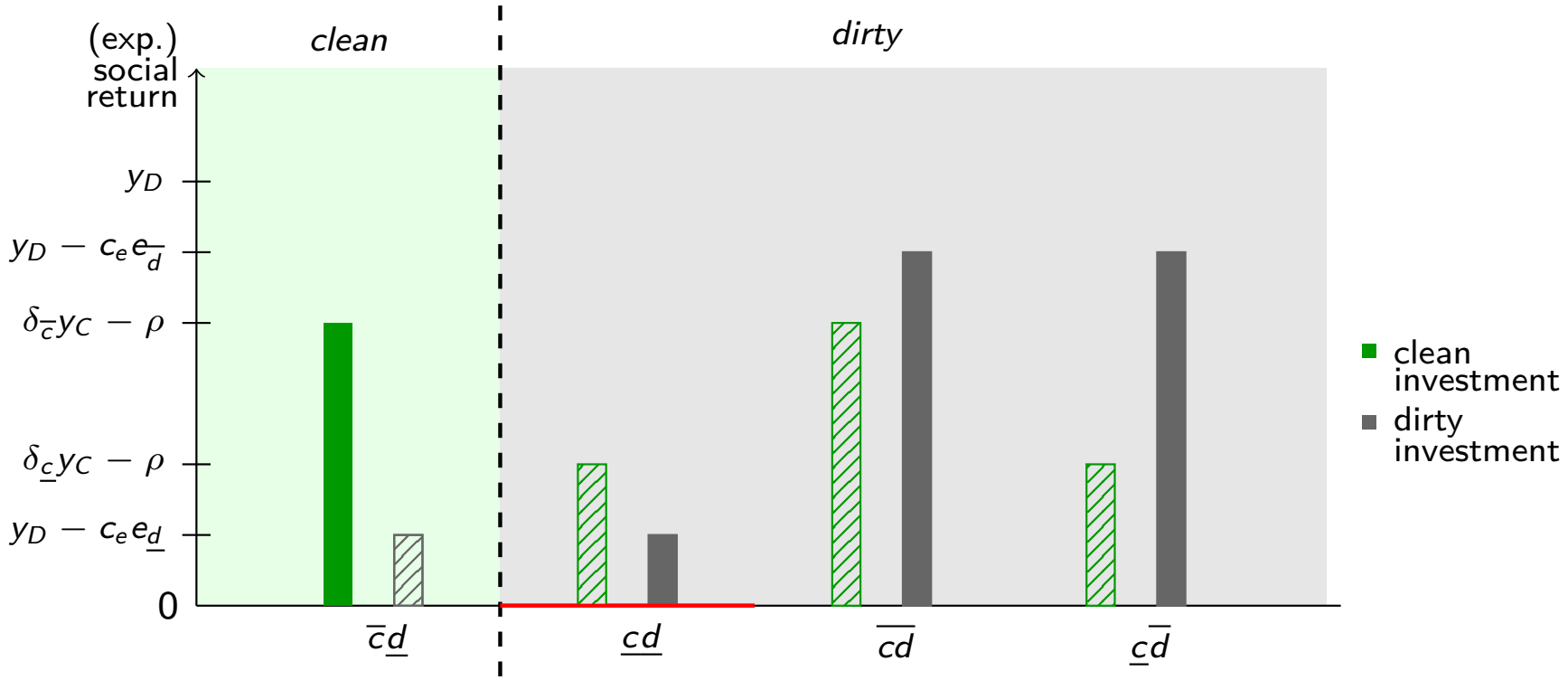
& 0 \leq \pi_{c\underline{d}} \leq 1.
\end{aligned}$$

The profit-maximising solution for the probability of receiving a loan is given by

$$\pi^*_{\overline{c}\underline{d}} = 1$$

$$\pi^*_{\underline{cd}} = \begin{cases} 0 & \textit{if} \quad \frac{\left(\delta_{\underline{c}} y_C - \rho\right) - \left(y_D - \tau e_{\underline{d}}\right)}{\left(y_D - \tau e_{\underline{d}}\right)} < \frac{1-\theta_c}{\theta_c} \frac{\delta_{\overline{c}} - \delta_{\underline{c}}}{\delta_{\underline{c}}} \quad \text{(CR condition)} \\ 1 & \textit{otherwise.} \end{cases}$$

Allocation with emission tax only



- The lender offers loan contracts maximising expected profit, s.t. participation constraints and incentive compatibility constraints of all types of firms.

$$\pi^*_{\underline{cd}} = 0 \qquad R^*_{\underline{cd}} = \textit{any value}$$

$$\pi^*_{\overline{c}\underline{d}} = 1 \qquad R^*_{\overline{c}\underline{d}} = y_C - \frac{y_D - \tau e_{\underline{d}}}{\delta_{\overline{c}}}$$

Economy with emission tax

Economy with emission tax and credit market intervention

Government intervention on credit market

We consider two instruments:

- Interest subsidy, s, paid by government if a project is successful.

$\rightarrow$ Borrower's new expected profit:

$$P_{cd,k} = \pi_k \left[\delta_c \left[\, y_C - (R_k - s) \,\right] - (y_D - \tau e_d)\right]. \tag{4}$$

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- Loan guarantee, g, paid by government if a project is unsuccessful.

$\rightarrow$ Lender's new expected profit:

$$B_k = \pi_k \left[\delta_c R_k + (1 - \delta_c)\, g - \rho\right]. \tag{5}$$

Government intervention on credit market

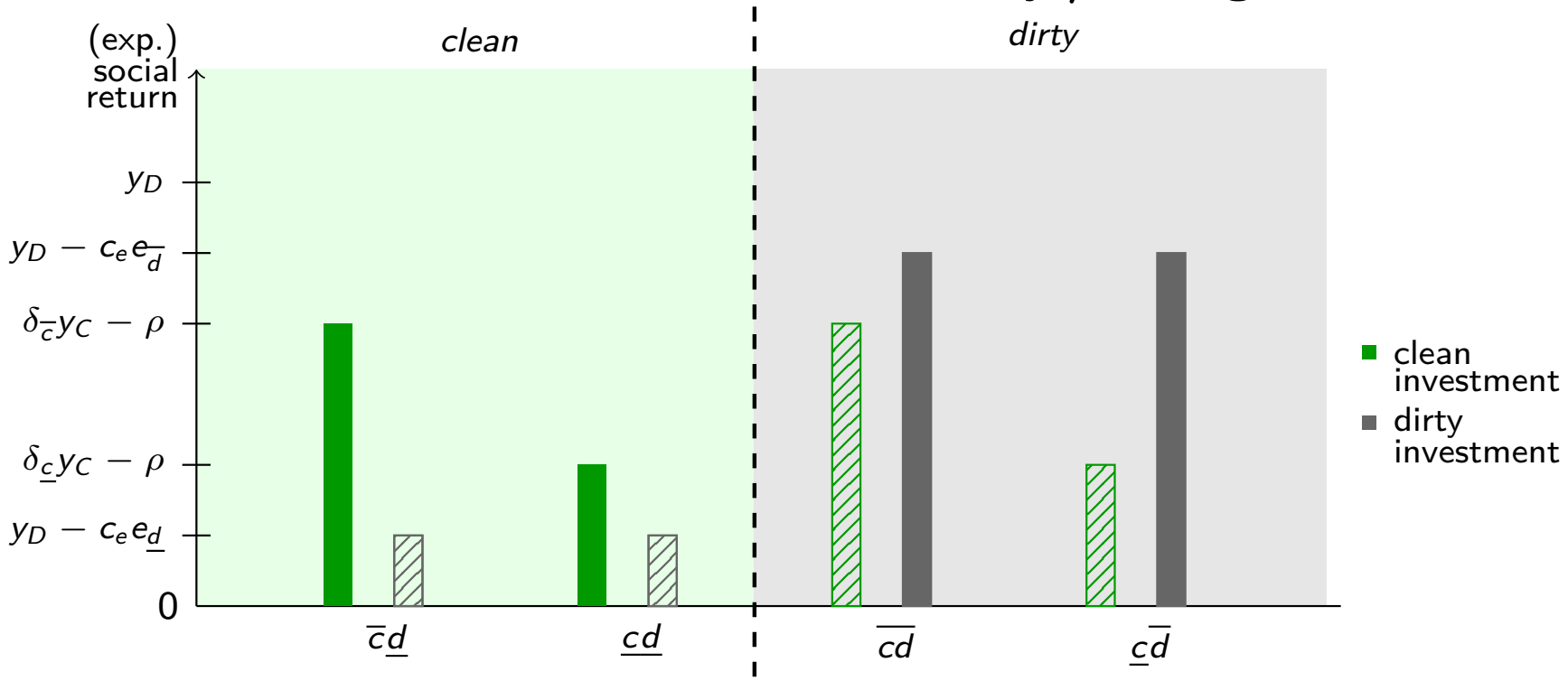
- Interest subsidy paid by government to avoid credit rationing:

$$s^* = \frac{\rho + \left(y_D - \tau e_{\underline{d}}\right)\left[1 + \frac{1-\theta}{\theta}\frac{\delta_{\overline{c}} - \delta_{\underline{c}}}{\delta_{\underline{c}}}\right] - \left(1 - \delta_{\underline{c}}\right) g}{\delta_{\underline{c}}} - y_C$$

- Loan guarantee paid by government to avoid credit rationing:

$$g^* = \frac{\rho + \left(y_D - \tau e_{\underline{d}}\right)\left[1 + \frac{1-\theta}{\theta}\frac{\delta_{\overline{c}} - \delta_{\underline{c}}}{\delta_{\underline{c}}}\right] - \delta_{\underline{c}}\left(y_C + s\right)}{1 - \delta_{\underline{c}}}$$

Allocation with emission tax and interest subsidy / loan guarantee



- Combined use of an emission tax and credit market instrument can resemble first best outcome from total welfare perspective.
- Minimum effective government expenditures with loan guarantee are lower than with interest subsidy, $G_g < G_s$.

Some Considerations on Dynamic Effects

- Innovation Spillovers $\rightarrow$ type-$\underline{c}d$ catches up to type-$\overline{c}d$ (in infinite time):
$\dot{\delta}_{\underline{c},t} \equiv \delta_{\underline{c},t} - \delta_{\underline{c},t-1} = \theta_d \left(\pi_{\underline{c},t-1}\theta_c + \pi_{\overline{c},t-1}(1-\theta_c)\right) \left(\delta_{\overline{c},t-1} - \delta_{\underline{c},t-1}\right) \quad \forall\ t > 0$

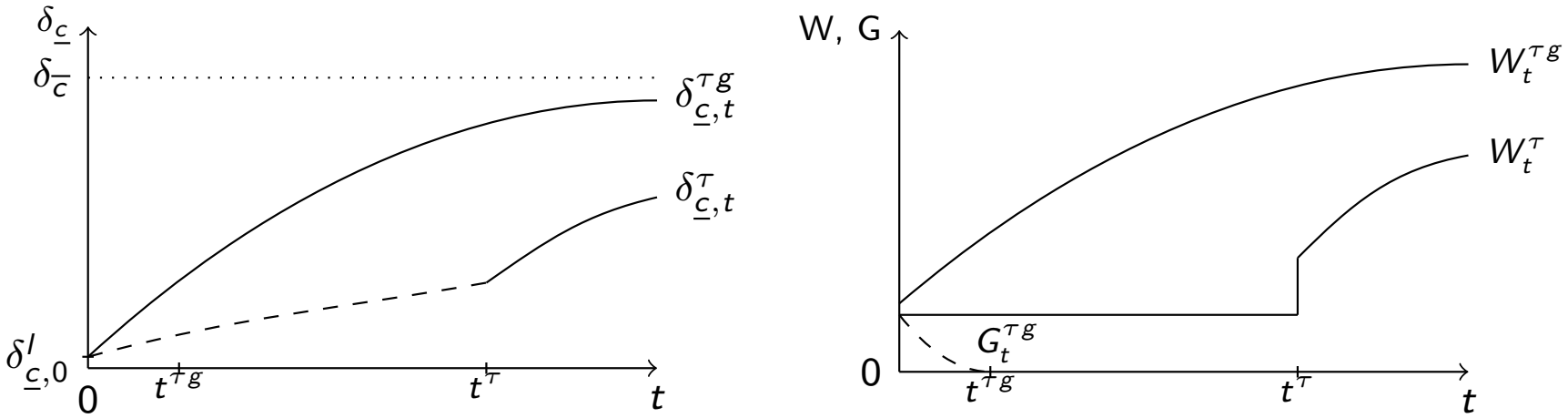


Figure 3: Left: Evolution of the probability of success of type-$\underline{c}d$ with loan guarantee ($\delta^{\tau g}_{\underline{c}}$) and without ($\delta^{\tau}_{\underline{c}}$). Right: Total welfare with loan guarantee ($W^{\tau g}_t$) and without (W^{τ}_t), and government expenditures ($G^{\tau g}_t$).

- Credit rationing (CR) reduces spillovers $\rightarrow \delta^{\tau}_{\underline{c},t} < \delta^{\tau g}_{\underline{c},t}\ \forall\ t > 0$
- CR vanishes at $t^{\tau g}$ with and at t^{τ} without government intervention.
- Forgone welfare resulting from no or delayed intervention on loan market.

Main Results

Static analysis:

- An emission tax alone is not sufficient if there are information asymmetries on credit markets $\rightarrow$ credit rationing.
- Interest subsidy or loan guarantee can resolve issue of credit rationing.

Additional Results (not presented today):

- If an emission tax is (politically) not feasible, an interest subsidy can be used to induce clean investment.
- However, policy mix with emission tax yields superior results with respect to total welfare ($\rightarrow$ one instrument per market failure).

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- However, policy mix with emission tax yields superior results with respect to total welfare ($\rightarrow$ one instrument per market failure).

Dynamic analysis:

- Necessity of government intervention on credit market is finite (credit rationing vanishes at some point).
- Risk of substantial welfare costs resulting from no or delayed intervention on credit markets.

Grazie per l'attenzione!
Thank you for your attention!

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Overview of firm types in economy

	$\overline{c}$-type (high success prob. / high productivity)	$\underline{c}$-type (low success prob. / low productivity)	$\sum$
$\overline{d}$-type (low emissions / high productivity)	$(1-\theta_d)(1-\theta_c)$	$(1-\theta_d)\theta_c$	$1-\theta_d$
$\underline{d}$-type (high emissions / low productivity)	$\theta_d(1-\theta_c)$	$\theta_d\theta_c$	θ_d
$\sum$	$(1-\theta_c)$	θ_c	1

Table 1: Contingency table of firm types in the economy

- Clean sector uses relatively new technologies
  - significant share of firms of type $\underline{c}d$
  - significant variance of technologies

Assumption 2

$$\frac{\delta_{\underline{c}} y_C - \rho - o}{o} < \frac{1-\theta_c}{\theta_c} \frac{\delta_{\overline{c}} - \delta_{\underline{c}}}{\delta_{\underline{c}}} < \left[\left(y_D - c_e c_{\underline{d}} \right) - \frac{\delta_{\underline{c}}}{\delta_{\overline{c}}} \left(y_D - c_e c_{\overline{d}} \right) - \left(1 - \delta_{\underline{c}} \right) \rho \right] / y_D - c_e \overline{e}$$

Bank's (reduced) maximisation problem with interest subsidy is:

$$\max_{\pi_{\underline{c}}, R_{\underline{c}}, \pi_{\overline{c}}, R_{\overline{c}}} \; B = \theta_c \pi_{\underline{c}} \left[\delta_{\underline{c}} R_{\underline{c}} - \rho\right] + (1-\theta_c)\, \pi_{\overline{c}} \left[\delta_{\overline{c}} R_{\overline{c}} - \rho\right]$$

$$\text{subject to} \quad IC_{c\underline{d}} \quad \text{and} \quad PC_{c\underline{d}}.$$

- The solution to this problem is given by

$$R_{\underline{c}}^* = \begin{cases} \textit{any value} & \textit{if} \quad \pi_{\underline{c}}^* = 0 \\ y_C + s - \frac{y_d - \tau e_{\underline{d}}}{\delta_{\underline{c}}} & \textit{otherwise} \end{cases}$$

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$$\pi_{\underline{c}}^* = \begin{cases} 0 & \textit{if} \quad \frac{\left(\delta_{\underline{c}}(y_C + s) - \rho\right) - \left(y_D - \tau e_{\underline{d}}\right)}{\left(y_D - \tau e_{\underline{d}}\right)} < \frac{1-\theta_c}{\theta_c} \frac{\delta_{\overline{c}} - \delta_{\underline{c}}}{\delta_{\underline{c}}} \quad \text{(CR condition)} \\ 1 & \textit{otherwise} \end{cases}$$

$$\pi_{\overline{c}}^* = 1.$$

- Government chooses s such that CR condition holds with equality
  $\rightarrow s^* \equiv$ minimum effective interest subsidy

Bank's (reduced) maximisation problem with loan guarantee is:

$$\max_{\pi_{\underline{c}}, R_{\underline{c}}, \pi_{\overline{c}}, R_{\overline{c}}} \; B = \theta_c \pi_{\underline{c}} \left[\delta_{\underline{c}} R_{\underline{c}} - \rho + \left(1 - \delta_{\underline{c}}\right) g\right] + \left(1 - \theta_c\right) \pi_{\overline{c}} \left[\delta_{\overline{c}} R_{\overline{c}} - \rho + \left(1 - \delta_{\overline{c}}\right) g\right]$$

$$\text{subject to} \quad IC_{c\underline{d}} \quad \text{and} \quad PC_{c\underline{d}}.$$

- The solution to this problem is given by

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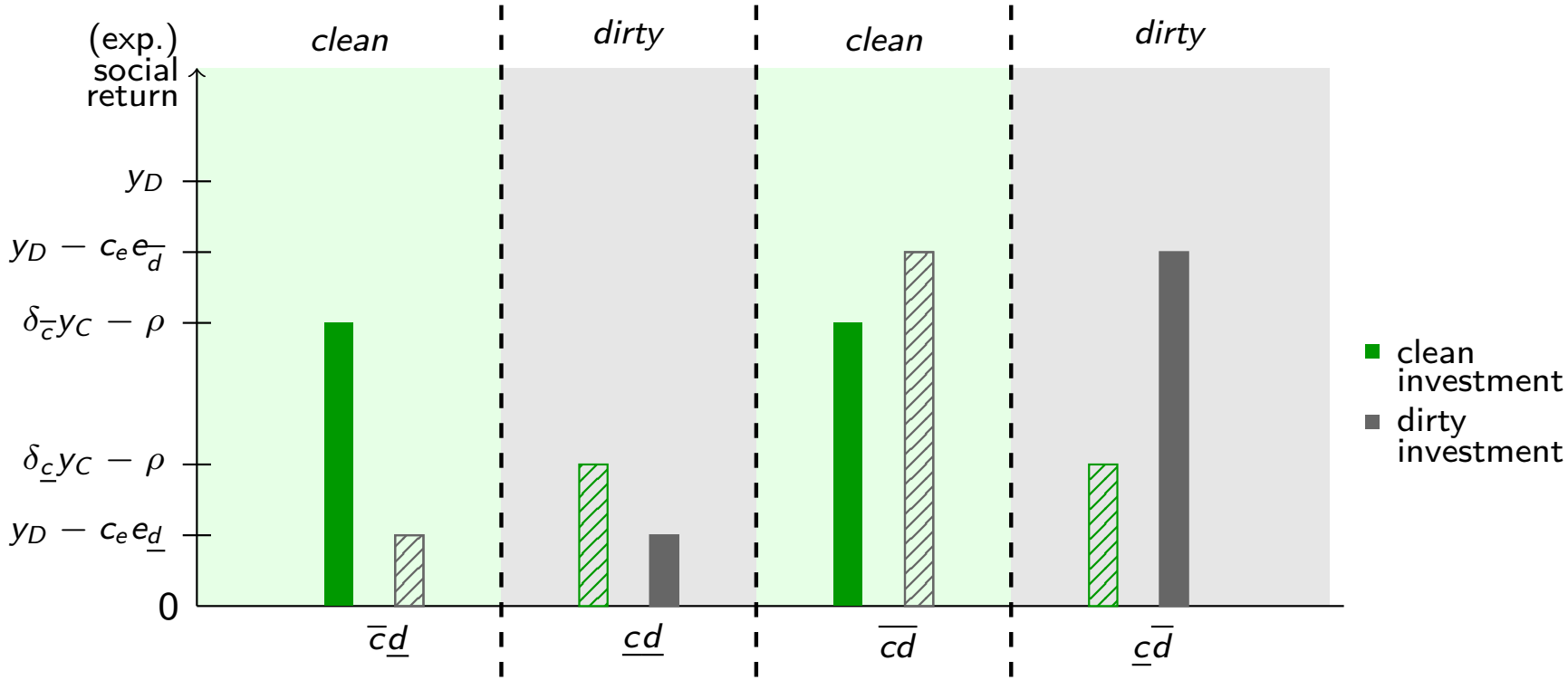
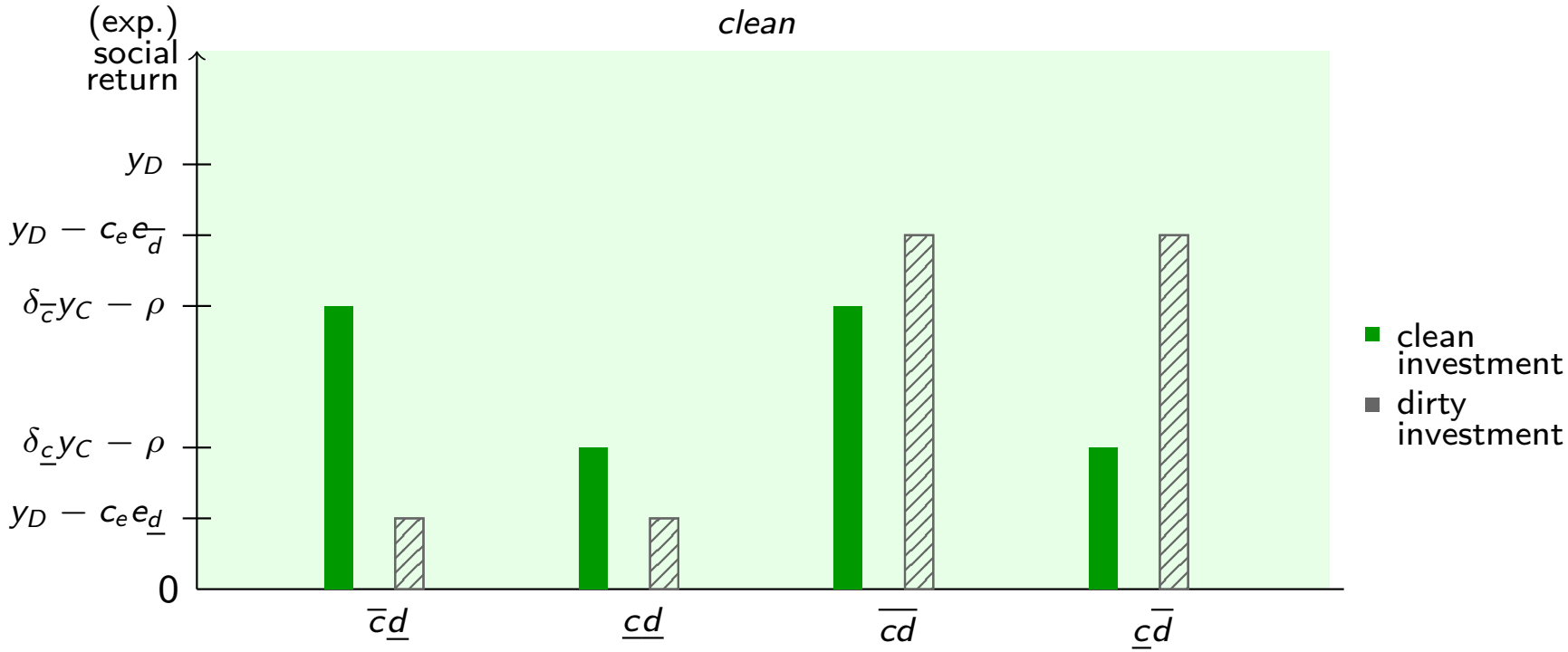
Allocation without emission tax and with interest subsidy $\underline{s}^*$



- Government can stimulate clean investment with interest subsidy.
- However, no self-selection in the dirty sector.
  - Misallocation of type $\underline{cd}$ and type $\overline{cd}$.
  - Government is unable to resemble first best outcome.

Allocation without emission tax and with interest subsidy $\overline{s}^*$ (combined with loan guarantee)



- Government can stimulate clean investment with interest subsidy.
- However, no self-selection in the dirty sector.
  - Misallocation of type $\underline{c}\overline{d}$ and type $\overline{cd}$.
  - Government is unable to resemble first best outcome.

Some Considerations on Dynamic Effects

- Consider learning-by-doing and learning through observing in the clean sector (sector with relative new technology),
- particularly, type $\underline{c}d$ catches up to type $\overline{c}d$ (in infinite time):

$$\dot{\delta}_{\underline{c},t} \equiv \delta_{\underline{c},t} - \delta_{\underline{c},t-1} = \theta_d \left(\pi_{\underline{c},t-1}\theta_c + \pi_{\overline{c},t-1}\left(1-\theta_c\right)\right) \left(\delta_{\overline{c},t-1} - \delta_{\underline{c},t-1}\right) \quad \forall\ t > 0$$

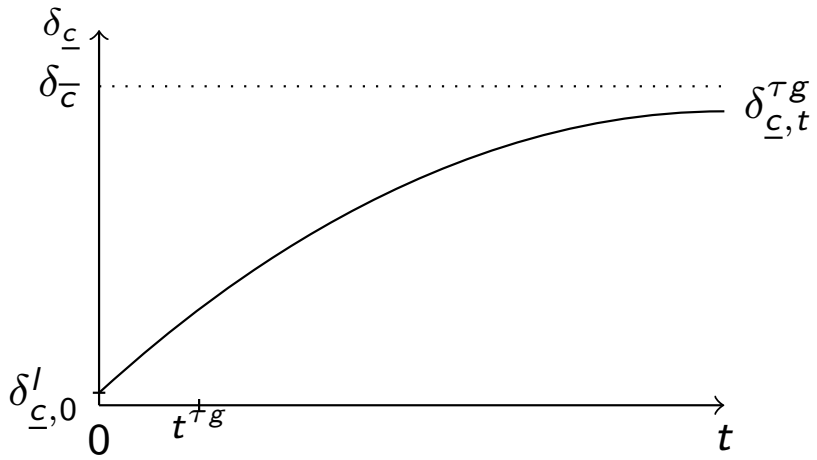


Figure 4: Evolution of the probability of success of $\underline{c}d$-type borrowers in the clean energy sector with government intervention on credit markets ($\delta^{\tau g}_{\underline{c},t}$).

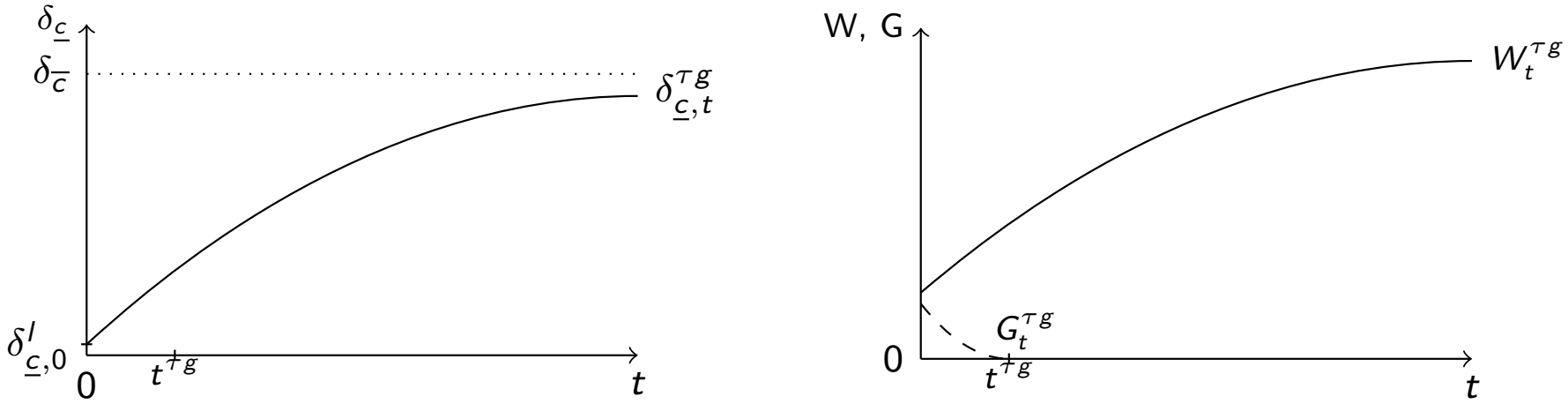


Figure 5: Left: Evolution of the probability of success of type $\underline{c}d$ ($\delta^{\tau g}_{\underline{c}}$). Right: Total welfare ($W^{\tau g}_t$) and government expenditures ($G^{\tau g}_t$).

Impact of the increase in the probability of success of type $\underline{c}d$:

- Direct positive effect on total welfare.
- Positively affects government expenditures:
  - Directly: reduced probability of default ($1 - \delta_{\underline{c}} \downarrow$).
  - Indirectly: reduced minimum effective loan guarantee ($g^*_t(\delta_{\underline{c}t})$).
  - At $t = t^{\tau g}$, credit rationing vanishes $\rightarrow$ government intervention on credit market no longer required.

Without government intervention on credit market

- Temporary, spillovers from type $\overline{c}d$ only :

$$\dot{\delta}_{\underline{c},t} \equiv \delta_{\underline{c},t} - \delta_{\underline{c},t-1} = \theta_d \left(\pi_{\underline{c},t-1} \theta_c + \pi_{\overline{c},t-1} (1 - \theta_c) \right) \left(\delta_{\overline{c},t-1} - \delta_{\underline{c},t-1} \right) \quad \forall \ t > 0$$

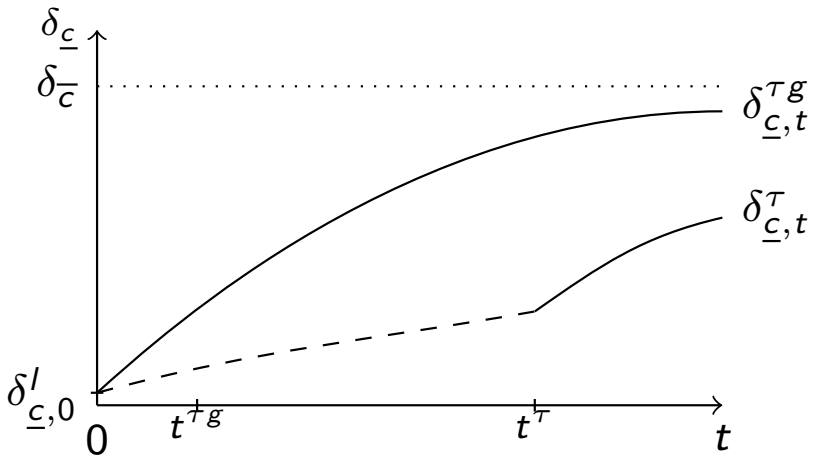


Figure 6: Evolution of the probability of success of $\underline{c}d$-type borrowers in the clean energy sector with government intervention on credit markets ($\delta^{\tau g}_{\underline{c},t}$) and without ($\delta^{\tau}_{\underline{c},t}$).

- Credit rationing vanishes in finite time (at time $t = t^{\tau}$).

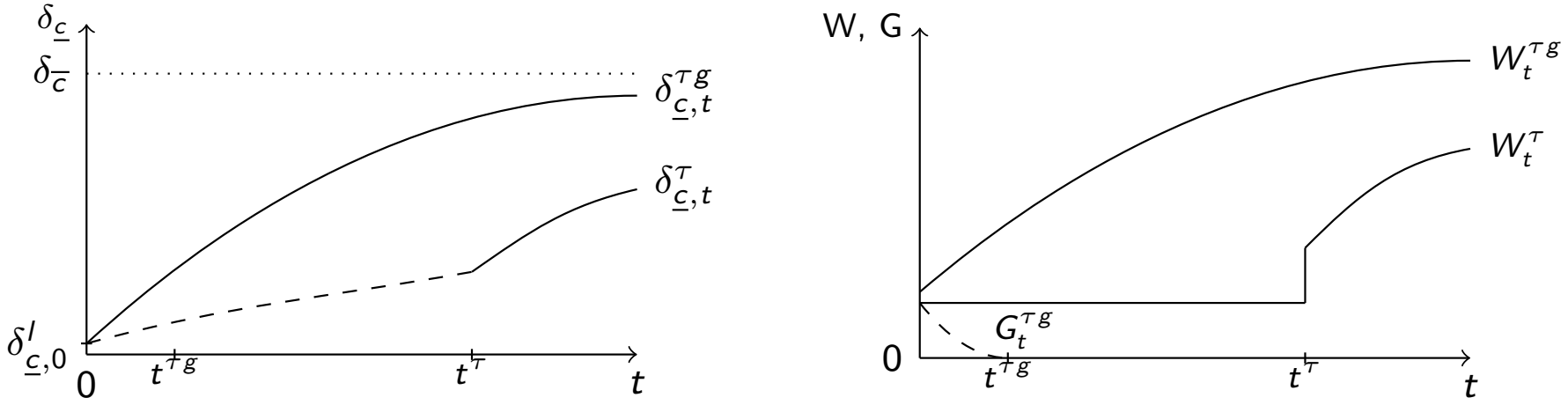


Figure 7: Left: Evolution of the probability of success of type $\underline{c}d$ with loan guarantee ($\delta^{\tau g}_{\underline{c}}$) and without ($\delta^{\tau}_{\underline{c}}$). Right: Total welfare with loan guarantee ($W^{\tau g}_t$) and without (W^{τ}_t), and government expenditures ($G^{\tau g}_t$).

- Social costs (forgone welfare) resulting from no or delayed intervention on credit market
- Furthermore, adverse effects on government behaviour:
  - When clean technology is new, short run gains from government intervention on credit market are relatively low, and government expenditures are relatively high.
  - However, overall welfare gains from intervention are relatively high.