How Effective are Portfolio Mandates?*

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Abstract

We evaluate the effectiveness of portfolio mandates on the equilibrium allocation of physical capital. We show that the impact of mandates crucially depends on firms' demand elasticity of capital. In a production economy with constant returns to scale, firms' demand for capital is infinitely elastic, and mandates can significantly impact the allocation of capital across sectors despite having a negligible impact on the cost of capital. This is in contrast to an endowment economy where demand for capital is inelastic, and therefore, equilibrium price reactions to mandates significantly reduce their effectiveness. Within a canonical real-business-cycle model calibrated to match key asset-pricing and macroeconomic moments, we estimate that the mandate is effective in shaping equilibrium capital allocation in the long run, even when there is little disparity in the cost of capital across sectors. Hence, our analysis challenges the common practice of judging the effectiveness of portfolio mandates by their impact on firms' cost of capital. We also show that in the short run, the mandate is satisfied by the rebalancing of financial portfolios in secondary markets, while in the long it is satisfied through the reallocation of physical capital in primary markets, with the relative importance of these two markets depending on capital adjustment costs and investors' risk attitudes.

Keywords: ESG, cost of capital, capital allocation, green transition.
JEL Classification: D53, G11, G12.

1 Introduction

Responsible investing, a strategy aimed at generating social and environmental impact alongside financial returns, has grown tremendously over the last decade. Portfolio "screens" or "mandates" are common implementations of socially responsible investing strategies. Such policies aim to restrict capital allocation to specific firms to increase target firms' cost of capital and make it more costly for them to fund their operations. PricewaterhouseCoopers (2022) forecasts that assets under management that are screened by Environmental, Social, and Governance (ESG) criteria are expected to increase from \$18.4tn in 2021 to \$33.9tn by 2026, with ESG assets on pace to constitute 21.5% of total global assets under management. Bloomberg Intelligence (2021) expects global ESG assets to exceed \$53 trillion by 2025, representing more than a third of total assets under management. On the other hand, partly on the grounds that it reduces investment returns, several states in the US have introduced proposals *against* responsible investing (Donefer, 2023), and twenty-five US states have sued the Biden Administration to halt a Department of Labor rule that prioritizes ESG concepts into retirement-fund regulations (Mayer, 2023).

Despite the large sums of assets allocated to responsible investing and the controversy about its costs and benefits, the academic literature to date provides a skeptical view of its effectiveness. In their pioneering work, Heinkel, Kraus, and Zechner (2001) and, more recently, Berk and van Binsbergen (2024) argue that responsible-investing policies have a negligible impact on targeted firms' cost of capital and are, therefore, ineffective in influencing capital allocation. There is also a large literature that uses the change in the cost of capital to gauge the effectiveness of various socially responsible policies.[1]

In this paper, we show that differences in the cost of capital across sectors are generally *not* informative about differences in sectoral capital allocations. Employing both a simplified theoretical model and a quantitative framework, we illustrate that portfolio mandates are likely to lead to substantial disparities in sectoral capital allocation, even when the cost-of-capital differences across sectors are minimal. Our analysis applies more broadly beyond socially responsible investing

[1] See, for instance, the article from McKinsey "Why ESG is Here to Stay," which discusses how ESG scores are related to the cost of capital. The article states "...there have been more than 2,000 academic studies, and around 70 percent of them find a positive relationship between ESG scores on the one hand and financial returns on the other, whether measured by equity returns or profitability or valuation multiples. Increasingly, another element is the cost of capital. Evidence is emerging that a better ESG score translates to about a 10 percent lower cost of capital." For a further discussion of the effect of ESG on the cost of capital, see Edmans (2023).

and extends to situations where portfolio constraints are imposed to influence investor behavior for various reasons, including, for example, regulatory compliance and economic sanctions.[2]

Heinkel et al. (2001), Berk and van Binsbergen (2024), and the literature using the cost of capital to measure the effectiveness of ESG-related policies reach their conclusions based on the analysis of an endowment economy. In such an economy, a firm's dividends are *exogenous*, and only its asset returns depend on market-clearing prices. In this paper, we revisit the conclusion that responsible investment policies have a negligible impact on targeted firms' cost of capital and are, therefore, ineffective in influencing capital allocations by studying the equilibrium effect of portfolio mandates in a model with production. In contrast to an endowment economy, in a production economy *both* dividends (payoffs or output) and asset returns are determined endogenously in equilibrium. We show that this has important implications for understanding the real effects of portfolio mandates: in particular, portfolio mandates can lead to large differences in the equilibrium sectoral allocation of physical capital despite negligible differences in the cost of capital.

To understand the intuition driving our result that portfolio mandates can lead to significant changes in capital allocation despite a negligible effect on the cost of capital, we study two versions of a production economy with two sectors, consisting of "green" and "brown" firms, and two groups of investors: one group is constrained by a portfolio mandate, e.g., pension funds, while the other is unconstrained, e.g., hedge funds. The first version of the model is a stylized single-period (two-date) frictionless production economy that allows us to develop the key intuition for our findings and *qualitatively* assess the effectiveness of portfolio mandates in equilibrium. The second version of the model extends the stylized model to a multiperiod setting with realistic frictions that allow us to match macroeconomic and asset-pricing moments in the data and hence *quantitatively* assess the effectiveness of portfolio mandates in equilibrium. To highlight the equilibrium effect of mandates, we assume that the green and brown assets are identical, other than the fact that one of the two, e.g., the green asset, is favored by the mandate. Although, in reality, mandates may be imposed in response to externalities, e.g., pollution, we abstract away from modeling the rationale for their existence in the economy.

[2]For example, Article 5 of Regulation (EU) No 833/2014, enacted after the onset of the war between Russia and Ukraine, states that "It shall be prohibited to directly or indirectly purchase, sell, provide investment services for or assistance in the issuance of, or otherwise deal with transferable securities" `https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022R0328`.

In the single-period version of the model, we consider an economy in which firms use capital K supplied by investors to produce output Y according to the production function $Y = A\,K^{\alpha}$, with A denoting an exogenous productivity shock, and $\alpha \in [0,1]$ the returns-to-scale parameter. The case of $\alpha = 1$, where output is given by $Y = A\,K$, represents the typical "AK" model of a production economy with constant returns to scale. The case of $\alpha = 0$ represents an *endowment* economy, in which output is exogenously given $Y = A\,K^{\alpha} = A$, and hence capital is not used in production.[3] In this economy, the marginal productivity of capital, that is, $R \equiv \alpha A K^{\alpha-1}$, represents the "cost of capital". The relationship between the cost of capital R and capital K represents firms' *demand of capital*. Suppose the economy has two sectors, green (G) and brown (B), and denote by R_G and R_B the cost of capital in each sector, that is, the marginal productivity of sectoral capital. The ratio of the cost of capital is then $R_G/R_B = (A_G/A_B) \times (K_G/K_B)^{\alpha-1}$.

In an endowment economy, $\alpha = 0$ and $R_G/R_B = (A_G/A_B) \times (K_G/K_B)^{-1}$. In this economy, a portfolio mandate designed to increase K_G relative to K_B leads to a corresponding decrease in R_G relative to R_B. Therefore, in this economy, the mandate is effective ($K_G \gg K_B$) if and only if the difference in the cost of capital is large ($R_B \gg R_G$). Hence, the difference in the cost of capital is informative about the difference in capital allocation and, therefore, about the effectiveness of a mandate. When the difference in returns is large, unconstrained investors have an incentive to shift their portfolio toward the B sector. In equilibrium, the response of the unconstrained investors to the change in relative returns across sectors undoes a part of the intended effect of the portfolio mandate, thus limiting the effectiveness of the mandate. In contrast, in the case of a production economy with constant returns to scale, $\alpha = 1$ and $R_G/R_B = A_G/A_B$. In this economy, a portfolio mandate designed to increase K_G relative to K_B has *no effect* on the cost of capital R_G and R_B. As a result, unconstrained investors have no incentive to shift their portfolio toward the B sector. Therefore, in equilibrium, the unconstrained investors' response does not offset the portfolio mandate's effect. Thus, mandates can be fully effective in shaping capital allocation even though they have no impact on the sectoral cost of capital.

To measure the effectiveness of a portfolio mandate on the sectoral allocation of physical capital in equilibrium, we introduce the concept of "*mandate pass-through.*" To illustrate the main idea, consider an economy where both investors have equal wealth and both sectors have identical risk-return tradeoffs so that the optimal unconstrained allocation for both investors is to hold 50%

[3] Appendix B shows formally that an endowment economy can be obtained as the limit of a production economy when the returns-to-scale parameter α goes to zero.

of their portfolio in each sector. Suppose now that a mandate requires constrained investors to have 75% of their portfolio in the green sector. If we were to ignore the mandate's effect on equilibrium asset prices, the capital allocated to the green sector would be $(50\% + 75\%)/2 = 62.5\%$, instead of the 50% in the absence of a mandate. We refer to this difference, 12.5%, as the *maximum* mandate pass-through.

However, in equilibrium, the imposition of a mandate in favor of the green sector may raise the price of green assets and lower that of brown assets, making the return on brown assets more attractive. As a result of the higher return on brown assets, the unconstrained investor would then invest more than 50% in the brown sector, undoing part of the effect of the portfolio mandate. If, after accounting for general equilibrium effects, the overall allocation of capital to green assets is, say, only 56.25%, then the equilibrium mandate pass-through is only 6.25%. Thus, the *effective* mandate pass-through, defined as the ratio of the equilibrium to maximum mandate pass-through, is $6.25\%/12.5\% = 50\%$; that is, 50% of the mandate survives the equilibrium effects. The mandate pass-through generally depends on the unconstrained households' capital supply elasticity and the firms' demand elasticity. In the single-period version of the general equilibrium production model, we find that when α is close to one, firms' demand elasticity is close to perfectly elastic, making the households' supply elasticity irrelevant and leading to a 100% pass-through.

One might think that a constrained investor could, upon facing a mandate, trade green shares for brown shares with an unconstrained investor in the secondary market, thereby satisfying the constraint without altering the physical quantity of capital. However, this argument overlooks the fact that the unconstrained investor would become underdiversified and would therefore demand a discount on the brown shares. With constant returns to scale and in the absence of capital adjustment costs, the constrained investor could avoid this discount by simply being an "activist" and directly shift physical capital from brown to green. This would allow the investor to meet the mandate while keeping the unconstrained investor perfectly diversified. In this case, the mandate is fully effective. On the other hand, when there are decreasing returns to scale or capital adjustment costs, shifting physical capital is costly and therefore part of the mandate will be satisfied through trades in the secondary market. However, even in this case, in equilibrium the mandate will have an effect on the real capital allocation.[4]

[4]The discussion above highlights that the value of the returns-to-scale parameter, α, is important to assess the effectiveness of a mandate. Empirical estimates from the macroeconomic literature indicate that returns to scale are nearly constant in the US economy, i.e., $\alpha \approx 1$, see, e.g., Hall (1988, 1990), Ahmad, Fernald, and Khan (2019),

To assess the *quantitative* effects of portfolio mandates on the financial and real sectors, in the multiperiod version of the model, we study a dynamic general-equilibrium production economy that we calibrate to match asset-pricing and macroeconomic moments in the US. For the case of constant returns to scale, $\alpha = 1$, and no portfolio constraints, our model is a canonical real-business-cycle model, similar to that in King, Plosser, and Rebelo (1988) and Jermann (1998), among many others. Just as in the simple single-period model, we consider an economy characterized by two sectors with different technologies, "green" and "brown," and two types of investors, "constrained" and "unconstrained." However, we relax many of the simplifying assumptions made in the single-period model. In particular, we consider an infinite-horizon, overlapping-generations economy in discrete time where investors have Epstein-Zin recursive preferences, consume at each date, and are endowed with one unit of labor that they supply to firms inelastically. Firms are all-equity financed, incur convex capital-adjustment costs (e.g., Hayashi, 1982), and choose labor and investment to maximize shareholder value subject to a capital-accumulation constraint. We solve for the equilibrium in this economy and then study the effect of a portfolio mandate on the equilibrium stock returns (cost of capital) and capital allocations in the two sectors.

The calibrated multiperiod model confirms the intuition of the simple one-period model. In equilibrium, the optimal portfolio decisions of the unconstrained investor "undo" some of the effects of the portfolio mandate. This occurs because unconstrained investors face a trade-off. On the one hand, the desire to diversify pushes the portfolio towards a 50/50 allocation. On the other hand, the mandate makes the brown sector more attractive from a risk-reward perspective, which induces unconstrained investors to tilt their portfolios toward it. We find, however, that portfolio mandates retain a quantitatively significant impact in equilibrium under a realistic calibration that matches asset-pricing and macroeconomic moments of the US economy. For example, under our preferred model that is calibrated to the recent mandates favoring green assets, the *effective* mandate pass-through is at least 50%. In contrast, the effect on the equilibrium cost of capital of the two types of firms remains negligible, consistent with evidence in the existing literature. We also solve several alternative versions of the multiperiod model. We find that the pass-through is stronger when investors are more risk averse, when the mass of constrained investors is larger, when the mandate is weaker but spread over a larger mass of investors, when returns to scale are high, and when investors' labor income is less correlated with investment income.

and Way, Ives, Mealy, and Farmer (2022). In Section 3.2, we explain in greater detail that estimates from the macroeconomic literature suggest that $\alpha \approx 1$.

In summary, our analysis suggests that in a dynamic general equilibrium production economy designed to match the macroeconomic and asset-pricing moments of the US economy, portfolio mandates can have a quantitatively significant impact on aggregate capital allocation, even if their effect on the cost of capital is negligible. This result sharply contrasts with the conclusion drawn from studying endowment economies, where, because dividends are exogenous, there is a direct relation between firms' cost of capital and equilibrium capital allocations.

The main contribution of our paper is to study how much of the intended effect of portfolio mandates is undone in equilibrium. Our paper makes two key points. First, we highlight that studying the effects of portfolio mandates in an endowment economy, as most of the finance literature on portfolio mandates has done, is likely to lead to misleading conclusions. In particular, to measure the effectiveness of portfolio mandates, it is essential to focus on the *quantity* of capital flowing to the mandated sectors instead of the effect on the *cost* of capital. Second, we quantify the impact of portfolio mandates on capital allocation. Specifically, in a general-equilibrium production-economy model calibrated to match key macroeconomic and asset-pricing moments, we show that the real effect of portfolio mandates can be substantial, even if their impact on the cost of capital is negligible.

Our paper relates to the growing literature on socially responsible investing. This literature consists of two main strands: exclusion (exit) and engagement (voice). The first strand of this literature focuses on a "discount-rate channel" in that it studies the effects of limiting (or excluding entirely) investment in certain firms from an investor's portfolio on the cost of capital of targeted firms. The key mechanism in this literature is reduced risk-sharing, which affects the cost of capital in an endowment economy.[5] Notably, Heinkel et al. (2001) and Berk and van Binsbergen (2024) focus on the result that the effect on risk premia is small if profit-seeking investors can substitute for the capital they are restricted from holding. This intuition implies that mandates are effective only if they lead to significantly higher cost of capital for brown firms. Some empirical studies, e.g., Hong and Kacperczyk (2009) and Bolton and Kacperczyk (2021a,b) find a higher cost of debt and equity financing for "brown" (or "sin") firms although the magnitudes are not substantial, especially for

[5]See, e.g., Heinkel et al. (2001); Zerbib (2019, 2022); Berk and van Binsbergen (2024); Pástor, Stambaugh, and Taylor (2021, 2022); Pedersen, Fitzgibbons, and Pomorski (2021); Broccardo, Hart, and Zingales (2022); Sauzet and Zerbib (2022); De Angelis, Tankov, and Zerbib (2023); and Cheng, Jondeau, Mojon, and Vayanos (2023).

debt financing.[6] Other studies find insignificant or even lower returns for brown firms.[7] Our paper revisits this evidence by considering a production economy and studies the quantitative effects of portfolio mandates in a calibrated model designed to match key asset-pricing and macroeconomic moments.

In a recent paper, Dangl, Halling, Yu, and Zechner (2023a) study how different types of investor *preferences* affect equilibrium capital allocation. They find that if investments are endogenous, the effect of social preferences on corporate decisions may be sizable even if the difference in the cost of capital between the green and brown sectors is negligible. Dangl, Halling, Yu, and Zechner (2023b) extend this analysis to the case of time-varying social preferences. Unlike them, we show that portfolio mandates can affect capital allocations across sectors—despite small differences in the cost of capital across these sectors—in a standard macroeconomic framework with the portfolio mandate imposed on only a fraction of investors. We also illustrate that the degree of the returns to scale has a crucial impact on the ability of portfolio mandates to influence equilibrium capital allocation.

Finally, Hong, Wang, and Yang (2023) introduce decarbonization capital in a representative-agent dynamic stochastic general-equilibrium model and investigate the effectiveness of sustainable finance mandates in mitigating externalities within the economy. In their economy, the mandate affects all investors and is, therefore, by definition, effective. In contrast, we study an economy where only a fraction of investors are constrained. Because unconstrained investors can trade against constrained investors, in equilibrium, they can potentially undo the effect of mandates. Our finding that mandates can substantially impact equilibrium capital allocation aligns with their conclusion that mandates can effectively address externalities.

The second strand of literature focuses instead on the "cash-flow channel." Broccardo et al. (2022), following Hart and Zingales (2017), conclude that "voice" is more effective than "exit." Oehmke and Opp (2024) focus on activist investors who care about the social cost of investing in brown firms and provide a corporate perspective on the economics of motivated investors: socially responsible activists subsidize firms to adopt clean technologies. Chowdhry, Davies, and Waters (2019) show that if a firm cannot credibly commit to social goals, such subsidies take the form

[6] See, e.g., Goss and Roberts (2011); Chava (2014); Zerbib (2019); Baker, Bergstresser, Serafeim, and Wurgler (2022); Fatica, Panzica, and Rancan (2021); Huynh and Xia (2021); Seltzer, Starks, and Zhu (2022); Pástor et al. (2022); El Ghoul, Guedhami, Kwok, and Mishra (2011); Aswani and Rajgopal (2022)

[7] See, e.g., Larcker and Watts (2020); Flammer (2021); Tang and Zhang (2020), and Kontz (2023).

of investment by socially-minded activists. Our paper does not contribute directly to this strand of literature; however, our focus on production economies allows us to consider jointly the cash-flow and discount-rate channels emphasized separately by the engagement and exclusion literature, respectively.

The rest of the paper proceeds as follows. In Section 2, we develop intuition in a simple one-period (two-date) general equilibrium model that we can solve analytically. In Section 3, we assess the real impact of portfolio mandates in a multiperiod general-equilibrium model with heterogeneous investors that is calibrated to match asset-pricing and macroeconomic moments in the US economy. Section 4 concludes. Appendix A contains detailed proofs for the results of the single-period model studied in Section 2, Appendix B shows formally that the endowment economy is the limit of a production economy when the returns-to-scale parameter goes to zero, and the Internet Appendix provides details of the numerical solution of the multiperiod model studied in Section 3.

2 A Single-Period Equilibrium Model with Portfolio Mandates

To understand the economic intuition driving our key results, in this section, we consider a single-period general-equilibrium economy with several simplifying assumptions that make transparent the economic forces at work. Then, to establish the quantitative implications of portfolio mandates, in the next section, we consider a multiperiod model without these simplifying assumptions.

2.1 Setup

The economy consists of a continuum of firms and investors. Investors supply capital to firms. There is one consumption good, which is used as a numéraire. Consumption can be costlessly converted to capital.

2.1.1 Firms

We assume that there are two sectors in the economy, green and brown, and we refer to them using the subscripts G and B, respectively. Each of these sectors consists of a large number of atomistic, identical, all-equity-financed firms. There are no externalities. The key difference is that some investors have a portfolio mandate to hold sector G's equity. Output Y_j in each sector $j = G, B$ is given by the production function[8]

$$\tilde{Y}_j = \tilde{A}_j K_j^{\alpha}, \quad j = G, B, \tag{1}$$

where $\alpha \geq 0$ is the returns-to-scale parameter, $\tilde{A}_j$ denotes a random productivity shock, and K_j is the aggregate capital invested in sector j. We assume that the productivity shocks $\tilde{A}_j$ are normally distributed random variables, that is, $\tilde{A}_j \sim \mathcal{N}(\mu_{A_j}, \sigma^2_{A_j})$, $j = G, B$, and denote by ρ the correlation between $\tilde{A}_G$ and $\tilde{A}_B$.

Atomistic firms choose investment K_j in order to maximize their net present value (NPV_j), given by

$$\text{NPV}_j = \max_{K_j} \mathbb{E}[\tilde{M}\tilde{Y}_j] - K_j = \max_{K_j} \mathbb{E}[\tilde{M}\tilde{A}_j K_j^{\alpha}] - K_j, \tag{2}$$

with $\tilde{M}$ denoting the stochastic discount factor (SDF) that firms take as given. Firm j's optimal choice of capital K_j must then satisfy

$$\mathbb{E}[\tilde{M}\alpha\tilde{A}_j K_j^{\alpha-1}] = 1. \tag{3}$$

The Euler equation (3) implicitly defines the aggregate *demand* for capital from firms in sector j and the return on invested capital,[9]

$$\tilde{R}_j \equiv \alpha\tilde{A}_j K_j^{\alpha-1} = \alpha\frac{\tilde{Y}_j}{K_j}, \quad j = G, B. \tag{4}$$

The return $\tilde{R}_j$ represents the *cost of capital* for firm j. Because in this simple model, capital is the only input of production and can be adjusted costlessly, the realized profit is[10]

$$\tilde{\Pi}_j = \tilde{A}_j K_j^{\alpha} - \tilde{R}_j K_j = (1-\alpha)\tilde{A}_j K_j^{\alpha}. \tag{5}$$

Constant returns to scale, $\alpha = 1$, implies zero profits. Profits are positive (negative) when return to scale are decreasing (increasing), $\alpha < 1$ ($\alpha > 1$).

The NPV in sector j is given by

$$\text{NPV}_j = \mathbb{E}[\tilde{M}\tilde{A}K_j^{\alpha}] - K_j = K_j\left(\frac{1}{\alpha} - 1\right). \tag{6}$$

[8]Here we assume that capital is the only input of production. The model of Section 3 consider a more general production function with capital and labor as inputs.

[9]Putting together equations (3) and (4) leads to the familiar asset-pricing equation, $\mathbb{E}[\tilde{M}\tilde{R}_j] = 1$.

[10]Because capital can be adjusted costlessly, in this model, the marginal price of capital, or Tobin's Q, is always equal to 1. Section 3 generalizes the model to account for the case with convex adjustment costs.

The NPV is zero for constant returns to scale, positive, for decreasing return to scale, and negative for increasing returns to scale. As $\alpha \to 0$, which corresponds to the case of an *endowment economy* in which the output $Y_j = \tilde{A}_j$ is entirely exogenous, the optimal demand for capital $K_j \to 0$ and the return to capital and NPV are well defined in the limit.

From equation (4), we can infer that firms' *demand for capital* in sector j as a function of the expected cost of capital $\mathbb{E}[R_j]$ is

$$K_j^{\text{demand}} = \left(\frac{\alpha \mu_{A_j}}{\mathbb{E}[\tilde{R}_j]} \right)^{\frac{1}{1-\alpha}}. \tag{7}$$

We see from equation (7) that for $\alpha \in (0, 1)$, firm j's demand for capital is inversely related to the expected cost of capital $\mathbb{E}[\tilde{R}_j]$. From equation (4), when $\alpha \to 1$, $\mathbb{E}[R_j] = \mu_{A_j}$ for all K_j, and therefore the demand for capital is *infinitely elastic*. When $\alpha \to 0$, $K_j \to 0$ for all $\mathbb{E}[R_j]$, and the demand for capital is *infinitely rigid* at $K_j = 0$.

2.1.2 Investors

There is a continuum of identical investors who live for one period (two dates). Each investor is endowed with $e_{0,i}$ units of the consumption good. Consumption can be costlessly converted into capital for sector $j = G, B$. A fraction x of investors faces a constraint that either requires a minimum investment in green firms ("mandate") or restricts the maximum investment in brown firms ("screen"). We refer to the constrained investors using the subscript c. The remaining fraction $1 - x$ of investors are unconstrained, and we refer to them using the subscript u. For tractability, we assume that both types of investors have constant absolute risk aversion (CARA) preferences with an identical coefficient of risk aversion γ.

At $t = 0$, each investor $i = u, c$ chooses consumption $c_{0,i}$. Unconstrained investors can choose how to optimally allocate their savings in the G and B sectors and in the risk-free asset, yielding a gross return R_f, to be determined as part of the equilibrium. Constrained investors are restricted to holding a specific fraction of savings in each sector, with the residual invested in the risk-free asset. We denote by $w_{j,i}$ the portfolio weights, as a fraction of savings, that agent $i = u, c$ allocate to sector $j = G, B$. For constrained agents, $w_{j,c}$ are set to

$$w_{G,c} = \overline{w}_G, \quad w_{B,c} = \overline{w}_B, \quad \text{with} \quad \overline{w}_G + \overline{w}_B \leq 1. \tag{8}$$

At time 1, investors' terminal consumption $\tilde{c}_{1,i}$ consists of (1) the return on capital invested, which is determined by the firm's optimality condition (4), and (2) a fraction of the total profit $\tilde{\Pi}_j$ from each sector, defined in equation (5). Specifically, each investor $i = u, c$ faces the following intertemporal budget constraint

$$\tilde{c}_{1,i} = (e_{0,i} - c_{0,i}) \Big(R_f + w_{G,i}(\tilde{R}_G - R_f) + w_{B,i}(\tilde{R}_B - R_f) \Big) + \tilde{\pi}_{G,i} + \tilde{\pi}_{B,i}, \tag{9}$$

where $\tilde{\pi}_{j,i}$ is investor's i claim to the total profit $\tilde{\Pi}_j$. Because investors are atomistic, when choosing their optimal portfolios $w_{j,i}$, they take the profit share $\tilde{\pi}_{j,i}$ and the return on capital $\tilde{R}_j$ as given because these are quantities that are decided by the firm's optimization problem and, therefore, are beyond the control of atomistic investors.

The unconstrained agent solves the following problem

$$\max_{\{c_{0,u}, w_{G,u}, w_{B,u}\}} -\frac{e^{-\gamma c_{0,u}}}{\gamma} - \beta \mathbb{E}\left[\frac{e^{-\gamma \tilde{c}_{1,u}}}{\gamma} \right], \tag{10}$$

where β is a time-preference parameter and where $\tilde{c}_{1,u}$ satisfies the intertemporal budget constraint in equation (9). Constrained agents only choose their consumption at time 0 because their portfolio weights are determined exogenously by the mandate. Specifically, the constrained agents solve the following problem

$$\max_{c_{0,c}} -\frac{e^{-\gamma c_{0,c}}}{\gamma} - \beta \mathbb{E}\left[\frac{e^{-\gamma \tilde{c}_{1,c}}}{\gamma} \right], \tag{11}$$

where $\tilde{c}_{1,c}$ is given by the intertemporal budget constraint (9) in which $w_{G,c} = \overline{w}_G$ and $w_{B,c} = \overline{w}_B$.

The following proposition characterizes the optimal consumption of both agents, and the optimal portfolio of the unconstrained agent.

Proposition 1. *Given the return on invested capital $\tilde{R}_j = \alpha \tilde{A}_j K_j^{\alpha-1} = \alpha \tilde{Y}_j / K_j$, $j = G, B$ from equation (4) and the gross risk-free rate R_f, the unconstrained and constrained investors supply of capital to sector $j = G, B$ is*

$$k_{j,u} \equiv w_{j,u}(e_{0,u} - c_{0,u}), \tag{12}$$

$$k_{j,c} \equiv \overline{w}_j(e_{0,c} - c_{0,c}), \tag{13}$$

where

$$w_u \equiv [w_{G,u}, w_{B,u}]^\top = \frac{1}{(e_{0,u} - c_{0,u})} \frac{\alpha}{\gamma} \Sigma_R^{-1} (\mathbb{E}[\tilde{R}] - R_f \mathbf{1}), \tag{14}$$

with Σ_R denoting the covariance matrix of returns, $\tilde{R} \equiv [\tilde{R}_G, \tilde{R}_B]^\top$, and $\mathbf{1} = [1, 1]^\top$. The consumption $c_{0,i}$, $i = u, c$, satisfies equations (A14) and (A23) in Appendix A.

Proposition 1 can be used to infer households' *supply* of capital to sector j, taking as given the return $\tilde{R}_j$ and the risk-free rate R_f. To fix ideas, consider the simpler case of uncorrelated productivity shocks. In this case, from equations (12), (13), and (14), the total supply of capital to sector $j = G, B$ can be written as

$$K_j^{\text{supply}} = \underbrace{x\,\overline{w}_j(e_{0,c} - c_{0,c})}_{\text{supply of constrained investor}} + \underbrace{(1-x)\frac{\alpha}{\gamma}\frac{(\mathbb{E}[\tilde{R}_j] - R_f)}{\text{Var}[\tilde{R}_j]}}_{\text{supply of unconstrained investors}}. \tag{15}$$

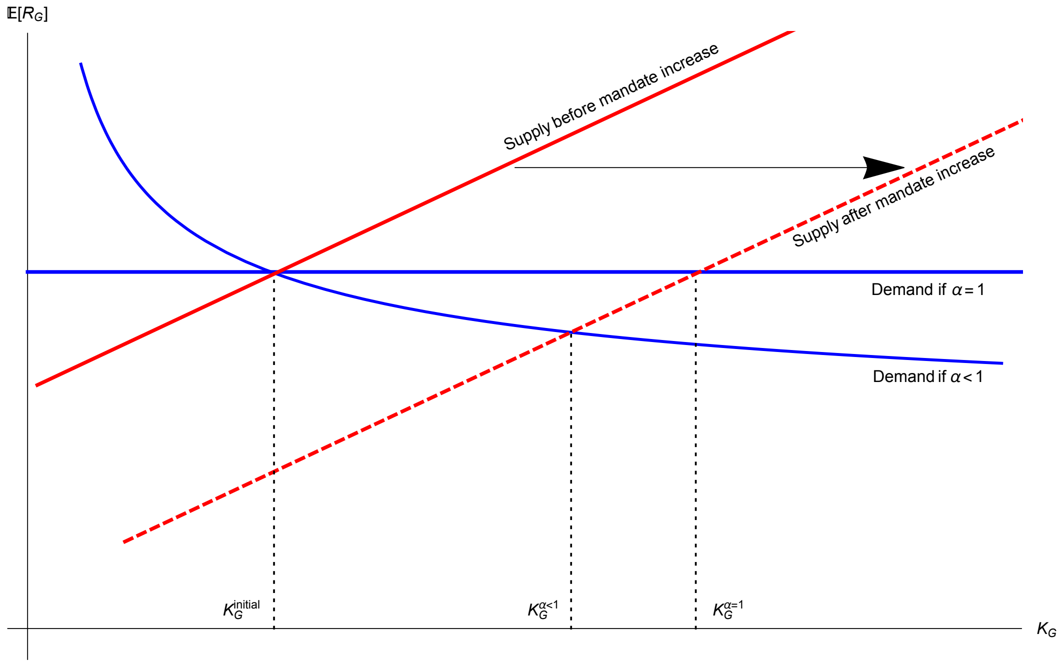
Equation (15) shows that, for $\alpha \in (0, 1]$ the supply of capital K_j^{supply} increases with the expected return, $\mathbb{E}[\tilde{R}_j]$. Furthermore, the sensitivity of capital supply K_j^{supply} to the expected cost of capital $\mathbb{E}[\tilde{R}_j]$ decreases as risk aversion γ increases, as the return to scale parameter α decreases, as the fraction of constrained agents x increases, and as the volatility of returns $\text{Var}[\tilde{R}_j]$ increases. A low sensitivity of capital supply to its costs imply a "steeper", or less elastic, curve in the $(\mathbb{E}[\tilde{R}_j], K_j)$-space. In the same space, a stronger mandate, i.e., a higher $\overline{w}_j$ corresponds to a shift of the supply curve to the right (see the dashed line in Figure 1).

Figure 1 provides an intuitive way to understand how the returns-to-scale parameter α influences the effectiveness of an increase in a portfolio mandate in favor of G capital even in partial equilibrium. In this figure, the horizontal axis represents the aggregate capital stock in the green sector, K_G, and the vertical axis represents the expected costs of capital, $\mathbb{E}[R_G]$. The two upward-sloping red lines represent capital *supply* from equation (15): the solid red line shows the supply before the increase in the mandate, while the dashed red line shows the supply after the increase in the mandate. Both supply functions are drawn for a particular value of α, taking as given the returns investors face.

An increase in the mandate that requires some investors to increase their investments in asset G leads to higher capital being supplied to sector G, represented in the figure by a shift from the solid red line to the dashed red line. However, because the demand for capital from firms is downward sloping, the effectiveness of the mandate depends on the elasticity of demand (blue lines). When $\alpha = 1$, the demand for capital from firms is perfectly elastic (flat blue line), implying that the aggregate supply of capital to the green sector, K_G, increases one-for-one with the constrained

Figure 1: Mandate effectiveness

The figure shows the firms' demand for capital from equation (7) and the investors' supply, from equation (15). The solid red line shows the supply function before the increase in the mandate, while the dashed red line shows the supply after the increase in the mandate, which increases the supple of capital to the green sector. Both supply functions are drawn for a given value of α, taking as given the returns faced by investors. The firms' demand for capital is shown by the blue lines, which are drawn for two values of α: (1) $\alpha < 1$ and (2) $\alpha = 1$.



agent's investment (from K_G^{initial} to $K_G^{\alpha=1}$), regardless of the capital supply elasticity. On the other hand, when $\alpha < 1$, firms' demand for capital is less elastic (curved blue line), in which case the increase in K_G is smaller (from K_G^{initial} to only $K_G^{\alpha<1}$) than it was for the case of perfectly elastic demand (from K_G^{initial} to $K_G^{\alpha=1}$). Thus, Figure 1 illustrates that, even ignoring equilibrium effects, the effectiveness of a mandate to increase investment in the green sector will be reduced as the returns-to-scale parameter α from 1 toward 0.

Figure 1 also indicates that the effect on $\mathbb{E}[R_G]$, the cost of capital in the green sector, of a change in the mandated investment in this sector, depends on the firms' demand elasticity: when α is close to 1, the effect of a change in the mandate on the cost of capital is close to zero; in contrast, when α is close to 0, the effect on the cost of capital is larger.

2.1.3 Equilibrium

Proposition 1 provides the optimal portfolio and consumption choices of atomistic investors, *given* the return on capital, $\tilde{R}_j = \alpha \tilde{A}_j K_j^{\alpha-1}$, and the risk-free rate, R_f. In equilibrium, these returns are determined endogenously by imposing the market-clearing conditions that the aggregate supply of capital from households equals the aggregate demand for capital from firms and that the aggregate quantity of risk-free borrowing (or lending) is zero. The equilibrium aggregate capital K_j (and hence the return $\tilde{R}_j$) in sector j and the risk-free rate are determined by the following three market-clearing conditions:

$$K_G = xk_{G,c} + (1-x)k_{G,u}, \tag{16}$$

$$K_B = xk_{B,c} + (1-x)k_{B,u}, \quad \text{and} \tag{17}$$

$$0 = \underbrace{x(e_{0,c} - c_{0,c} - k_{G,c} - k_{B,c})}_{\text{constrained risk-free borrowing/lending}} + \underbrace{(1-x)(e_{0,u} - c_{0,u} - k_{G,u} - k_{B,u})}_{\text{unconstrained risk-free borrowing/lending}}, \tag{18}$$

where the portfolio weights $w_{j,u}$ and the consumptiona $c_{0,u}$ and $c_{0,c}$ are given in Proposition 1. The above system of equations does not admit a closed-form solution. In what follows we analyze the equilibrium numerically focusing on the effect of the return-to-scale parameter α.

2.1.4 Effective Mandate Pass-Through

To quantify the equilibrium effect of portfolio mandates, we introduce the concept of *effective mandate pass-through*, a measure designed to capture the equilibrium impact of a portfolio mandate. We define the effective pass-through as the fraction of the *intended* impact of a mandate that *survives* in general equilibrium, that is,

$$\text{Effective mandate pass-through} \equiv \frac{w_G^{\text{GE}} - w_G^*}{w_G^{\text{PE}} - w_G^*}. \tag{19}$$

where w_G^* is the ratio of green capital to total capital in an economy without mandates (0.50 when both sectors are symmetric); w_G^{GE} is the ratio of green capital to total capital in the economy with constrained agents, determined in general equilibrium; and w_G^{PE} is the ratio of green capital if unconstrained agents do not change their portfolio shares in response to changes by constrained agents and to equilibrium movements in expected returns; in other words, it is the share of green capital in partial equilibrium. We define it as $w_G^{\text{PE}} \equiv x \times \overline{w}_G + (1-x) \times w_G^*$. Hence, the effective mandate pass-through in equation (19) measures the percentage of the maximum effect of the mandate that is actually achieved in equilibrium.

For a specific example of the effective mandate pass-through measure, consider the case of an economy where the green and brown sectors are perfectly symmetric so that, in the absence of a mandate, it would be optimal for all investors to invest 0.50 in sector G and 0.50 in B. Suppose now that $x = 50\%$ of investors are constrained to invest $\overline{w}_G = 0.75$ in the green sector and $\overline{w}_B = 0.25$ in the brown sector, while $1 - x = 50\%$ of the investors are unconstrained. Then, the maximum allocation of capital to G as a result of the mandate imposed on half the investors would be: $w_G^{\text{PE}} = 50\% \times 0.75 + 50\% \times 0.50 = 50\%(0.75 + 0.50) = 62.50\%$, implying that the maximum *reallocation* of capital is $w_G^{\text{PE}} - w_G^* = 12.50\%$. Suppose, however, that in general equilibrium, the actual reallocation of capital to G is only 6.25%. Then, the effective mandate pass-through would be $\frac{6.25\%}{12.50\%} = 50\%$.

2.2 Results

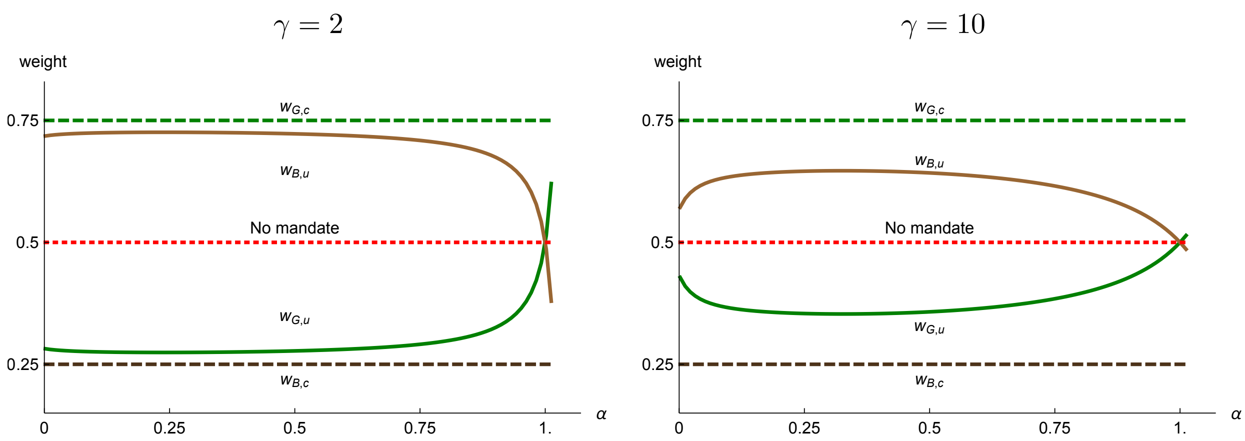
In this section, we illustrate the properties of the general equilibrium in the simple model with portfolio mandates described above. To do so, we consider an economy with two identical and independent technologies, G and B, where the productivity shocks $\tilde{A}_j \sim \mathcal{N}(\mu_j, \sigma^2_{A_j})$, with $\mu_{A_G} = \mu_{A_B} = 1.05$ and $\sigma_{A_G} = \sigma_{A_B} = 0.2$. Investors have CARA preferences with absolute risk aversion γ and are identically endowed with wealth $e_{0,u} = e_{0,c} = 1$. We set the time-preference parameter to $\beta = 0.99$ (implying a per-period risk-free rate of $1/\beta = 1.01\%$ in a deterministic, representative-agent economy). We assume that $x = 50\%$ of the investors face a mandate to invest $w_{G,c} = \overline{w}_G = 0.75$ of their savings in sector G and $w_{B,c} = \overline{w}_B = 0.25$ in sector B. The quantities of interest obtained from the numerical solution are illustrated in Figures 2 and 3. The panels on the left in these figures refer to the case of low risk aversion, $\gamma = 2$, while the panels on the right refer to the case of high risk aversion, $\gamma = 10$.

Panel A of Figure 2 shows the portfolio weights of investors who are constrained by the portfolio mandate and who are unconstrained. The dotted red line represents the portfolio weights of all investors if there were no mandates: in this case, each investor would have 0.50 invested in the green asset and 0.50 in the brown asset. If a fraction of investors are constrained by the portfolio mandate, their portfolio weights are displayed by the flat dashed lines—$w_{G,c} = \overline{w}_G = 0.75$ for the green asset and $w_{B,c} = \overline{w}_G = 0.25$ for the brown asset. The plot also shows the portfolio

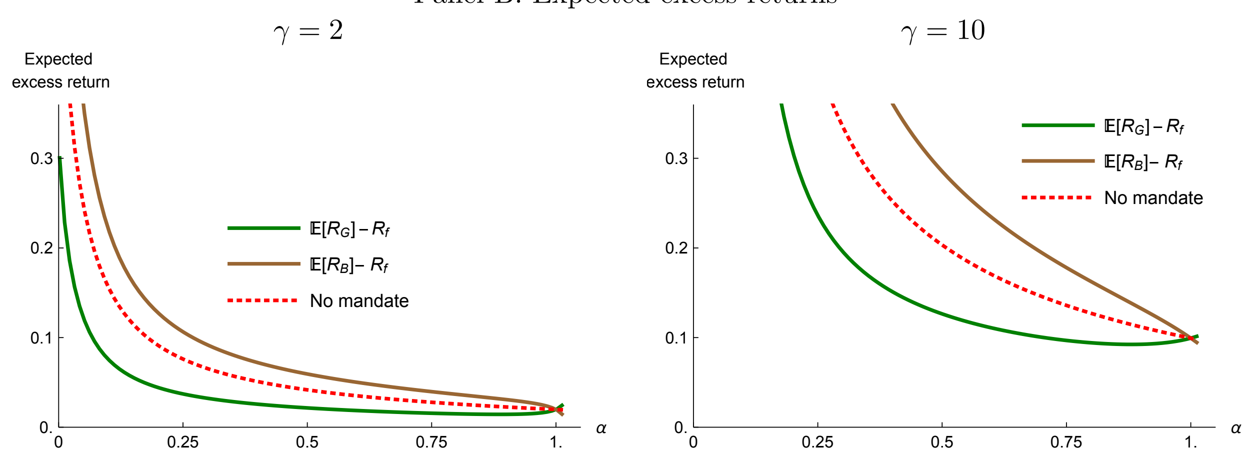
Figure 2: Equilibrium portfolio weights and expected returns

Panel A shows the equilibrium portfolio weights of the unconstrained and constrained investors that are allocated to the G and B sectors. Panel B shows the equilibrium expected returns in excess of the risk-free rate. The dashed red line represents the weights and expected returns in the absence of a portfolio mandate. In the left panels, agents' risk aversion is $\gamma = 2$, and in the right panels $\gamma = 10$. The other parameter values are: $e_{0,u} = e_{0,c} = 1$, $\mu_{A_G} = \mu_{A_B} = 1.05$, $\sigma_{A_G} = \sigma_{A_B} = 0.2$, $x = 50\%$, $\overline{w}_G = 0.75$, $\overline{w}_B = 0.25$.

Panel A: Portfolio weights



Panel B: Expected excess returns



weights of the unconstrained investors. The solid green and brown lines represent $w_{G,u}$ and $w_{B,u}$, respectively. Panel B shows that the mandate increases the expected return of the brown asset relative to that of the green in the region where $\alpha < 1$. Because the mandate makes the brown asset more attractive, the portfolio of the unconstrained investor overweights the brown asset and underweights the green. Consequently, in equilibrium the portfolio chosen by the unconstrained agent undoes part of the effect of the mandate.

Comparing the left and right plots of Panel A, we see that when risk aversion is low (left panel) the unconstrained agents are willing to hold a less diversified portfolio than when risk aversion is high (right panel). Hence, all else being equal, when risk aversion is low, the portfolio choice of unconstrained investors tends to "undo" the intended effect of the mandate. The key takeaway is the magnitude of the effect of the mandate depends crucially on the level of the return-to-scale parameter α. When α is small, the portfolio weights chosen by unconstrained investors undo most of the benefits of the portfolio mandate; that is, the substantial *decrease* in $w_{G,u}$ undoes the effect of the mandated *increase* in $\overline{w}_{G,c}$, relative to the no-mandated 0.50. However, if $\alpha \approx 1$, the unconstrained agent holds the same portfolio as in the case of no mandate, regardless of the level of risk aversion. In this case, the mandate is most effective.

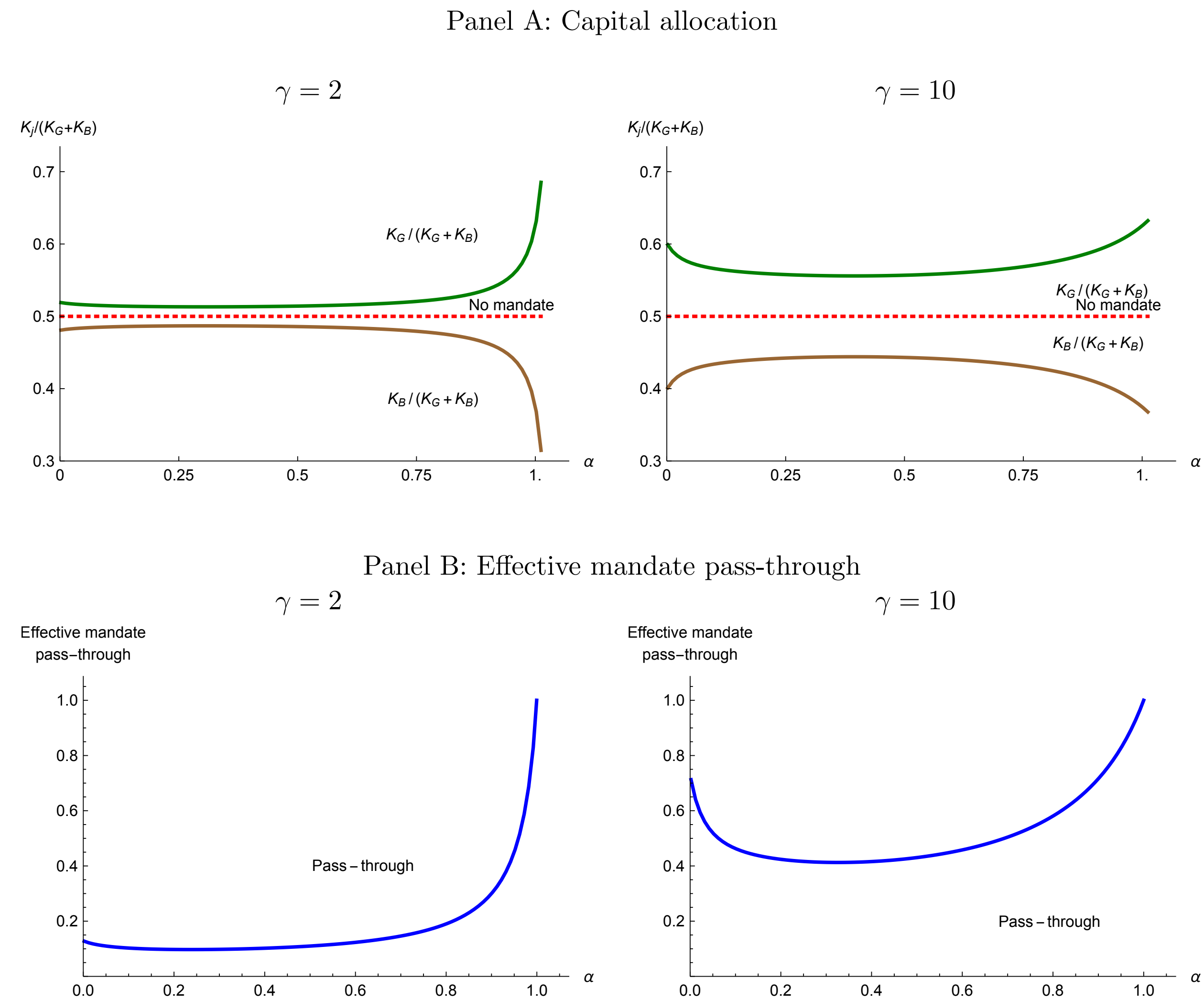
Panel B of Figure 2 shows that the mandate, by creating excess demand for G capital, increases its price and lowers its required return (cost of capital) relative to the B sector. This effect is amplified by high risk aversion, as can be seen by comparing the left and right plots of Panel B. However, the panel also shows that, in equilibrium, the spread $\mathbb{E}[R_B] - \mathbb{E}[R_G]$ decreases with α. In fact, for the case where the returns-to-scale parameter is $\alpha = 1$, the difference in the cost of capital between the two sectors is zero (Panel B), while the difference in the capital allocation is extremely large (Panel A).

Figure 3 shows in Panel A the equilibrium aggregate sectoral capital allocation and in Panel B the effective mandate pass-through, which is defined in equation (19). The figure shows that the equilibrium allocation of physical capital varies substantially with the returns-to-scale parameter, α. In particular, the mandate increases the allocation of capital to the G sector relative to the benchmark no-mandate case in which the allocation is 0.50. The equilibrium capital allocation to the green sector is closer to the no-mandate case for low values of risk aversion (left plot) and for low values of α. This is a direct implication of the portfolio decisions of unconstrained agents discussed in Figure 2. As α increases, firms' demand for capital becomes more elastic, the cost of capital of G and B firms is more similar, and therefore mandates are effective in increasing the capital allocated to the G sector.

The effectiveness of mandates is summarized in the pass-through measure shown in Panel B of Figure 3. The effective mandate pass-through, defined in equation (19), is the capital allocated to the G sector in equilibrium as a fraction of the maximum allocation that would result if we ignored the equilibrium effects on asset prices. Consistent with the patterns of portfolio weights

Figure 3: Equilibrium capital allocation and mandate pass-through

Panel A shows the equilibrium capital allocation across the G sector (green line) and B sector (brown line) as a function of the returns-to-scale parameter, α. The dashed red line is the capital allocation without a portfolio mandate. Panel B shows the equilibrium mandate pass-through, defined in equation (19). In the left panels, agents' risk aversion is $\gamma = 2$ and in the right panels $\gamma = 10$. The other parameter values are: $e_{0,u} = e_{0,c} = 1$, $\mu_{A_G} = \mu_{A_B} = 1.05$, $\sigma_{A_G} = \sigma_{A_B} = 0.2$, $\rho = 0$, $x = 0.5$, $\overline{w}_G = 0.75$, $\overline{w}_B = 0.25$.



and capital allocation described above, Panel B shows that the mandate's effectiveness is small for low values of the returns-to-scale parameter α but can be substantial as α approaches 1, reaching a value of 100 percent when $\alpha = 1$. Risk aversion significantly impacts mandate effectiveness. All else being equal, a higher risk aversion (the plots on the right) increases the pass-through because unconstrained investors are less willing to hold poorly diversified portfolios, thus increasing the effectiveness of mandates. However, risk aversion and, more generally, the elasticity of capital supply, are irrelevant to the mandate's effectiveness when $\alpha = 1$.

In summary, Figures 2 and 3 show that to fully understand the effectiveness of portfolio mandates, it is essential to consider production models. Models without production, such as the endowment models of Heinkel et al. (2001) and Berk and van Binsbergen (2024), where output is exogenous, can lead to the inference that a low cost-of-capital spread also implies a negligible effect on the allocation of real capital across the G and B sectors, which is not true in general. As the case of constant returns to scale shows, the difference in returns can be zero, yet the mandate's real effect can be substantial. Thus, studying the difference in cost of capital for firms in the G and B sectors is generally not the best way to evaluate whether portfolio mandates are effective; instead, one should directly measure the physical capital allocated to each sector.

So far, we have focused our analysis on the cost of capital of *firms*. But, one could also discuss the implications of portfolio mandates for *investors*. Obviously, the expected return of unconstrained investors' portfolios is higher than that of constrained agents. The reason for this is that when some investors are constrained by the portfolio mandate to invest in the green asset, demand for the brown asset relative to that for the green asset decreases, so the relative price of the brown asset decreases, leading to an increase in its expected return, and unconstrained investors take advantage of this by tilting their portfolio toward brown assets. However, as $\alpha \approx 1$, the difference in expected returns is small compared to the case without a mandate. In this case, although mandates do affect equilibrium capital allocation, their effect does not have any impact on the moments of asset returns or the portfolio weights of unconstrained investors.

The results of this section, obtained from a transparent model, are meant to illustrate the *qualitative* impact of portfolio mandates in a general equilibrium production economy. To assess these claims *quantitatively*, we now turn to a state-of-the-art dynamic general-equilibrium production economy model.

2.3 Primary vs. secondary markets

One might think that trade in the secondary market would render our argument moot. For instance, a constrained investor could, upon facing a constraint, simply offer to trade green shares for brown shares with an unconstrained investor, thereby satisfying the constraint without altering the physical quantity of capital. However, this argument overlooks the fact that the unconstrained investor would become underdiversified and would therefore demand a discount on the brown shares.

Consider a scenario with no capital adjustment costs and constant returns to scale. In this case, the only way for the constrained investor to avoid the discount on the sale of brown shares is by directly shifting physical capital from brown to green. This will allow the investor to meet the mandate while keeping the unconstrained investor perfectly diversified.[11] Since there are no adjustment costs and returns to scale are constant, this capital shift would be costless and the mandate pass-through will be 100%. On the other hand, when there are decreasing returns to scale or capital adjustment costs, physically shifting capital becomes costly, resulting in less than a full pass-through. In Section 3, we examine more realistic cost scenarios.

3 A Multiperiod Equilibrium Model with Portfolio Mandates

In this section, we embed portfolio mandates in a canonical neoclassical general equilibrium model with production that is then calibrated to match empirical macroeconomic and asset-pricing moments. Our model, when returns to scale are constant ($\alpha = 1$) and there are no portfolio constraints, is a canonical real-business-cycle model, similar to King et al. (1988) and Jermann (1998), among many others.[12] We use this model to assess quantitatively the impact of portfolio mandates in equilibrium.

In the baseline version of the multiperiod model, we assume that the technologies for the firms in the green and brown sectors are identical. In the absence of mandates, the equilibrium in this economy implies that each investor allocates an equal fraction of its risky portfolios to the two sectors. As a result, in equilibrium, capital is equally distributed between the green and brown sectors. Portfolio mandates distort this allocation directly, through the portfolio constraint, and indirectly through the equilibrium effect on prices. Solving for the equilibrium in this economy allows us to assess the magnitudes of these distortions quantitatively. The analysis in this section highlights that the qualitative effects identified in the simple model of Section 2 are also quanti-

[11]For example, constrained investors might be "activists" by pressuring the brown firms they own to transition to green. Alternatively, they could raise financing for green firms, use those funds to purchase physical capital from brown firms, and then pay themselves a dividend from the proceeds. This transaction ultimately reduces the physical capital of the brown sector.

[12]For example, our model is identical to King et al. (1988) if we shut down capital-adjustment costs and set the utility of leisure to zero, and is similar to Jermann (1998) with the only difference being the adjustment-cost specification—we use quadratic adjustment costs, as in Hayashi (1982).

tatively substantial. In particular, portfolio mandates can significantly impact the allocation of real capital even when the difference in the cost of capital in the two sectors is negligible. Finally, we also study the transition from an equilibrium without portfolio mandates to one with portfolio mandates. Our analysis shows that, although portfolio mandates can have a large impact in the long term, the transition may be very slow if capital adjustment costs are substantive.

3.1 Setup

Below, we describe how we model investors, firms, and labor. We conclude this section by specifying the conditions for equilibrium.

3.1.1 Investors

We consider an infinite-horizon, overlapping generation (OLG) economy in discrete time $t = \{0, 1, \ldots\}$. The economy is populated by a continuum of measure-one "perpetual youth" investors with a per-period probability of survival p, following Blanchard (1985). There is no bequest motive, and each newborn investor inherits the average wealth of the dead investor.[13] Investors supply labor and invest in firms with one of two production technologies: G and B. A fraction x of agents are born constrained (c) and they stay constrained throughout their life. Constrained investors are subject to a portfolio mandate to hold the risky assets in a given fixed proportion. The remaining fraction $1 - x$ of investors are unconstrained (u). When investors die, they are replaced by new investors whose wealth is the average of the wealth of both constrained and unconstrained deceased investors. Because the wealth levels of constrained and unconstrained investors are not significantly different, this has a minimal impact on the wealth distribution within each period. However, over the long term, this mechanism prevents the model from drifting towards a wealth share of 1 or 0.

Let $W_{i,t}$, $C_{i,t}$, and $L_{i,t}$ represent, respectively, the net worth, consumption, and labor supply of investor $i = \{u, c\}$. Investors are endowed with one unit of labor that they supply inelastically, that is, $L_{i,t} = 1$ for all i and t for the wage ω_t. Let $B_{u,t+1}$ denote the face value at time $t + 1$ of the one-period risk-free bond held by the unconstrained investors and by $R_{f,t}$ the risk-free rate; hence, $B_{u,t+1}/R_{f,t}$ represents the time t value of the holdings of the risk-free bond. We denote by $w_{G,i,t}$

[13] Allowing for an OLG setup with such transfers helps with the stability of the numerical solution. Without this, the constrained investors' share of wealth can drift toward zero or one for long periods. We have experimented with alternative values for the probability of death, including probabilities very close to zero, and our key results on the effect of mandates are fairly insensitive to this parameter.

and $w_{B,i,t}$ the share of the investible wealth of investor i that is invested in the G and B sectors, respectively. The cum-dividend time-t values of the green and brown firms are, respectively, $V_{G,t}$ and $V_{B,t}$, with dividends $D_{G,t}$ and $D_{B,t}$.

We assume investors have Epstein-Zin recursive preferences with risk aversion γ, elasticity of intertemporal substitution ψ, and time-discount parameter β. The unconstrained investors solve

$$U_u(W_{u,t}) = \max_{\{C_{u,t}, w_{G,u,t}, w_{B,u,t}\}} \left\{ C_{u,t}^{1-1/\psi} + p \times \beta \left(\mathbb{E}_t[U_u(W_{u,t+1})^{1-\gamma}] \right)^{\frac{1-1/\psi}{1-\gamma}} \right\}^{\frac{1}{1-1/\psi}}, \quad (20)$$

subject to the intertemporal budget constraint

$$W_{u,t+1} = (W_{u,t} + \omega_t L_{u,t} - C_{u,t}) \left(R_{f,t} + w_{G,u,t}(R_{G,t+1} - R_{f,t}) + w_{B,u,t}(R_{B,t+1} - R_{f,t}) \right), \quad (21)$$

where the return $R_{j,t+1} = V_{j,t+1}/(V_{j,t} - D_{j,t})$, $j = \{G, B\}$, with $V_{j,t}$ and $D_{j,t}$ denoting firm j's value and dividend, defined below in equations (23) and (25). The optimality conditions for the problem (20)–(21) result in three standard Euler equations, one for each of the three financial assets, that is, the bond and the stocks for G and B firms.

The constrained investors' problem is identical to that of unconstrained investors, with the only difference being that constrained investors cannot choose their equity shares; instead, they face a mandate to invest in the G and B sectors in given proportions, $\overline{w}_{j,c} \in (0, 1)$, $j = \{G, B\}$.[14] As a result, the optimality conditions for constrained investors consist of a single Euler equation, characterizing the optimal consumption decision.

3.1.2 Firms

There are two types of firms, G and B, which make optimal hiring and investment decisions to maximize shareholders' value. As in a standard neoclassical model, we assume that firms incur convex capital-adjustment costs when making investment decisions (e.g., Hayashi, 1982). We assume that firms are all-equity financed, with investors being the shareholders. Investors' consumption and portfolio decisions result in a supply of capital $K_{j,t}$, $j = \{G, B\}$ to the two sectors of the economy. Firms operate in a perfectly competitive market and produce identical goods but are subject to different productivity shocks.

[14] In our baseline model, the constrained agent makes no portfolio choice at all because the risk-free share is simply equal to $1 - \overline{w}_{G,c} - \overline{w}_{B,c}$ which is fixed. We have also solved a version of the model where constrained agents can choose the risky vs. risky share of the portfolio but are constrained as to the brown vs. green fraction within the risky portfolio. The results are quantitatively similar to our baseline case in Table 3, although the effective mandate pass-through is slightly weaker.

Firms produce output $Y_{j,t}$ according to a Cobb-Douglas production function

$$Y_{j,t} = (K_{j,t})^{\alpha\theta}(A_{j,t}L_{j,t})^{(1-\theta)}, \tag{22}$$

where $\theta \in [0,1]$ controls the relative importance of capital in the production and $\alpha \in [0,1]$ is a returns-to-scale parameter. The production function exhibits constant returns to scale if $\alpha = 1$ and declining returns to scale if $\alpha < 1$. The quantity $A_{j,t}$ in equation (IA3) denotes a stochastic process representing neutral (TFP) productivity shocks. This shock may contain aggregate or firm-specific components; the aggregate component may have stationary and non-stationary components.

Firms choose labor $L_{j,t}$ and investment $I_{j,}$ to maximize shareholder value. Formally, firm j's value $V_{j,t}$ results from the solution of the following problem

$$V_{j,t}(K_{j,t}) = \max_{L_{j,t},I_{j,t}} D_{j,t}(K_{j,t}) + \mathbb{E}_t\left[\tilde{M}_{u,t+1}V_{j,t+1}(K_{j,t+1})\right], \tag{23}$$

where $\tilde{M}_{u,t+1}$ is the stochastic discount factor (SDF) of the unconstrained investors, who are the marginal investors in this economy. When maximizing shareholder value, firms take $\tilde{M}_{u,t+1}$ as given. The optimization in (23) is subject to the capital accumulation equation, which, using $\delta > 0$ to denote capital depreciation, is

$$K_{j,t+1} = (1-\delta)K_{j,t} + I_{j,t}. \tag{24}$$

As is well known, when $\alpha = 1$ the firm value $V_{j,t}(K_{j,t})$ can be written as $V_{j,t}(K_{j,t}) = K_{j,t} \times Q_{j,t}$, with $Q_{j,t}$ denoting Tobin's Q, or the market-to-book ratio. In the presence of adjustment costs, there is a wedge between the price of installed capital (firm value) and uninstalled capital (consumption), and therefore, Tobin's Q will, in general, be different from one.

3.1.3 Labor

In equation (23), $D_{j,t}(K_{j,t})$ represents the dividends firm j distributes to its shareholders. To define this quantity, we need to describe how wages are set in the model. If labor markets were perfectly flexible, the aggregate wage would be far too volatile, having the same properties as output; this would also counterfactually imply that profits and dividends are counter-cyclical and that equity volatility is too low. As shown by Favilukis and Lin (2016), introducing wage rigidity into a production-economy model makes wages, profits, and dividends behave more like in the data and improves the model's asset-pricing performance. Because asset prices are crucial for our mechanism, we introduce wage rigidity in a reduced-form manner.

Specifically, we assume that firms must hire at least labor $\overline{L} < L_{j,t}$ at a rigid wage $\overline{\omega}_t$, but are free to choose how much remaining labor, $L_{j,t} - \overline{L}$, to hire, and that labor is paid a competitive spot wage $\tilde{\omega}_t$ that clears labor markets.[15] Because labor supply is inelastic and set to $L_{j,t} = 1$, the average wage paid is therefore $\omega_t L_{j,t} = \overline{\omega}_t \overline{L} + \tilde{\omega}_t (L_{j,t} - \overline{L})$, which, in equilibrium, is smoother than $\tilde{\omega}_t$. Note that the firm's first-order condition for investment is independent of $\overline{L}$; therefore, this reduced-form way of modeling wage rigidity does not affect the firm's investment choice. However, it does affect dividends, wages paid, firm value, and equity returns. Firm j's dividends are therefore given by

$$D_{j,t}(K_{j,t}) = Y_{j,t} - \omega_t L_{j,t} - I_{j,t} - \eta \left(\frac{I_{j,t}}{K_{j,t}} - \hat{\delta} \right)^2 K_{j,t}, \quad \eta > 0, \ \hat{\delta} > 0, \tag{25}$$

where $Y_{j,t}$ is output, defined in equation (IA3), $\hat{\delta} = \delta + \hat{g}$ is capital depreciation δ gross of the growth rate g, and the term $\eta \left(\frac{I_{j,t}}{K_{j,t}} - \hat{\delta} \right)^2 K_{j,t}$ represents a quadratic adjustment-cost function.[16]

3.1.4 Equilibrium

An equilibrium of this economy consists of the following: (i) investors' consumption and portfolio policies, $\{C_{i,t}, w_{G,i,t}, w_{B,i,t}\}$; (ii) firms' investment and hiring policies, $\{I_{j,t}, L_{j,t}\}$; (iii) wages $\tilde{\omega}_t$; (iv) prices of the two risky assets, $\{V_{G,t}, V_{B,t}\}$, and the risk-free rate, $R_{f,t}$, such that: investors maximize their lifetime utility in equation (20), firms maximize shareholder value in equation (23), and the markets for labor, the two risky assets, and the risk-free asset clear. By Walras' law, the goods market automatically clears; that is, the aggregate budget constraint holds.

3.2 Calibration

We solve numerically for an equilibrium in the economy described above using dynamic programming. We calibrate the model's parameters at an annual frequency to match key macroeconomic

[15] The reason for the subscript t on the rigid wage $\overline{\omega}_t$ is that, as we discuss below, productivity in our model grows at rate g, which implies that along the balanced growth path, most variables in the model grow at rate $\hat{g} = (1+g)^{\alpha} - 1$. In the detrended version of the model, the rigid wage is constant and equal to the unconditional average of the detrended wage, which we define as $\overline{\omega} = \mathbb{E}[\omega_t]$. However, because the economy is growing, the rigid wage must grow too, therefore $\overline{\omega}_t = \overline{\omega}(1+g)^{\alpha t}$.

[16] Because we set gross depreciation to $\hat{\delta} = \delta + \hat{g}$, adjustment costs are zero in the steady state.

and asset-pricing moments. Table 1 shows the parameter values used in our baseline calibration. In our baseline case, we consider a coefficient of relative risk aversion $\gamma = 5$. However, we also solve the model with higher risk aversion, up to $\gamma = 50$, to explore the model's implications with a more realistic value of the equity risk premium. We set the elasticity of intertemporal substitution (EIS) to $\psi = 0.2$ so that for the benchmark case of $\gamma = 5$, the investors' preferences are time-separable CRRA. We set $\beta = 1.025$ to target a ratio of capital to output K/Y of around 2.9 in the steady state and an aggregate productivity growth rate of $g = 1.5\%$, which implies that most variables along the balanced growth path grow at a rate $\hat{g} = (1+g)^{\alpha} - 1$.[17] We assume that 50% of investors are subject to a portfolio mandate ($x = 0.5$) requiring them to hold their wealth in the ratio 75% to 25% between the G and B sectors. We set the probability of survival p to be 99% per period.

We choose parameters for the Markov chain describing the TFP process to match the volatility and autocorrelation of Hodrick-Prescott (H-P) filtered output.[18] Specifically, we assume that the firm's productivity is separated into aggregate and industry-level components: $A_t^j = A_t Z_t^j$. The aggregate component $A_t = (1+g)^t$ captures the growth trend. The industry component Z_t^j drives the business cycle. We assume that the industry TFP shocks Z_t^j, $j = G, B$ are uncorrelated and follow a 2-state Markov chain with values Z_L^j and Z_H^j, with probability $q = 0.82$ of remaining in the current state.

We set the capital adjustment cost $\eta = 5$ to match investment volatility. We set the fraction of labor receiving a fixed wage $\overline{L} = 0.50$ so that the volatility of wages is about half that of output, which also implies reasonable values for the volatility and procyclicality of dividends and profits. We set depreciation $\delta = 0.06$, a standard value in the literature. We set capital share $\theta = 0.35$ so that 65% of output is paid to labor.

Empirical estimates from the macroeconomics literature indicate that returns to scale are nearly constant in the US economy. Hall (1988, 1990) argues that market power and increasing

[17] A β of 1.025 may appear to be high. Note that if we were to shut down all risk, the model's steady state would be analytically solved for by two equations: the Euler equation $1 = \beta \times p \times (1+g)^{-1/\psi} \times R$ where $(1+g)^{-1/\psi}$ is the growth rate of aggregate consumption, and the definition of return as the marginal product of capital $R = \theta(K(1+g))^{\theta-1} + 1 - \delta$. Thus, if the capital share $\theta = 0.35$ and the depreciation rate $\delta = 0.06$, then the only way to target an average return on capital of $R \approx 1.058$ (equivalently $K/Y \approx 3$), is to set $\beta \times p = (1/1.058) \times (1+g)^{1/\psi}$, which implies $\beta = 1.015$ when $g = 0.015$ and $\gamma = 1/\psi = 5$. This is the preference parameter of a representative agent. In the real world, households face various uninsurable idiosyncratic risks (income, health, death) that lead to precautionary saving, implying that an individual's β should be lower than the representative agent's. One may also be concerned that with $\beta > 1$ equation (20) does not define a contraction mapping. However, note that we numerically solve the *detrended* model, which is isomorphic to a model where $g = 0$ and the time discount factor is $\beta \times p \times (1+g)^{1-1/\psi} = 0.966$.

[18] We use a filtering parameter of 100, as proposed by Backus and Kehoe (1992).

Table 1: Parameter values

The table reports the values for the parameters used in the benchmark calibration of the multiperiod model described in this section.

Parameter	Symbol	Baseline Economy	Current Green Economy
Investors			
Relative risk aversion	γ	5.00	
Elasticity of intertemporal substitution	ψ	0.20	
Time discount rate	β	1.025	
Survival probability	p	0.99	
Fraction of constrained investors	x	0.50	0.126
Portfolio mandate	$(\overline{w}_G, \overline{w}_B)$	(0.75,0.25)	(1.0,0.0)
Faction of labor receiving government fixed	$\overline{L}$	0.50	
Fraction of labor income to investors	λ	1.00	0.25
Firms			
Aggregate growth rate	g	0.015	
Green TFP shock realization	(Z_L^G, Z_H^G)	(0.912, 1.088)	(0.923 1.082)
Brown TFP shock realization	(Z_L^B, Z_H^B)	(0.912, 1.088)	(0.914 1.071)
Probability of remaining in current state	q	0.82	
Depreciation rate	δ	0.06	
Capital adjustment cost	η	5.00	
Parameter controlling the capital share	θ	0.35	
Return to scale	α	1.00	

returns to scale can explain procyclical productivity in the US. Subsequent work by Basu and Fernald (1997) estimates constant or slightly decreasing returns to scale but notes varying estimates at different industry levels, with typical industries showing decreasing returns while total manufacturing shows increasing returns.[19] In light of this evidence, in our baseline model, we set returns to scale to be constant, that is, $\alpha = 1.0$. Then, in Section 3.4, we allow for both decreasing and increasing returns to scale.

In our calibration, we allow for the existence of a government sector, which enables us to distinguish between total and private-sector GDP. It is well known that the latter is much more volatile than the former. To model the government in a simple way, we assume that the actual amount of labor supplied by investors is 1.35 instead of 1.0, as described in the model section above,

[19] Ahmad et al. (2019) present new estimates for 1989-2014, finding constant or slightly decreasing returns to scale at the aggregate level but not ruling out increasing returns in specific industries or due to factors like technological progress. For instance, Way et al. (2022) argue that clean-energy technologies show increasing returns to scale because of learning curves.

Table 2: Macroeconomic and asset-pricing moments

Panel A shows macroeconomics moments from the model and compares them to corresponding quantities in the data. All variables, other than the Share of GDP, are H-P filtered. Volatility is in annual percentage units. GDP-P refers to private sector GDP. The values in the "Model" columns are obtained by solving a version of the model with a portfolio mandate that constrains 50% of investors to invest 75% of their wealth in firms in the G sector and 25% in firms in the B sector. The model is calibrated at an annual frequency. Panel B shows the annual mean and volatility of the risk-free rate, $\mathbb{E}[R_f]$ and $\sigma(R_f)$, and of the market risk premium, $\mathbb{E}[R^M - R_f]$ and $\sigma(R^M - R_f)$ obtained from a model with a portfolio mandate that constrains 50% of investors to invest 75% of their wealth in firms in the G sector and 25% in firms in the B sector. The model is calibrated at an annual frequency. The equity return is levered using a leverage ratio of 2. Values in the Data column are based on the sample period 1950–2021 and are from Ken French's website. Parameter values are reported in Table 1.

Panel A: Macroeconomic moments

	Share of GDP		Volatility (%)		Corr with GDP		Autocorr	
	Data	Model	Data	Model	Data	Model	Data	Model
GDP	1.00	1.00	2.33	2.32	1.00	1.00	0.54	0.35
GDP-P	0.80	0.81	2.74	2.85	0.91	1.00	0.48	0.35
Consumption	0.63	0.64	1.72	1.60	0.91	0.99	0.53	0.34
Investment	0.17	0.18	7.60	7.42	0.78	0.99	0.45	0.34
Wages	—	—	1.17	1.42	0.49	1.00	0.58	0.35

Panel B: Asset-pricing moments

		Model	
	Data	$\gamma = 5$	$\gamma = 50$
$\mathbb{E}[R_f]$	0.91	5.78	4.17
$\sigma(R_f)$	2.27	3.27	3.29
$\mathbb{E}[R^M - R_f]$	8.99	1.42	4.36
$\sigma(R^M - R_f)$	17.89	16.32	16.28

with 1.0 working in the private sector and 0.35 in government. Unlike private-sector employees, government employees are paid a constant wage adjusted for growth. That is, the government wage rate is set to $\overline{\omega}(1+\hat{g})^t$ where $\overline{\omega}$ is the unconditional average of the detrended market-clearing wage. Hence, total government expenses are equal to $0.35 \times \overline{\omega}$ and total labor income is then $(\omega_t \times 1) + (\overline{\omega} \times 0.35)$. We assume that government expenditure equals a lump-sum tax levied on total labor income. With this assumption, the problem's solution is independent of government size. The only quantity affected by government expenditure is total GDP, which is equal to the sum of private-sector GDP and government expenditure. The choice of 1.35 for total labor implies that private sector GDP is 80% of total GDP, as in the data.[20]

[20]Note that labor is approximately 65% of output, so if private labor is 1.0, then private output is 1.0/0.65=1.54. Government labor, which equals government output, is 35%. Therefore private output as a share of total output is 1.54/(1.54+0.35)=81%.

Panel A of Table 2 compares macroeconomic moments in the data to corresponding quantities in the baseline model with mandates, under the assumption that 50% of investors face a mandate to invest 75% of their wealth in firms in the G sector and 25% in the B sector. The values reported in the table are obtained by simulating the model for 10,000 years and using a 100-year burn-in period. The table reports five quantities: total GDP, private-sector GDP (GDP-P), Consumption, Investment, and Wages. For each quantity, we compute the share of GDP, the volatility, the correlation with GDP, and the autocorrelation and compare them to the corresponding values in the data. The table shows that the model matches key macroeconomic moments reasonably well under the baseline parameters given in Table 1. The only moments significantly different from the data are the correlations of investment and wages with GDP, which, in the data, are much smaller than in the model. This is not surprising because, with only one aggregate shock, model correlation with GDP tends to be close to 1. We also solve several other models with different values of risk aversion, alternative calibrations, or additional features. Those models will be discussed below in the results section. However, for all models, the macroeconomic moments are very similar to the ones presented in Panel A of Table 2.

Panel B of Table 2 reports four asset-pricing moments: the annual mean and volatility of the risk-free rate and of the equity-market risk premium. As with Panel A, we only present results for the baseline model in Panel B because, conditional on a choice of risk aversion, the financial moments are very similar across models. The equity return used to compute the market risk premium is levered using a factor of two, equivalent to an economy-wide 50/50 debt/equity ratio. The table shows that the model does a good job of matching the volatility of the risk-free rate and of the equity risk premium in the data. However, not surprisingly, for the case of low risk aversion, $\gamma = 5$, the risk-free rate is too high, and the equity risk premium is too low. This is just a manifestation of the equity-premium puzzle. With a risk aversion of $\gamma = 50$, the equity premium and risk free rate are closer to the data.[21] Finally, note that even though we assume that the TFP shocks for the G and B sectors are uncorrelated, equity returns have a correlation of about 0.82 in our baseline calibration, similar to the values observed in the data.

[21]Note that as we change risk aversion, EIS stays constant, which explains why the macroeconomic moments do not change much.

3.3 Results in the Baseline Economy

In this section, we study the equilibrium effects of portfolio mandates in the multiperiod production economy described in Section 3.1 for the parameter values discussed in Section 3.2 and also for several alternative economies.

Table 3 contains our main quantitative results. The table reports the equilibrium effective mandate pass-through (first two columns) and the cost of capital spread between Brown and Green sectors (last two columns) for two values of the risk aversion parameter, $\gamma = 5$ and $\gamma = 50$. Although risk aversion $\gamma = 50$ is clearly unreasonable, we considered this case as a reduced-form way of capturing high risk premia in the economy arising from, e.g., limited participation, idiosyncratic labor income risk, taxes, and intermediary frictions.[22] We define the cost-of-capital spread as the difference in the "Brown-Minus-Green" (BMG) expected return spread in the constrained economy, R^c_{BMG}, and the BMG spread in the unconstrained economy, R^*_{BMG}.

The first row in Table 3 refers to the baseline economy whose parameters are described in the first column of Table 1. The remaining seven rows refer to alternative economies that are constructed as variations of the baseline and are discussed further below.

In the baseline economy, the technologies of firms in the two sectors are identical and therefore, when all investors are unconstrained, the optimal portfolio is equally weighted between the G and B sectors. Hence, in an otherwise unconstrained economy where there are no mandates, the equilibrium fraction of capital allocated to G is $w^*_G = K^*_G/(K^*_G + K^*_B) = 0.50$. To evaluate the magnitude of the equilibrium effect of mandates on capital allocation, we follow the construction of the "effective mandate pass-through" in equation (19) of Section 2 and report the values in the first two columns of Table 3. Specifically, we first compute the maximum effectiveness of a mandate, ignoring any equilibrium consideration. In our setting, because the constrained investor represents 50% of the entire mass of investors, a portfolio mandate of 75% in G and 25% in B implies that $w^{\text{PE}}_G = 62.5\%$ $(= 0.5 \times 75\% + 0.5 \times 50\%)$ of the entire capital should be allocated to the G sector. Under this "partial equilibrium" intuition, the *maximum* deviation from the unconstrained 50/50 allocation is, therefore, $12.5\% = 62.5\% - 50\%$.

The values of the effective mandate pass-through in the first two columns of Table 3 show that, although general-equilibrium effects undo part of the mandate, a significant part remains

[22] For example, in standard habit models, (e.g., Campbell and Cochrane, 1999), while the curvature parameter in the utility function is 2, the average effective risk aversion is around 80.

Table 3: Equilibrium effects of portfolio mandates

The table shows the mandate pass-through, defined in equation (19), and the difference in the cost of capital spread between the B and G sector, $R^c_{BMG} - R^*_{BMG}$, with R^c_{BMG} denoting the spread in an economy with mandates that constrain the portfolios of some investors and R^*_{BMG} the spread in an otherwise unconstrained economy (i.e., without mandates). The Baseline economy is obtained using the parameters reported in Table 1. In Economy 1, we assume the existence of "hand-to-mouth" workers; in Economies 2 and 3, we consider respectively the case of decreasing and increasing returns to scale; in Economy 4 the mass of constrained investors is only 25% instead of 50%, with constrained investors mandated to hold 75% of their wealth in the Green asset; in Economy 5, constrained agents represent only 25% of the entire population, but they are mandated to hold 100% of their wealth in the Green asset; Economy 6 considers a benchmark unconstrained economy where the G capital share is 73%, consistent with Berk and van Binsbergen (2024). Economy 7 is the "Current Green Economy", calibrated to capture representative moments of the US economy in 2010 (See Section 3.5 for details).

	Pass-through (%)		Cost of capital spread $R^c_{BMG} - R^*_{BMG}$ (%)	
	$\gamma = 5$	$\gamma = 50$	$\gamma = 5$	$\gamma = 50$
Baseline economy	31.4	80.0	0.010	0.031
Alternative economies				
1. Hand-to-mouth workers	61.0	111.8	0.024	0.297
2. Decreasing return to scale ($\alpha = 0.90$)	2.1	18.1	0.017	0.13
3. Increasing return to scale ($\alpha = 1.005$)	47.4	87.5	-0.010	0.090
4. Fewer constrained investors	22.2	72.2	0.003	0.064
5. More concentrated mandate	22.0	61.8	0.009	0.095
6. Higher share of green capital	31.1	87.9	0.007	0.074
7. Current Green Economy	51.4	154.7	0.008	0.119

effective. For example, in the baseline economy, with a risk aversion of 5 and constant returns to scale ($\alpha = 1$), 31.4% of the mandate remains effective. For relative risk aversion of $\gamma = 50$, the pass-through is more than 2.5 times larger, at 80%. This implies that the share of G capital rises from 50% to 53.9% ($= 0.314 \times 0.125 + 0.5$) when risk aversion is $\gamma = 5$, and to 60.0% ($= 0.8 \times 0.125 + 0.5$) when risk aversion is $\gamma = 50$. Intuitively, by increasing the cost of capital of firms in the B sector, the mandate makes them more attractive to unconstrained investors who trade off higher returns for worse diversification. As risk aversion increases, the mandate pass-through is larger because the unconstrained agent finds it more costly to deviate from the well-diversified unconstrained 50/50 allocation in response to the increase in risk-premium in the B sector.

Unlike the single-period model of Section 2, the mandate pass-through for $\alpha = 1$ is significantly less than 100%. The reason why it is lower here is because of households' desire to hedge labor income risk. If the constrained agent overweights G and the unconstrained does not overweight B in response, overall output in the economy is more correlated with shocks to G than shocks to B. Because labor income is perfectly correlated with output in the baseline economy, labor income is also more correlated with G shocks. Thus, the unconstrained agent can hedge labor income risk by overweighting asset B, thus reducing the effectiveness of the mandate. This mechanism may be less relevant in the real world than in our model because (i) labor income tends to be imperfectly correlated with output, and (ii) the marginal investor tends to be different from the average labor-income earner. Therefore, our model may be underestimating the mandate pass-through. Below, in Section 3.4, we explore the effect of imperfectly correlated labor income and output by analyzing a more realistic economy with "hand-to-mouth" workers (Economy 1).

The last two columns of Table 3 report the effect of mandates on the firms' cost of capital. Unlike the significant values of the mandate pass-through in the first two columns, the effect on the cost of capital is minimal. Recall that for the baseline economy $R^*_{BMG} = 0$, and therefore the difference $R^c_{BMG} - R^*_{BMG}$ is exactly the difference in the cost of capital between the B and G sectors. In the baseline economy, when $\gamma = 5$, this spread is 1 basis point. This negligible difference in the cost of capital contrasts with the significant effective mandate pass-through of 31.4% reported in the first column. The contrast between the mandate's "real" and "financial" effects is even stronger when risk premia are closer to their value in the data ($\gamma = 50$). In this case, the difference in the cost of capital under constant returns to scale is 3.1 basis points, while the effective mandate pass-through is 80%.

In summary, the quantitative result from the our baseline economy support the central intuition developed in the simple model of Section 2. First, in an economy with production, the difference in the cost of capital is a poor metric to assess the real impact of portfolio mandates in equilibrium. Second, mandates can have a quantitatively significant impact on capital allocation, despite having a negligible effect on firms' cost of capital. These findings caution against using the cost of capital to measure the effectiveness of portfolio mandates in equilibrium; instead, one should measure the flow of capital.

3.4 Results for Alternative Economies

The analysis of alternative economies 1–7 in Table 3 provides deeper insights into the economic mechanisms that can enhance or diminish the effectiveness of mandates in equilibrium. In Economy 1, we assume that, unlike the baseline economy, some workers are "hand-to-mouth", and do not participate in financial markets. This is a more realistic characterization of the economy than the baseline, in which all workers are also investors. To do so, in the intertemporal budget constraint equation (21) we replace labor income $\omega_t L_{i,t}$ with $\lambda\,\omega_t L_{i,t}$, where $\lambda = 0.25$ represents the fraction of total labor income earned by equity investors.[23] The rest of the labor income is earned by "hand-to-mouth" workers who play no role in the optimization problem. The presence of hand-to-mouth workers significantly increases the mandate pass-through, which is now roughly double that in the baseline case. The mandate's intent is to make the G sector larger. When workers are also investors, the mandate implies a high correlation between their labor income and the return in the G sector. In response, households hold the B asset to hedge, thereby "undoing" some of the mandate's effect on the share of green capital. This hedging motive is particularly strong when workers are investors, as in the baseline case. Allowing for some workers to be hand-to-mouth, makes labor income less important for investors, thus reducing their incentive to hold asset B for hedging purposes. As a result we observe less "undoing" of the mandate, leading to an increase in the effective mandate pass-through. Note that for the case of $\gamma = 50$, the pass-through is larger than 100%. This happens because the wealth share of the constrained agent increases in this case.

In Economies 2 and 3 we consider, respectively, the case of decreasing ($\alpha = 0.9$) and increasing ($\alpha = 1.005$) returns-to-scale production technologies. Consistent with the main intuition from the simple model of Section 2, in an economy with decreasing returns to scale, the pass-through is significantly smaller than the baseline economy with constant return to scale and it is larger in economies with increasing returns to scale.

Economies 4 and 5 explore the effect of mandate design. Specifically, in Economy 4, we assume that the mass of constrained agents is smaller (25%) than in the baseline economy (50%). In Economy 5 we consider the case of a "concentrated" constraint, that is, we lower the mass of constrained investor from 50% to 25% but we assume that each has to hold 100% of their wealth in the G asset, as opposed to 75%. In this economy, the amount of excess capital committed to the Green assets is the same as in the baseline economy because $0.25 \times (1.0 - 0.5) = 0.5 \times (0.75 - 0.5) = 0.125$. The results in Table 3 show that both modifications slightly lower the effectiveness of the mandate for both levels of risk aversion. In the economy with fewer constrained agents (Economy 4), the effective mandate pass-through is smaller simply because the mass of constrained agents is

[23] To choose the value of λ, for each year in the Survey of Consumer Finances (once every 3 years from 1986–2019), we sort households from lowest to highest according to their equity investments (defined as the sum of IRAs, mutual fund, and directly held equity). We then identify the holdings cutoff such that households above this cutoff jointly own 90% of all equity. On average (across all years), these households make up 10.2% of the population, but their labor income makes up $\lambda = 25.2\%$ of all labor income.

smaller, and therefore, less capital is mandated to the G sector. In the economy with a more concentrated constraint (Economy 5), the pass-through is lower because while the size of excess demand is the same as in the baseline case, it is being spread out among a larger number of unconstrained investors. Therefore, *per investor*, the unconstrained agents are absorbing less of this excess asset. Because their excess undiversified risk is smaller, they undo more of the mandate, resulting in a lower pass-through.

In Economy 6, we target a benchmark unconstrained economy in which the share of green capital is set to 73%, instead of 50%, following the estimated value reported in Berk and van Binsbergen (2024).[24] The result in Table 3 confirms that this alternative benchmark has a negligible effect on the equilibrium mandate pass-through, relative to the benchmark case. The overall message from the analysis in Table 3 is that, across several alternative specifications of the economy, mandates can have significant capital allocation impact, as emphasized by the values of the equilibrium pass-through, while affecting only negligibly the equilibrium cost of capital across sectors.

3.5 Results in the Current Green Economy

For transparency, the baseline economy in Table 3 is calibrated to have symmetry between the fraction of Green versus Brown capital (when both investors are unconstrained), as well as the fraction of constrained versus unconstrained investors. In this section, we instead calibrate the economy to moments we believe represent roughly the US economy in 2010, a time period before there was serious discussion of portfolio constraints for Green investments. We refer to this case as the "Current Green Economy."

Most parameters remain identical to the baseline economy, with the exception of three changes. First, identical to Economy 2, we set the fraction of labor income received by investors to be $\lambda = 0.25$ because, as discussed above, this is a better representation of reality than $\lambda = 1.0$ in the baseline model. Second, we set the fraction of constrained investors to be $x = 12.6\%$ and the fraction of their portfolio invested in Green versus Brown assets to be $(\overline{w}_G, \overline{w}_B) = (100\%, 0\%)$—we do this based on estimates inferred from the Global Sustainable Investment Alliance (2022)

[24] To do this, we increase the productivity of the green sector and simultaneously decrease that of the brown sector, while keeping average productivity at 1. We also reduce the spread between the high and low state of the Markov chain for Z_t^j to match the volatility of GDP. The corresponding values of the Markov chain for the Green and Brown TFP are identical to "Current Green Economy" values reported in the last column of Table 1.

report.[25] Third, identical to Economy 6 and explained in footnote 24, we set the fraction of Green capital in the unconstrained economy to be $w_G^* =$73% by increasing the productivity of Green assets and decreasing the productivity of Brown assets. We do this based on estimates in Berk and van Binsbergen (2024). Together, these values imply that the maximum Green capital in the absence of general-equilibrium forces is $w_G^{max} = 0.764$ $(= 0.126 \times 1.0 + (1 - 0.126) \times 0.73)$. Thus, in the absence of general-equilibrium forces, this constraint would lead to Green capital increasing from 73% to 76.4% of all capital. The results from this economy are presented in the last row of Table 3. When risk aversion is 5, the share of Green capital increases from 73% to 74.75%, implying a pass-through of 51.4%. This is quantitatively similar to Economy 1, which also has hand-to-mouth workers but slightly weaker because the mandate is more concentrated. When risk aversion is 50, the share of Green capital increases from 73% to 78.26%, implying a pass-through of 154.7%. As in the previous section, the cost of capital differences remain small.

3.6 Transition Dynamics

So far, the analysis has compared unconditional averages across steady states. In order to understand the mechanism through which mandates achieve their goal, in this section we study the transition dynamics upon the imposition of a mandate on a fraction of investors.

We start from the average steady state of the Current Green Economy with only unconstrained investors. Specifically, we set the Green share of capital to be 0.73, and the total capital to be equal to the unconditional average of the unconstrained model. We then assume that 12.6% of investors are required to satisfy a portfolio mandate that requires them to hold only green assets. We then simulate the model for 100 years using policy functions from the constrained version of the economy. We assume that the imposition of a mandate is an unanticipated "shock", frequently referred to in the literature as an "MIT shock."[26]

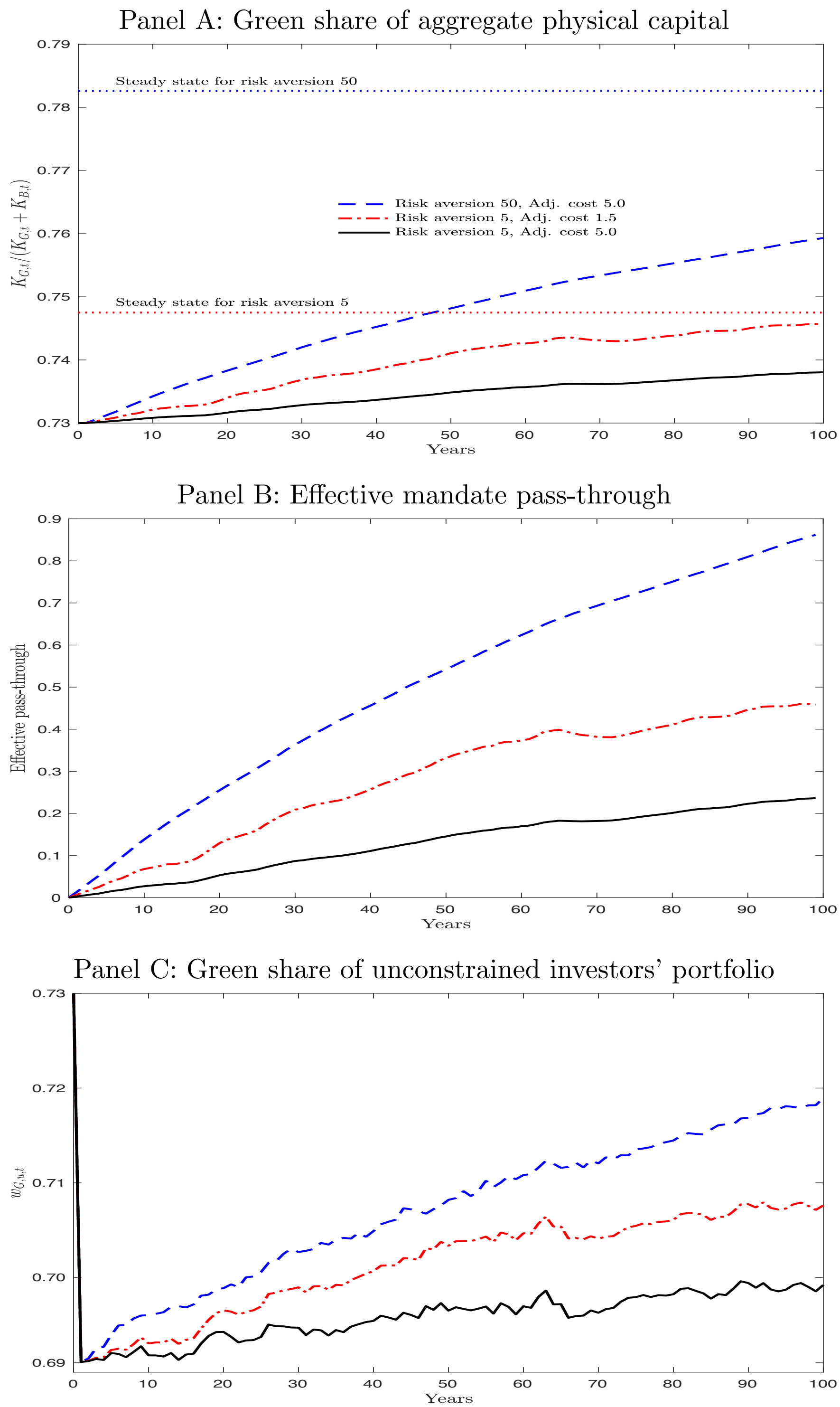
Figure 4 shows the transition dynamics for three quantities: the green share of aggregate physical capital (Panel A), the effective mandate pass-through (Panel B), and the green share of unconstrained investors' portfolio (Panel C). The dotted lines in Panel A refer to the steady state

[25] In Appendix 1, p. 43 the Global Sustainable Investment Alliance (2022) report estimates that \$8.4tr out of \$66.6tr of professionally managed assets are subject to a sustainability mandate. This implies an estimate for x of $8.4/66.6 = 12.6\%$.

[26] Specifically, we start the productivity process in each of the four possible TFP realizations. For each of the four initial realizations, we run 500 simulations for 100 years. In each simulation, the realized TFP shocks are random. We then compute the average across all simulations and all initial realizations.

Figure 4: Dynamics of green transition

Panel A of the figure shows the dynamics of the green share of aggregate physical capital, $K_{G,t}/(K_{G,t}+K_{B,t})$, Panel B shows the effective mandate pass-through, and Panel C shows the green share of unconstrained investors' portfolio, following the imposition of a portfolio mandate at time 0. Specifically, we set the wealth of constrained agents to be $x = 0.126$, the share of green capital to be 0.73, and the total capital to be equal to the unconditional average of the unconstrained model. We start the productivity process in each of the four possible TFP realizations. For each of the four initial realizations, we run 500 simulations for 100 years. In each simulation, the realized TFP shocks are random. We then compute the average across all simulations and all initial realizations.



green capital share of the constrained economy, with the top blue line indicating that for risk aversion 50 it is 78.26% and the lower red line indicating that for risk aversion 5 it is 74.75%. The three increasing lines in Panel A, drawn for different combinations of risk aversion and capital adjustment costs, show how these two forces drive the transition to a more green economy.[27] Unconstrained investors trade off the diversification benefits of a fast transition versus the adjustment costs. As one would expect, the higher the adjustment costs the slower is the transition to the steady state. This can be seen by comparing the black line, where adjustment costs are high, to the red line, where adjustment costs are lower.

Comparing the black and red lines in Panel B, we see that the effective mandate pass-through is much smaller when adjustment costs are high. The reason for this is that, in the short run, changing the scale of capital is costly and consequently investors facing the mandate find it optimal to satisfy it by rebalancing their portfolio in the secondary market. Panel C illustrates this by showing that, upon the imposition of the mandate, there is a large decrease in the share of the unconstrained investors' portfolio invested in the green sector to accommodate the increase in demand for green assets from the investors facing the mandate. Prior to the shock, all investors are unconstrained and their portfolio share in the green asset is 73%, that is, the same as the green share of aggregate physical capital. Upon the imposition of the mandate, the unconstrained investors' share falls significantly to approximately 69% to accommodate the jump in the constrained investors' portfolio. If the unconstrained investor were to do nothing in the secondary market, to satisfy the mandate, a large fraction of capital would need to immediately shift from the Brown to the Green sector, thus incurring large adjustment costs. Over time, the aggregate capital stock will respond to the mandate (Panel A), the effective mandate pass-through will increase (Panel B), and consequently the unconstrained investors' share of green assets in their portfolio rises, eventually reaching its long-term stochastic steady state (Panel C).

When investors are more risk averse, unconstrained investors are less willing to accommodate the increase in portfolio demand for green assets from the constrained investors. Consequently, the mandate is much more effective in shifting physical capital from the brown to the green sector.

[27]As discussed in Section 3.2, the adjustment cost in the baseline model is $\eta = 5$ and is calibrated to match the ratio of aggregate investment volatility to aggregate output volatility, which is 3.25. In the model with lower costs, we set $\eta = 1.5$, which implies a ratio of 3.7. In principle, this parameter may also depend on the industry or the type of sanction. For example, after Russia's invasion of Ukraine in 2022, many firms exited Russia, leaving all of their physical capital behind and receiving zero compensation. Thus, they were unable to shift any physical capital out of Russia. In this case, the long-term steady state will be reached only through the depreciation of assets in Russia and the simultaneous building up from scratch of assets outside of Russia.

This can be seen by comparing the blue line (for risk aversion equal to 50) to the black line (for risk aversion equal to 5), where both lines are drawn for the same level of capital adjustment cost. For both the case of low and high risk aversion and the case of low and high adjustment costs, the impact of the mandate on the cost of capital in the green and brown sectors along the transition path remains negligible, consistent with the cost of capital spreads across the green and brown sectors reported in the last two columns of Table 3.

4 Conclusion

In this paper, we examine the impact of portfolio mandates on the allocation of physical capital in a general-equilibrium economy with production and heterogenous investors. In contrast to the existing literature that has studied responsible investing in models of an endowment economy, we consider a production economy that, we show, nests the endowment economy as a special case.

To assess the quantitative importance of the effect of portfolio mandates, we study a dynamic general equilibrium production economy. Under a realistic calibration of the multiperiod model that matches asset-pricing and macroeconomic moments of the US economy, we find that the effect of portfolio mandates on the allocation of physical capital across sectors can be substantial in the long run. In contrast, the impact on the equilibrium cost of capital and Sharpe ratios of firms in the two sectors remains negligible, consistent with existing evidence.

A key takeaway of our analysis is that judging the effectiveness of portfolio mandates by studying their effect on the cost of capital of affected firms can be misleading: small differences in the cost of capital across sectors can be associated with significant differences in the allocation of physical capital across these sectors. Furthermore, we demonstrate the relative importance of trading in the primary and secondary markets for satisfying the mandate. While in the short run the mandate is satisfied by the rebalancing of financial portfolios in secondary markets, in the long it is satisfied through the reallocation of physical capital in primary markets. We show that the relative importance of these two markets depends on capital adjustment costs and investors' risk attitudes, however, the impact of mandates on the cost of capital across sectors remains negligible in both the short and long run.

A Proofs

Proof of Proposition 1

Unconstrained agents. Because productivity shocks are normally distributed, we can explicitly write the expectation in equation (10) as follows

$$\max_{\{c_{0,u},w_u\}} -\frac{1}{\gamma}e^{-\gamma c_{0,u}} - \frac{\beta}{\gamma}e^{-\gamma \mathbb{E}[\tilde{c}_{1,u}]+\frac{\gamma^2}{2}\operatorname{Var}[\tilde{c}_{1,u}]}, \tag{A1}$$

where, from the intertemporal budget constraint in equation (9)

$$\tilde{c}_{1,u} = (e_{0,u} - c_{0,u})(R_f + w_u^\top(\tilde{R} - R_f\mathbf{1})) + \mathbf{1}^\top\tilde{\pi}_u, \tag{A2}$$

with $w_u \equiv [w_{G,u}, w_{B,u}]^\top$ the vector of portfolio weights, $\tilde{R} \equiv [\tilde{R}_G, \tilde{R}_B]^\top$ the vector of returns on capital, and $\tilde{\pi}_u \equiv [\tilde{\pi}_{G,u}, \tilde{\pi}_{B,u}]^\top$ the vector of realized profits accruing to the unconstrained agent.

Each unconstrained investor is entitled to a fraction of the total profit $\tilde{\Pi}_j$ that is proportional to $\hat{k}_{j,u}/K_j$, the share of capital invested in sector j, that is,

$$\tilde{\pi}_{j,u} = \frac{\hat{k}_{j,u}}{K_j}\tilde{\Pi}_j, \quad j = G, B, \tag{A3}$$

where, by equation (5), the total realized profit in sector j is $\tilde{\Pi}_j = (1-\alpha)\tilde{A}_j K_j^\alpha$, $j = G, B$. Because investors are atomistic, when choosing their optimal portfolio weights w_u in equation (A1), they take the vector of returns $\tilde{R}$ and profits $\tilde{\pi}_u$ as given.

From equation (4), the return on capital is $\tilde{R}_j = \alpha\tilde{A}_j K_j^{\alpha-1}$, and, therefore, we can write the profit $\tilde{\pi}_{j,u}$ as follows

$$\tilde{\pi}_{j,u} = \hat{k}_{j,u}\frac{1-\alpha}{\alpha}\tilde{R}_j, \quad j = G, B. \tag{A4}$$

To emphasize that the profit $\tilde{\pi}_{j,u}$ is beyond the control of the atomistic investor, we indicate the invested capital $\hat{k}_{j,u}$ as follows

$$\hat{k}_{j,u} \equiv \hat{w}_{j,u}(e_{0,u} - c_{0,u}), \quad j = G, B, \tag{A5}$$

where the portfolio weights $\hat{w}_u \equiv [\hat{w}_{G,u}, \hat{w}_{B,u}]^\top$ are taken as given in the optimization (A1). Of course, in equilibrium, it must be that $\hat{w}_u$ equals the optimal portfolio w_u^*.

Under these assumptions, we can rewrite the intertemporal budget constraint in equation (A2) as follows

$$\tilde{c}_{1,u} = (e_{0,u} - c_{0,u})\left(R_f(1 - w_u^\top\mathbf{1}) + \left(w_u + \frac{1-\alpha}{\alpha}\hat{w}_u\right)^\top\tilde{R}\right), \tag{A6}$$

from which obtain

$$\mathbb{E}[\tilde{c}_{1,u}] = (e_{0,u} - c_{0,u}) \left(R_f(1 - w_u^\top \mathbf{1}) + \left(w_u^\top + \frac{1-\alpha}{\alpha} \hat{w}_u^\top \right) \mathbb{E}[\tilde{R}] \right) \tag{A7}$$

$$\mathrm{Var}[\tilde{c}_{1,u}] = (e_{0,u} - c_{0,u})^2 \left(w_u + \frac{1-\alpha}{\alpha} \hat{w}_u \right)^\top \Sigma_R \left(w_u + \frac{1-\alpha}{\alpha} \hat{w}_u \right), \tag{A8}$$

with Σ_R denoting the covariance matrix of return, i.e., $\mathrm{Cov}(\tilde{R}_j, \tilde{R}_\ell) = \alpha^2 \rho \sigma_{A_j} \sigma_{A_\ell} K_j^{\alpha-1} K_\ell^{\alpha-1}$, with $j, \ell \in \{G, B\}$.

Taking the first-order conditions with respect to w_u in equation (A1), and using equations (A7) and (A8), we obtain

$$- R_f \mathbf{1} + \mathbb{E}[\tilde{R}] - \gamma \left((e_{0,u} - c_{0,u}) \Sigma_R \left(w_u + \frac{1-\alpha}{\alpha} \hat{w}_u \right) \right) = 0. \tag{A9}$$

Imposing the equilibrium condition $\hat{w}_u = w_u$ we obtain that the optimal portfolio of the unconstrained agent is

$$w_u^* = \frac{1}{(e_{0,u} - c_{0,u})} \frac{\alpha}{\gamma} \Sigma_R^{-1} (\mathbb{E}[\tilde{R}] - R_f \mathbf{1}), \tag{A10}$$

which is equation (14). Setting $w_u = \hat{w}_u = w_u^*$ in equations (A7) and (A8) we obtain

$$\mathbb{E}[\tilde{c}_{1,u}] = (e_{0,u} - c_{0,u}) R_f + \frac{\alpha}{\gamma} \left(\mathbb{E}[\tilde{R}] - R_f \mathbf{1} \right)^\top \Sigma_R^{-1} \left(\frac{\mathbb{E}[\tilde{R}]}{\alpha} - R_f \mathbf{1} \right), \quad \text{and} \tag{A11}$$

$$\mathrm{Var}[\tilde{c}_{1,u}] = \frac{1}{\gamma^2} \left(\mathbb{E}[\tilde{R}] - R_f \mathbf{1} \right)^\top \Sigma_R^{-1} \left(\mathbb{E}[\tilde{R}] - R_f \mathbf{1} \right). \tag{A12}$$

Taking the first-order condition with respect to $c_{0,u}$ in equation (A1), we obtain

$$e^{-\gamma c_{0,u}} = e^{-\gamma \mathbb{E}[\tilde{c}_{1,u}] + \frac{\gamma^2}{2} \mathrm{Var}[\tilde{c}_{1,u}]} \beta \left(- \frac{\partial \mathbb{E}[\tilde{c}_{1,u}]}{\partial c_{0,u}} + \frac{\gamma}{2} \frac{\partial \, \mathrm{Var}[\tilde{c}_{1,u}]}{\partial c_{0,u}} \right) = e^{-\gamma \mathbb{E}[\tilde{c}_{1,u}] + \frac{\gamma^2}{2} \mathrm{Var}[\tilde{c}_{1,u}]} \beta R_f, \tag{A13}$$

where the second equality follows directly from equations (A11) and (A12). Substituting the expressions of $\mathbb{E}[\tilde{c}_{1,u}]$ $\mathrm{Var}[\tilde{c}_{1,u}]$ from equations (A11) and (A12) and simplifying we obtain the following expression for the optimal consumption of the unconstrained agent:

$$c_{0,u}^* = \frac{1}{1 + R_f} \left(e_{0,u} R_f + \frac{1}{2\gamma} \left(\mathbb{E}[\tilde{R}] - R_f \mathbf{1} \right)^\top \Sigma_R^{-1} \left(\mathbb{E}[\tilde{R}] - (2\alpha - 1) R_f \mathbf{1} \right) - \frac{\ln \beta R_f}{\gamma} \right). \tag{A14}$$

Equations (A10) and (A14) represent the solution of the unconstrained agent problem defined in equation (A1).

Constrained agents. Constrained agents solve only an intertemporal consumption/saving problem, because their portfolio weights are fixed by the mandate at $\overline{w}_c \equiv [\overline{w}_G, \overline{w}_B]^\top$. Specifically, they solve

$$\max_{c_{0,c}} -\frac{1}{\gamma} e^{-\gamma c_{0,c}} - \frac{\beta}{\gamma} e^{-\gamma \mathbb{E}[\tilde{c}_{1,c}] + \frac{\gamma^2}{2} \operatorname{Var}[\tilde{c}_{1,c}]}, \tag{A15}$$

where

$$\tilde{c}_{1,c} = (e_{0,c} - c_{0,c})(R_f + \overline{w}^\top (\tilde{R} - R_f \mathbf{1})) + \mathbf{1}^\top \tilde{\pi}_c. \tag{A16}$$

Following the same steps as for the unconstrained agents' problem, we can rewrite the intertemporal budget constraint in equation (A16) as

$$\tilde{c}_{1,c} = (e_{0,c} - c_{0,c}) \left(R_f (1 - \overline{w}^\top \mathbf{1}) + \left(\overline{w} + \frac{1-\alpha}{\alpha} \hat{w}_c \right)^\top \tilde{R} \right) \tag{A17}$$

$$= (e_{0,c} - c_{0,c}) \left(R_f + \overline{w}^\top \left(\frac{\tilde{R}}{\alpha} - R_f \mathbf{1} \right) \right). \tag{A18}$$

From equation (A18) we obtain

$$\mathbb{E}[\tilde{c}_{1,c}] = (e_{0,c} - c_{0,c}) \left(R_f + \overline{w}^\top \left(\frac{\mathbb{E}[\tilde{R}]}{\alpha} - R_f \mathbf{1} \right) \right), \quad \text{and} \tag{A19}$$

$$\operatorname{Var}[\tilde{c}_{1,c}] = (e_{0,c} - c_{0,c})^2 \frac{\overline{w}^\top \Sigma_R \overline{w}}{\alpha^2}. \tag{A20}$$

Taking the first-order condition with respect to $c_{0,c}$ in equation (A15), we obtain

$$e^{-\gamma c_{0,c}} = e^{-\gamma \mathbb{E}[\tilde{c}_{1,c}] + \frac{\gamma^2}{2} \operatorname{Var}[\tilde{c}_{1,c}]} \beta \left(-\frac{\partial \mathbb{E}[\tilde{c}_{1,c}]}{\partial c_{0,c}} + \frac{\gamma}{2} \frac{\partial \operatorname{Var}[\tilde{c}_{1,c}]}{\partial c_{0,c}} \right)$$

$$= e^{-\gamma \mathbb{E}[\tilde{c}_{1,u}] + \frac{\gamma^2}{2} \operatorname{Var}[\tilde{c}_{1,u}]} \beta \Gamma_c, \tag{A21}$$

where

$$\Gamma_c \equiv R_f + \overline{w}^\top \left(\frac{\mathbb{E}[\tilde{R}]}{\alpha} - R_f \mathbf{1} \right) - \gamma (e_{0,c} - c_{0,c}) \frac{\overline{w}^\top \Sigma_R \overline{w}}{\alpha^2}. \tag{A22}$$

Hence the optimal consumption $c^*_{0,c}$ of the constrained agent is defined implicitly as the solution of the following non-linear equation

$$c^*_{0,c} = \mathbb{E}[\tilde{c}_{1,c}] - \frac{\gamma}{2} \operatorname{Var}[\tilde{c}_{1,c}] - \frac{\log \beta \Gamma_c}{\gamma}, \tag{A23}$$

where $\mathbb{E}[\tilde{c}_{1,c}]$ and $\operatorname{Var}[\tilde{c}_{1,c}]$ are given in equations (A19) and (A20), respectively. ∎

B Endowment Economy as the Limit of a Production Economy

In this appendix, we show that an endowment economy is the limit of a production economy when the returns-to-scale parameter goes to zero.

We first solve for the equilibrium in a representative-agent economy with no uncertainty and log-utility investors for which we can obtain the equilibrium in closed form. We then solve for the decentralized equilibrium and show that it corresponds to the social-planners equilibrium. Finally, we show that in both the representative-agent economy and its decentralized counterpart, the equilibrium for the production economy converges to the equilibrium in an endowment economy as the returns-to-scale parameter goes to zero.

We consider an economy in which agents have log utility functions and live for two dates, $t = 0$ and $t = 1$. Agents are endowed with wealth W_0 and have access to a deterministic production technology $Y = AK^\alpha$.

B.1 Social Planner's Problem

The social planner chooses capital allocation K to solve the following problem

$$\max_{K,b} \log C_0 + \beta \log C_1, \tag{B1}$$

where

$$C_0 = W_0 - K - b/R_f \tag{B2}$$

$$C_1 = AK^\alpha + b, \tag{B3}$$

with b denoting the amount of lending (or borrowing) at time 0 and R_f the risk-free rate, which will be determined as part of the equilibrium.

The first-order condition with respect to b yields

$$\frac{1}{W_0 - K - b/R_f} \frac{1}{R_f} = \frac{\beta}{AK^\alpha + b}. \tag{B4}$$

In equilibrium, there is no borrowing or lending, and therefore, we set $b = 0$, which leads to

$$R_f = \frac{1}{\beta} \frac{AK^\alpha}{W_0 - K}. \tag{B5}$$

The first-order condition with respect to K yields

$$\frac{1}{W_0 - K - b/R_f} = \frac{\alpha\beta AK^{\alpha-1}}{AK^\alpha + b}. \tag{B6}$$

Setting $b = 0$ we obtain

$$K(1 + \alpha\beta) = \alpha\beta W_0, \tag{B7}$$

implying that in equilibrium the amount of capital invested is

$$K^* = \frac{\alpha\beta}{1 + \alpha\beta} W_0. \tag{B8}$$

Substituting K^* in the expression for the risk-free rate (B5), we have that the equilibrium risk-free rate is

$$R_f^* = \frac{1}{\beta} \frac{A}{W_0^{1-\alpha}} \frac{(\alpha\beta)^\alpha}{(1 + \alpha\beta)^{\alpha - 1}}. \tag{B9}$$

Note that, because $\lim_{\alpha \to 0} (\alpha\beta)^\alpha = 1$,

$$\lim_{\alpha \to 0} R_f^* = \frac{1}{\beta} \frac{A}{W_0}, \tag{B10}$$

and, from (B8),

$$\lim_{\alpha \to 0} K^* = 0. \tag{B11}$$

Hence, as $\alpha \to 0$, the production economy becomes an endowment economy in which both $C_0 = W_0$ and $C_1 = A$ are exogenous. The ratio A/W_0 in the equation for the risk-free rate, (B10), therefore, represents consumption growth.

B.2 Decentralized Economy

We now consider the decentralized economy, which consists of atomistic firms owned by atomistic households.

Firms. Firms take the discount rate R as given and choose capital K to maximize the firm's profit, which is the difference between the output $Y = AK^\alpha$and the cost of capital RK, that is,

$$\max_K \; \Pi = AK^\alpha - RK. \tag{B12}$$

The first-order condition with respect to K yields

$$R = \alpha A K^{\alpha - 1}, \tag{B13}$$

and the firm's profit is

$$\Pi = AK^\alpha - RK = (1 - \alpha) A K^\alpha. \tag{B14}$$

Hence, the firm earns positive profits if the returns to scale are declining, $\alpha < 1$, and zero profit if the returns to scale are constant, $\alpha = 1$.

Households. Households take as given the risk-free rate R_f from lending (or borrowing), the return R from investing in the firm, and the profit π distributed by the firm. Households solve the problem

$$\max_{C_0,w} \log C_0 + \beta \log C_1, \tag{B15}$$

where

$$C_1 = (W_0 - C_0)(R_f + w(R - R_f)) + \Pi. \tag{B16}$$

Note that as the profit Π is non-zero when $\alpha \neq 1$, we need to include it in the consumption of households because they receive it in the form of dividends as a result of owning the firm. Households, however, take this profit as given.

The first-order conditions with respect to w and C_0 yield,

$$\frac{\beta}{(R_f + w(R - R_f)) + \Pi}(R - R_f) = 0 \quad \text{and} \quad \frac{1}{C_0} = \frac{\beta}{C_1}(R_f + w(R - R_f)). \tag{B17}$$

The first condition implies that $R = R_f$, as it should be given that there is no uncertainty in this economy. Because in equilibrium there cannot be any borrowing or lending, it must be that $C_0 = W_0 - K$, where K is the amount of households' capital investment. Hence, from the first-order condition (B17) and the budget constraint(B16) we have

$$\frac{1}{W_0 - K} = \frac{\beta R_f}{K R_f + \Pi}. \tag{B18}$$

Because $R_f = R$, using the definition of returns from equation (B13), we obtain

$$K^* = \frac{\alpha\beta}{1 + \alpha\beta} W_0. \tag{B19}$$

Therefore, the optimal investment K^* in the decentralized economy, given by (B19), corresponds to that in the social-planner economy, given in equation (B8). This is just an implication of the First Fundamental Theorem of welfare economics (see, e.g., Mas-Colell, Whinston, and Green, 1995).

Substituting K^* from equation (B19) in the expression for the risk-free rate (B13), we have that the equilibrium risk-free rate is

$$R_f^* = \alpha A \left(\frac{\alpha\beta}{1 + \alpha\beta} W_0 \right)^{\alpha - 1} = \frac{1}{\beta} \frac{A}{W_0^{1-\alpha}} \frac{(\alpha\beta)^\alpha}{(1 + \alpha\beta)^{\alpha - 1}}, \tag{B20}$$

which corresponds to the equilibrium risk-free rate derived in equation (B9) for the social planner.

Just as for the social-planner's problem, as $\alpha \to 0$, we see from (B13), (B19), and (B20) that $\pi^* \to A$, $K^* \to 0$, and $R_f^* \to A/(\beta W_0)$. That is, the production economy converges to an endowment economy where consumption at $t = 0$ and $t = 1$ are exogenous: $C_0 = W_0$ and $C_1 = A$.

Online Appendix: Details of Solving the Multiperiod Model

In this Online Appendix, we explain how we solve the multiperiod model described in Section 3 of the manuscript. First, we explain how we detrend the model so that the resulting model is stationary. Then, we describe the numerical algorithm used to solve the stationary model.

IA.1 Detrending

The model is non-stationary because the aggregate component of TFP, A_t, grows at the rate g. However, it is possible to rewrite the model as a stationary model by detrending by the balanced growth path. Along the balanced growth path, the variables $Y_{j,t}$, $K_{j,t}$, $D_{j,t}$, $V_{j,t}$, $I_{j,t}$, $C_{i,t}$, $W_{i,t}$, w_t all vary around the trend $G_t^{t\lambda} = (1+g)^{t\frac{1-\theta}{1-\alpha\theta}}$, thus we can define $x_t = X_t G_t^{-t\lambda}$ for any of these variables, with lower case letters indicating detrended values.[28] To get λ, we simply apply this detrending to equation (IA3) and solve for the λ that makes this equation hold. One can then guess and verify that $U_i(W_{i,t})$ also varies around the same trend. The variables $\tilde{M}_{i,t+1}$, $R_{j,t}$, $w_{j,i,t}$, and $L_{j,t}$ do not need to be detrended as they are stationary in the original model. We can then rewrite the model's key equations in terms of their stationary versions.

The investors solve

$$u_i(x_{i,t}) = \max_{\{c_{u,t}, w_{G,i,t}, w_{B,i,t}\}} \left\{ c_{i,t}^{1-1/\psi} + p \times \beta G^{\lambda(1-1/\psi)} \left(E_t[u_i(x_{i,t+1})^{1-\gamma}] \right)^{\frac{1-1/\psi}{1-\gamma}} \right\}^{\frac{1}{1-1/\psi}}, \tag{IA1}$$

subject to the intertemporal budget constraint

$$x_{i,t+1} = G^{-\lambda}\big(x_{i,t} + \omega_t^d L_{u,t} - c_{i,t}\big)\left(R_{f,t} + w_{G,i,t}(R_{G,t+1} - R_{f,t}) + w_{B,i,t}(R_{B,t+1} - R_{f,t})\right), \tag{IA2}$$

where the return is $R_{j,t+1} = \frac{G^{\lambda} v_{j,t+1}}{v_{j,t} - d_{j,t}}$. Firms produce output $y_{j,t}$ according to a Cobb-Douglas production function

$$y_{j,t} = (k_{j,t})^{\alpha\theta}(Z_{j,t}L_{j,t})^{(1-\theta)}. \tag{IA3}$$

The firm's value is the discounted value of its dividends,

$$v_{j,t}(k_{j,t}) = \max_{L_{j,t}, i_{j,t}} d_{j,t}(k_{j,t}) + E_t\left[\tilde{M}_{u,t+1} G v_{j,t+1}(k_{j,t+1})\right], \tag{IA4}$$

where $\tilde{M}_{u,t+1}$ is the stochastic discount factor (SDF) of the unconstrained investors. The optimization in (IA4) is subject to the capital accumulation equation, which, using $\delta > 0$ to denote capital

[28] Because in the main text, we used the lower case variable ω to refer to wages, we denote the detrended wage by ω^d. Also, to avoid confusing the portfolio share (lower case w, which does not need detrending) with wealth, we will use the variable x to refer to detrended wealth.

depreciation, is

$$k_{j,t+1} = G^{-\lambda}\left((1-\delta)k_{j,t} + i_{j,t}\right). \tag{IA5}$$

Firm j's dividends are therefore given by

$$d_{j,t}(k_{j,t}) = y_{j,t} - \omega_t^d L_{j,t} - i_{j,t} - \eta\left(\frac{i_{j,t}}{k_{j,t}} - \hat{\delta}\right)^2 k_{j,t}, \quad \eta > 0,\ \hat{\delta} > 0. \tag{IA6}$$

IA.2 Numerical algorithm

In this section, we describe the algorithm to numerically solve the problem in Section 3. Broadly, we start with beliefs about the relevant variables in the model (e.g., wages, asset prices, etc.), as functions of the state, that the household needs to solve its problem. Next, we solve in partial equilibrium the problem for both constrained and unconstrained households using dynamic programming. Then, starting at each point in the state space, we simulate the problem for one period in order to update the beliefs about the relevant variables. Finally, we solve again the households' problem with these updated beliefs and continue until the beliefs converge. Once the beliefs have converged, we simulate the model for many periods to compute the moments of interest. Below, we describe these steps in greater detail.

Step 1: Defining the state and initial beliefs

The aggregate state space consists of the discrete Markov productivity state $(Z_{G,t}, Z_{B,t})$, which takes four values, the quantity of aggregate capital $k_t = k_{G,t} + k_{B,t}$, the share of capital that is green, $S_{G,t} = \frac{k_{G,t}}{k_t}$, and the share of wealth that is constrained, $S_{C,t} = \frac{x_{C,t}}{x_{C,t}+x_{U,t}}$. We discretize the three continuous variables on grids of sizes 11, 13, and 7, respectively; we have also experimented extensively with grid sizes and found that finer grids did not change our results. We define the aggregate state space as the vector $\Omega_t^{agg} = (Z_{G,t}, Z_{B,t}, k_t, S_{G,t}, S_{C,t})$, which can take $4\times11\times13\times7 = 4004$ values. Each household's state space consists of its wealth x_t, which we discretize on a grid of size 37, and an indicator for whether the household is constrained or not.

We begin by initializing beliefs about all the relevant aggregate variables as a function of the state. Specifically, we initialize beliefs about the risk free rate $R^f(\Omega_t^{agg})$, firm values $v_j(\Omega_t^{agg})$, investment $i_j(\Omega_t^{agg})$, wage $\omega(\Omega_t^{agg})$, and consumption $c_i(\Omega_t^{agg})$. We also initialize beliefs about the evolution of the state variables as a function of the current state and of the realized shocks: $k_{t+1}(\Omega_t^{agg}, Z_{G,t+1}, Z_{B,t+1})$, $S_{G,t+1}(\Omega_t^{agg}, Z_{G,t+1}, Z_{B,t+1})$, and $S_{C,t+1}(\Omega_t^{agg}, Z_{G,t+1}, Z_{B,t+1})$.[29]

[29] Defining the belief about $k_{t+1} = G^{-\lambda}((1-\delta)k_t + i_{G,t} + i_{B,t})$ and $S_{G,t+1} = \frac{G^{-\lambda}((1-\delta)k_t + i_{G,t}}{k_{t+1}}$ is trivial if one has beliefs about $i_{j,t}$, therefore the only additinal belief is $S_{C,t+1}$.

Additionally, we define an auxillary state space for asset price deviations from beliefs $\Omega_t^{aux} = (\tilde{v}_{G,t}, \tilde{v}_{B,t}, \tilde{R}_t^f)$ with size $5 \times 5 \times 5 = 125$, where $\tilde{v}_{j,t} \equiv v_{j,t} - v_j(\Omega_t^{agg})$ is the deviation of the price from the beliefs. Note that Ω_t^{aux} is not an actual state space because in equilibrium, all prices and aggregate quantities are functions of the aggregate state Ω_t^{agg}, and therefore, in equilibrium (i.e., once the model has converged), $\Omega_t^{aux} = (0, 0, 0)$. However, as will be explained below, defining Ω_t^{aux} is needed by our solution algorithm before it converges to equilibrium.

Step 2: Solving for the firm's optimal investment in partial equilibrium

Given beliefs about the consumption of the unconstrained households at t and the evolution of the state at $t+1$, we can compute beliefs about the realized stochastic discount factor at $t+1$. For example, if utility is CRRA, this involves computing $M(\Omega_t^{agg}, Z_{G,t+1}, Z_{B,t+1}) = \beta\left(\frac{G^{\lambda} c_U(\Omega_{t+1}^{agg})}{c_U(\Omega_t^{agg})}\right)^{-\gamma}$. This requires interpolating $c_U(\Omega_{t+1})$ over the state at $t+1$ because the predicted values of Ω_{t+1} may not lie exactly at the gridpoints. More generally, for Epstein-Zin utility, we must iterate the beliefs about c_U to compute the stochastic discount factor.

Next, at each point in the aggregate state space Ω_t^{agg}, we compute the firm's investment by satisfying the firm's Euler equation, $E_t[M_{t+1} R_{j,c,t+1}] = 1$, where $R_{j,c,t+1}$ is the firm's marginal return on capital.[30]

$$R_{j,c,t+1} = \frac{\frac{\partial \Pi_{j,t+1}}{\partial k_{j,t+1}} + 1 - \delta + 2\eta(1 - \delta + \hat{\delta})\left(\frac{i_{j,t+1}}{k_{j,t+1}} - \hat{\delta}\right) + \eta\left(\frac{i_{j,t+1}}{k_{j,t+1}} - \hat{\delta}\right)^2}{1 + 2\eta\left(\frac{i_{j,t}}{k_{j,t}} - \hat{\delta}\right)}, \tag{IA1}$$

$$\frac{\partial \Pi_{j,t+1}}{\partial k_{j,t+1}} = \frac{\theta}{1 - (1-\theta)\alpha} \Phi_{j,t+1} k_{j,t}^{\frac{\theta}{1-(1-\theta)\alpha} - 1}, \quad \text{and} \tag{IA2}$$

$$\Phi_{j,t+1} = (1 - (1-\theta)\alpha)\left(\frac{(1-\theta)\alpha Z_{j,t+1}}{\omega_{t+1}}\right)^{\lambda}. \tag{IA3}$$

To find investment such that $E_t[M_{t+1} R_{j,c,t+1}] = 1$, we start with a guess for investment, compute $E_t[M_{t+1} R_{j,c,t+1}] - 1$, and increase (decrease) investment if this quantity is positive (negative).

Step 3: Solving for household's consumption and portfolio in partial equilibrium

Given beliefs about dividends at t, firm values at t, and the evolution of the state at $t+1$, we can compute beliefs about returns $R_j(\Omega_t^{agg}, Z_{G,t+1}, Z_{B,t+1}) = \frac{G^{\lambda} v_j(\Omega_{t+1}^{agg})}{v_j(\Omega_t^{agg}) - d_j(\Omega_t^{agg})}$ as a function of the state

[30] When return to scale is constant ($\alpha = 1$) then there is no difference between firm j's marginal return on capital and the equity return $R_{j,t+1}$. However, in general the two are not the same and the firm optimal choice of investment satisfies the Euler equation with the marginal return on capital.

at t and the realized state at $t+1$. This requires interpolating $v_j(\Omega_{t+1})$ over the state at $t+1$ because the predicted values of Ω_{t+1} may not lie exactly at the gridpoints.

Then, using beliefs about returns, the wage at t, and the evolution of the state, we solve the household's problem using value-function iteration on equation (IA1). This is a standard and relatively fast computation, given modern computing power and parallel processing. This gives us policies as functions of the aggregate state for consumption $c_i(\Omega_t^{agg})$ and portfolio choice $w_{j,i}(\Omega_t^{agg})$.

In addition, in the last iteration, we solve the model over the extended state space $\Omega_t^{agg} \times \Omega_t^{aux}$. When $\Omega_t^{aux} = (0,0,0)$ this leads to identical policies as the original calculation. However, for example if $\Omega_t^{aux} = (\epsilon, 0, 0)$, we solve for a policy where everything is exactly as in the original calculation, but the current price of the Green firm is bigger than the belief: $v_{G,t} = v_G(\Omega_t^{agg}) + \epsilon$. This implies that the return on investing in Green firms is smaller than the equilibrium belief, and the household will invest less in Green firms.

Step 4: Updating the beliefs

Starting from every point on the aggregate state space $\Omega_t^{agg} = (Z_{G,t}, Z_{B,t}, k_t, S_{G,t}, S_{C,t})$, we simulate the model one period forward. This implies that the aggregate capital is k_t, the aggregate capital of green firms is $k_t S_{G,t}$, and the constrained households own a fraction $S_{C,t}$ of all wealth are determined at the start of the period.[31]

At this stage, there is one important complication. To solve for households' policies, we need to know the wealth of each household. However, to do that, we need to know aggregate wealth, which is the sum of the values of the green and brown firms ($v_{G,t} + v_{B,t}$), because the supply of shares is normalized to one and the aggregate supply of the risk-free asset is zero. While we have beliefs about $v_{G,t}$, $v_{B,t}$, and R_t^f as functions of the state Ω_t^{agg}, if the model has not yet converged to equilibrium, then setting prices equal to these beliefs would leave us no way to update beliefs. Furthermore, setting prices equal to these beliefs may result in markets not clearing—for example, if the belief about the price of green firms is too low, then the demand for green shares will exceed supply.

[31] Numerically, during this step, all constrained households are assigned exactly the same wealth, and separately all unconstrained households are assigned exactly the same wealth. In the long simulation, all households of the same type will not necessarily own exactly the same wealth because newborns are born with the average wealth of all of the dead (constrained and unconstrained), therefore the wealth of a newborn unconstrained household is not necessarily the same as a one year old unconstrained household. As discussed in the main text, this mixing prevents either type from dominating the wealth distribution. However, this mixing is very slow and therefore, in practice, the cross-sectional differences in wealth across agents of the same type are very small. Therefore, the mean wealth of each type is approximately a sufficient state variable. Krusell and Smith (1998) show that even in models with significantly larger cross-sectional variation in wealth, average wealth is approximately a sufficient state variable.

This is the reason we introduced the auxiliary state Ω_t^{aux}. At each point in the state space Ω_t^{agg}, we solve for the price $v_{j,t} = v_j(\Omega_t^{agg}) + \tilde{v}_{j,t}$ that clears markets. For example, if for a given $v_G(\Omega_t^{agg})$ the demand for green firms is too high, we increase $v_{G,t}$ by shifting higher on the grid for $\tilde{v}_{G,t}$. Because we have solved the household's problem for $\Omega_t^{agg} \times \Omega_t^{aux}$, it presents no difficulty to solve for policies at higher or lower prices than the belief. Market clearing is an iterative process because when the price $v_{G,t}$ increases, so does aggregate wealth, which causes a change in the households' policies. Clearing markets means finding the prices $(v_{G,t}, v_{B,t}, R_t^f)$ such that aggregate demand for shares of each type of firm is one, and the demand for bonds is zero.

Once we have cleared markets at a particular point on the state space, we use the market-clearing prices to update beliefs about the risk-free rate $R^f(\Omega_t^{agg})$ and firm values $v_j(\Omega_t^{agg})$. We also use the equilibrium quantities in the one-period simulation to update the beliefs about investment $i_j(\Omega_t^{agg})$, wage $\omega(\Omega_t^{agg})$, and household consumption $c_i(\Omega_t^{agg})$, and the evolution of the state $k_{t+1}(\Omega_t^{agg}, Z_{G,t+1}, Z_{B,t+1})$, $S_{G,t+1}(\Omega_t^{agg}, Z_{G,t+1}, Z_{B,t+1})$, and $S_{C,t+1}(\Omega_t^{agg}, Z_{G,t+1}, Z_{B,t+1})$.

We update the beliefs slowly, putting a weight of 0.95 on the old beliefs, so that the model converges smoothly. With an updated set of beliefs, we go back to Step 2 and continue until convergence. Once the model has converged, Step 2 ensures that the firm's Euler equation is satisfied, and the maximization in Step 3 ensures that the households' Euler equations are satisfied. We then simulate the model over many periods to compute the moments of interest. To confirm that the solution algorithm converged correctly, in the long simulation, we compute the Euler equation errors for the unconstrained household, that is, $\text{Avg}[MR_j] - 1$. In the baseline model with $\gamma = 5$, these are 0.0000, -0.0001, and 0.0002 for the risk-free rate, green return, and brown return, respectively; in the model with $\gamma = 50$, these are -0.0005, -0.0004, and -0.0005. We also compute the pseudo-R^2 between the beliefs and the simulated values of the key quantities in the model. In the baseline model with $\gamma = 5$, these are 0.9998, 1.0000, 0.9999, 0.9998, and 0.9999 for the stochastic discount factor, constrained households' share of wealth, value of the green firm, value of the Brown firm, and the risk free rate, respectively; in the model with $\gamma = 50$, these are 0.9999, 1.0000, 0.9996, 0.9996, and 0.9990.[32]

[32] We do not report the R^2 for aggregate capital or green capital share because they are 1.0000 by construction. This is because the investment function is determined optimally in Step 2 (conditional on the other beliefs), and investment in the simulation is set based on the investment in Step 2. We do not report the R^2 for consumption because what matters is the stochastic discount factor belief, not consumption itself. However, the consumption R^2 is even higher than the one for the stochastic discount factor.

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