# Green $Q$: Measuring and Valuing Green and Brown Capital*


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**Abstract**

We provide the first structural assessment of the U.S. green transition using the $q$-theory of investment. Distinguishing emissions-free green capital from emissions-intensive brown capital, we develop a transparent identification strategy that infers the replacement cost of the brown capital stock directly from observed emissions, avoiding concerns about greenwashing. Structural estimation yields the market values and adjustment costs of green and brown capital. A pronounced divergence emerges: by 2022, brown capital accounts for 37% of replacement costs but only 22% of market value, indicating that markets value green capital at a premium and discount brown capital. Green investment entails large adjustment costs— 16.7% of output—reflecting both its intensity and the frictions involved in scaling up green capital.



Keywords: Green Capital, Brown Capital, Emissions, Tobin's $Q$, Corporate Investment

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*"Investors, central banks, and financial regulators are driving increased awareness of climate risk. This increased awareness can support climate policy development and implementation."* – IPCC (2023, AR6 WGIII, Chapter 15, p. 1, 549)

# 1 Introduction

The United Nations' Intergovernmental Panel on Climate Change (IPCC) identifies financial markets as key engines of the green transition. Allocating financing to green projects and pricing environmental risks are necessary to mitigate the catastrophic effects of global warming. While an extensive literature, pioneered by Bolton and Kacperczyk (2021) and Pástor et al. (2021, 2022), explores the asset pricing and cost of capital implications of the green transition—often documenting a 'green premium' in equity returns—quantifying the true valuation impact of green investment remains a challenge due to the inherent noise and potential for greenwashing in self-reported ESG metrics. Moreover, while financial markets assign a significant valuation premium to emissions-free capital, a critical and less-explored question is whether this financial incentive translates into real capital reallocation.

We quantitatively assess the green transition through the lens of economic theory and emissions data, sidestepping inconsistent ESG ratings and industry benchmarks.[1] Instead, we turn to Tobin (1969) Nobel Prize-winning q-theory of investment and the supply approach to valuation (Belo et al., 2013, 2022), and distinguish between investment in emissions-free green capital and emissions-intensive brown capital. Our model predicts that growth in observable emissions is tied to growth in brown capital and links the marginal value of green and brown capital to investment dynamics, creating a transparent identification strategy. We take these predictions to the data and structurally estimate replacement costs, market values, and adjustment costs for the aggregate U.S. economy.

[1]The London Stock Exchange Group values the U.S. green economy at \$4.7 trillion, whereas the MSCI USA Selection Index points to a value of \$30.4 trillion. Indeed, sustainability assessments vary substantially across data providers (Berg et al. (2022)) and are susceptible to greenwashing (Wittreich (2025)).

We report two main findings. First, the U.S. economy is greenifying quickly. Replacement values and book values of brown capital are declining over time, reflecting the wedge between high economic growth and slowly growing – and even declining – emissions. Second, financial markets value these dynamics and assign a higher value to green investments than to brown investments. Firms maximize their value by choosing green investments.

Our theoretical analysis begins with an economy producing output with green and brown capital. Only brown capital contributes to emissions. Firms choose investment policies to maximize market values subject to real frictions such as capital adjustment costs and depreciation. We derive a closed-form solution for the market value of the economy and decompose the total value into the market value derived from green and brown capital, respectively. Importantly, the market value reflects corporate investment choices such that high valuations coincide with high investment rates. Taken together, the model ties emissions growth, green and brown investments, and market values together.

The closed-form solution and focus on observable quantities (emissions, investment rates, and market prices) make the model easy to apply to the data. Our emissions production function predicts that observable changes in emissions reflect changes in brown capital. Accounting for the loss in capital due to depreciation allows us to infer new investments in brown projects. Given observable total capital and investment dynamics, we can obtain the stock of green capital and investments therein as remainders. Armed with revealed investment policies and observed stock prices, we can turn to the second implication of our model: investment rates reveal market valuations (known as "Tobin's $q$"). This famous investment-$q$ is at the centre of financial economics and allows us to structurally estimate capital adjustment costs by aligning model-implied firm values with observed market prices (Belo et al. (2022)).

Intuitively, equilibrium asset prices embed investors' expectations about future cash flows, risks, and adjustment costs. Thus, modeling the joint dynamics of emissions, investments, and asset prices insulates our theoretical analysis from concerns about greenwashing by rewarding genuinely productive green capital and penalizing claims unsupported by fundamentals. Our market-based approach allows us to assess the green transition using signals that are comparable over time and robust to definitional ambiguity.

Empirically, our structural estimations include all assets located in the United States, along with the corresponding aggregate greenhouse gas emissions generated on U.S. soil. This geographic focus ensures that the asset base encompasses all domestic holdings, whether owned by U.S. or foreign entities, while intentionally excluding offshore assets held by U.S. firms to maintain precise alignment with domestic emission data. By adopting this comprehensive approach, we mitigate estimation biases caused by firms endogenously shifting emissions across corporate boundaries, legal jurisdictions, supply chains, and non-public firms (Duchin et al. (2025)).

While the pioneering empirical work of Bolton and Kacperczyk (2021) and Pástor et al. (2022) utilizes firm-level metrics to document how carbon risk and sustainable 'tastes' influence expected returns and thereby valuations, these studies—by necessity—rely on voluntary, self-reported disclosures (e.g., CDP reports or MSCI ESG ratings). Such metrics are subject to the inherent reporting frictions and self-selection challenges documented in the 'aggregate confusion' literature (Berg et al., 2022). We complement this research by utilizing mandatory regulatory data from the EPA's Greenhouse Gas Reporting Program. By leveraging this exhaustive, physically-monitored aggregate inventory, we sidestep the reporting noise and disclosure gaps inherent in voluntary firm-level metrics.

Our estimation results reveal a growing divergence between the market-based and replacement-cost measures of brown and green capital, suggesting that financial markets increasingly value green capital more highly than its physical costs would imply, while simultaneously discounting brown capital below its replacement value. In 2022, brown capital accounted for 37% of replacement costs but only 22% of aggregate market value, suggesting a clear market preference for emissions-free assets over carbon-intensive ones. Crucially, we find that this valuation premium is accompanied by substantially higher adjustment costs for green capital—averaging 16.7% of GDP—which reflects the significant real-resource intensity required to scale green investment, especially when compared to the significantly lower adjustment costs for brown capital at 5.8% of GDP. These findings remain robust across varying data samples and alternative functional forms of the emission production function that can include capital utilization and lags for time-to-emit.

# 2 *Q*-Theory with Green and Brown Capital

In this section, we present a neoclassical $q$-theory model which links financial markets to real corporate policies. The model considers an economy which generates output using green and brown capital input factors. Optimal investment policies maximize the market value subject to convex adjustment costs and capital depreciation.

## 2.1 Model Set-Up

We decompose the total capital stock $K_t$ into either emissions-free green capital $G_t$ and emissions-producing brown capital $B_t$ such that $K_t = G_t + B_t$. Green capital stands in for new productive capital that does not create emissions and for active environmental mitigation investments (Fang et al., 2025). Our capital heterogeneity complements previous studies which decompose total capital into, for example, physical capital, working capital, human capital, and intangible capital.

Producing output using brown capital creates carbon emissions $E_t$ which are proportional to the amount of installed brown capital,

$$E_t = \xi B_t \tag{1}$$

with $\xi > 0$. This may be the complete emissions production function or a first-order approximation thereof such that $E_t = 0$ if $B_t = 0$. This functional form is popular in the literature (Barnett et al. (2023), Hong et al. (2023), and Yin (2024)) and implies that emissions intensity, $\frac{E_t}{Y_t}$, is proportional to the brown capital-to-output ratio $\frac{B_t}{Y_t}$. In extensions of our model, we account for utilization intensity and lags in emissions.

The green capital stock, $G_t$, evolves according to the law of capital motion

$$G_{t+1} = (1-\delta)G_t + I_t^G, \tag{2}$$

where $\delta$ is the rate of capital depreciation and $I_t^G$ green investment. Analogously, given brown investment $I_t^B$, the law of motion for brown capital is

$$B_{t+1} = (1-\delta)B_t + I_t^B. \tag{3}$$

The capital adjustment costs for green capital, $\Phi_t^G$, are convex in the investment rate $\frac{I_t^G}{G_t}$, monotonic in the capital stock $G_t$, and homogeneous of degree one. A popular functional form is

$$\Phi^G(I_t^G, G_t) = \frac{g}{2}\left(\frac{I_t^G}{G_t}\right)^2 G_t. \tag{4}$$

The model parameter $g > 0$ determines the green investment-$q$ sensitivity. Equivalently, given the model parameter $b > 0$, the cost of adjusting the brown capital stock is

$$\Phi^B(I_t^B, B_t) = \frac{b}{2}\left(\frac{I_t^B}{B_t}\right)^2 B_t. \tag{5}$$

The net payout, $D_t$, is

$$D_t = (1-\tau_t)\left(\Pi_t - \Phi_t^B - \Phi_t^G\right) - I_t^B - I_t^G + \tau_t\delta B_t + \tau_t\delta G_t + L_{t+1} - R_t^{La} L_t, \tag{6}$$

where $L_t$ is the amount of outstanding debt or liabilities, $\tau_t$ is the corporate tax rate, and $R_t^{La} = R_t^L - (R_t^L - 1)\tau_t$ is the after-tax cost of debt.

Given an exogenous stochastic discount factor $M_{t,t+1}$, the economy maximizes the cum-dividend market value of equity:

$$V_t = \max_{\{B_{t+s+1}, G_{t+s+1}, L_{t+s+1}\}_{s=0}^{\infty}} \mathbb{E}_t \left[ \sum_{s=0}^{\infty} M_{t,t+s} D_{t+s} \right], \tag{7}$$

subject to a transversality condition, $\lim_{T \to \infty} \mathbb{E}_t[M_{t,t+T} L_{t+T+1}] = 0$, limiting borrowing.

In summary, the economy in our model captures forward-looking investment and financing choices. Green and brown capital are neither perfectly substitutable nor complementary and reflect their own investment opportunities. Intuitively, high emissions growth reflects growth in brown capital which reveals a high marginal $q$ on brown capital. As such, the model ties emissions to valuable investment opportunities.

## 2.2 Model Solution

We follow standard steps (Liu et al. (2009) and Belo et al. (2022)) to solve the model by deriving the closed-form solution for the market value in terms of observables quantities (investment rates) and model parameters (adjustment costs).

**Proposition 1** *The market price of equity (ex-dividend value),* $P_t = V_t - D_t$*, is*

$$P_t + L_{t+1} = q_t^G G_{t+1} + q_t^B B_{t+1}, \tag{8}$$

*where the marginal* $q$ *on green and brown capital are*

$$q_t^G = 1 + (1 - \tau_t) g \frac{I_t^G}{G_t}, \tag{9}$$

$$q_t^B = 1 + (1 - \tau_t) b \frac{I_t^B}{B_t}. \tag{10}$$

Equation (8) resembles a balance sheet identity which equates the market value of equity and debt with the market value of the green and brown capital. The unlevered asset value is endogenous and scales the green and brown capital stocks by their respective marginal $q$ reflecting the market value of an additional dollar spent on the respective capital stock. Thus, the marginal $q$'s are the shadow prices of green and brown capital, respectively and capture the marginal cost of investment in either capital stock. Importantly, green $q$ and brown $q$ may differ from each other. Marginal $q$ arises as a sufficient statistic to fully explain investment policies per Equations (9) and (10).

In our model, average $q$ equals marginal $q$ where marginal $q$ is the value-weighted combination of its green $q$ and brown $q$. Average $q$ is the ratio of the total market value to its book value.

**Proposition 2** *The average q (or Tobin's q) is*

$$\frac{P_t + L_{t+1}}{G_{t+1} + B_{t+1}} = \frac{G_{t+1}}{G_{t+1} + B_{t+1}} q_t^G + \frac{B_{t+1}}{G_{t+1} + B_{t+1}} q_t^B. \tag{11}$$

The equality of average $q$ and marginal $q$ implies that average $q$, too, is a function of the marginal cost of investing in green and brown capital and therefore depends on the respective investment rates and capital adjustment costs. However, the production function and the elasticity between green and brown capital do not directly impact market values.

# 3 Data

For our estimation, we need three sets of data: emissions, capital, and market values.

### 3.1 Greenhouse Gas Emission

We obtain greenhouse gas emissions data from the U.S. Environmental Protection Agency (EPA).[2] The EPA reports emissions by economic sector from 1990 to 2022 and covers a broad set of greenhouse gases, including not only carbon dioxide ($CO_2$), the focus of much of the prior sustainable finance literature, but also methane, nitrous oxide, and fluorinated gases. Because our objective is to assess how much the economy has "greened" over time, it is important to rely on comprehensive emissions measures that capture all major greenhouse gases rather than $CO_2$ alone (Hsu et al., 2023). Notwithstanding, the correlation between total emissions growth and $CO_2$ growth is 0.99.

The starting year of 1990 is dictated by the institutional architecture of international climate policy. Both the United Nations Framework Convention on Climate Change (UNFCCC, adopted in 1992) and the Kyoto Protocol (1997) designate 1990 emissions as the reference year, making it the standard benchmark in national emissions inventories.

Figure 1 illustrates the evolution of greenhouse gas emissions across economic sectors. Panel A shows emissions by sector (transportation, electric power, industry, agriculture, and the commercial sector) while Panel B presents the time series of total emissions aggregated across these five sectors. Although the EPA also reports emissions for the residential sector, we exclude it from our analysis because our focus is on corporate production and investment.

FIGURE 1 ABOUT HERE.

The related summary statistics are reported in Table 1. Average annual total greenhouse gas emissions amount to 6,531.71 million tons of $CO_2$ equivalents. Emissions average 6,701.89 million tons in the first half of the sample (1991–2006) and decline to 6,361.53 million tons in the second half (2007–2022), indicating a gradual reduction in aggregate emissions over time. Our model predicts that the growth rate of emissions is tied to the growth rate of

[2]Source: https://cfpub.epa.gov/ghgdata/inventoryexplorer/

brown capital (Equation (1)). As shown in the table, the growth rate of total emissions is slightly negative, averaging −0.08% per year over the full sample.

TABLE 1 ABOUT HERE.

## 3.2 Capital and Financial Market Data

To construct Tobin's $q$, we scale total firm market value by a comprehensive measure of capital. We obtain the latter from FRED via the series "Nonfinancial Corporate Business; Nonresidential Structures, Equipment, and Intellectual Property Products, Current Cost Basis, Level," which reflects total physical and intangible capital in the economy. Total firm market value is calculated as the sum of aggregate debt and aggregate market equity, both of which are sourced from FRED. Specifically, for aggregate debt, we use the series "Total Credit to the Private Non-Financial Sector, Adjusted for Breaks, for the United States." For market equity, we use the series "Nonfinancial Corporate Business; Market Value Estimate of Nonfinancial Assets, Level", originally available from Flow of Funds.

This market equity measure is standard in the literature, notably used by Moskowitz and Vissing-Jørgensen (2002), and offers the distinct advantage of capturing the market value of both public and private firms. This broad coverage ensures alignment with our capital and emissions data, which similarly encompasses both sectors, thereby maintaining internal consistency across our primary variables. Throughout the paper, we label our main results as FRED. Figure 2 illustrates the resulting evolution of Tobin's $q$ over our sample period.

FIGURE 2 ABOUT HERE.

We report summary statistics in Table 1. Average Tobin's $q$ is 3.28. Tobin's $q$ is 2.96 in the first half of the sample (1991-2006) and increases to 3.60 in the second half (2007–2022), indicating a gradual increase in the aggregate Tobin's $q$ over time. The dynamics align with those reported in the literature (Li and Liu (2024) and Crouzet et al. (2025)).

As noted above, our measurements of capital and emissions encompass the entire U.S. economy, integrating the economic activity of both public and private firms. While market prices are directly observable only for public entities, the FRED data uses estimated market prices for private firms to derive a total aggregate equity value. To ensure our results remain robust against potential estimation errors in this measure, we construct two alternative market equity series using data from CRSP and Compustat. As an initial check, the summary statistics for Tobin's $q$ presented in Table 1 are notably similar across our benchmark and robustness versions. This alignment is consistent with the structural estimations of Cooper and Priestley (2016), which demonstrate that valuations do not systematically differ between private and public firms.

Finally, following Liu et al. (2009), we measure the tax rate $\tau_t$ as the statutory corporate income tax rate, which averages 33% across our sample and was reduced to 22% in 2018.

# 4 Empirics

## 4.1 Replacement Costs and Investment Rates

In this section, we describe how we construct time series for brown and green capital.

In 1990, fossil fuels accounted for approximately 83% of U.S. primary energy consumption, underscoring the dominant role of coal, oil, and natural gas in electricity generation, transportation, and industrial production at that time (U.S. Energy Information Administration, 2007). Because productive capital is built to operate within the prevailing energy system, the composition of energy supply provides a natural anchor for the carbon intensity of the installed capital stock. Accordingly, we initialize the brown-capital share, defined as the ratio of brown capital stock to total capital stock, at 0.9. This calibration follows the energy-based approach used in Papageorgiou et al. (2017) and is consistent with theories of directed technical change, which emphasize the co-evolution of energy inputs, production technologies, and infrastructure and imply strong path dependence in the capital stock (Acemoglu et al., 2012; IPCC, 2023). Section 4.4 shows that our results are robust to alternative initial values.

This initial brown-capital share of 0.9 in 1990, combined with the aggregate capital stock obtained from FRED (see Section 3), allows us to construct the initial stocks of brown and green capital. We then use Equation (1) to obtain the growth of brown capital,

$$\frac{B_{t+1}}{B_t} = \frac{E_{t+1}}{E_t}. \tag{12}$$

Combining the initial stock with the estimated growth rates yields a complete time series of brown capital from 1990 to 2022. We obtain the green capital stocks from $G_t = K_t - B_t$. Following Zhang (2017) and Belo et al. (2022), we infer green and brown investment by inverting the laws of motion for capital and solving for the respective investment flows in Equations (2) and (3). We assume a common depreciation rate of $\delta = 10\%$ (Bloom, 2009; Kogan and Papanikolaou, 2013, 2014). Intuitively, the growth of green capital reflects any growth in productive capital that outpaces the growth in emissions (through more innovative production technology or pollution abatement technology that reduces regulatory, fiscal, or social costs from carbon emissions).

Table 2 shows that the average total investment rate is 12.73%, with brown and green investment rates averaging 9.92% and 19.22%, respectively. The total investment rate declines from 13.85% in the pre-2006 period to 11.74% thereafter. A similar downward pattern is observed for both brown investment, which falls from 10.88% to 8.71%, and green investment, which declines from 26.02% to 15.58%.

Table 2 about here.

Table 2 also reports the resulting brown-capital *share*, defined as the ratio of brown capital stock to total capital stock. Across the full sample, the average brown-capital share is

0.64, indicating that brown assets comprise the majority of the capital base. During this same period, the average total investment rate is 12.73%. However, a granular look at investment types reveals a significant divergence: the brown investment rate—defined as brown investment scaled by brown capital—is 9.92%, while the green investment rate is nearly double at 19.22%.

This disparity between green and brown investment rates is driven by two distinct economic forces. These dynamics are most clearly observed by dividing the sample into two subperiods: an early period (1991–2006) and a later period (2007–2022). In the early period, the green investment rate averaged 22.75%, significantly outpacing the brown investment rate of 10.83%. This gap was primarily a function of the small denominator effect; because the green capital share was only 0.21 (compared to a brown capital share of 0.79), even modest absolute investments in green technology resulted in a disproportionately high investment rate.

In the later period (2007–2022), the green investment rate remained higher than the brown rate (15.69% versus 9.00%), despite the fact that the green capital base had grown substantially. By this stage, the capital composition had shifted toward a more balanced distribution, with the brown capital share falling to 0.48 and the green capital share rising to 0.52. The sustained strength of the green investment rate in this latter half of the sample is largely attributed to the structural shift in production and the significant decrease in emissions observed since 2007, as illustrated in Figure 1.

Figure 3 illustrates that the brown-capital share has generally decreased over time. Interestingly, when measured using replacement costs, brown capital accounts for only 37% of total capital in 2022. The decline in the brown-capital share ($B/K$) mirrors that of total emissions ($E/K$) and of emissions intensity ($E/Y$), suggesting that our green and brown capital series capture the trends and dynamics of total emissions.

Figure 3 about here.

We further validate the economic underpinnings of our green and brown capital stocks by examining correlations between investment rates and economic growth and climate risk measures. We report the results in Table 3. Brown investment is more procyclical and correlates strongly with growth in real GDP per capita. This cyclicality reflects that firms choose to invest in brown capital performance-permitting, whereas green investment is a persistent continuity that is less exposed to the ups and downs of business cycles. Turning to the climate policy uncertainty index (CPU) from Baker et al. (2016), we find that brown investment is more impacted than green investment, suggesting that the "wait-and-see" delay incentive induced from high economic uncertainty is weaker for green investments. Conversely, investment in brown capital is subject to environmental regulatory risks and is therefore particularly exposed to CPU. Finally, we turn to the climate physical risk climate physical risk index (PRI) from **BuaKappRamellaRognoneBuaKappRamellaRognone20244** and the climate concern index (CCI) from Angelini et al. (2025). Both indices use textual data to measure how salient transition risks are covered in the popular press. Increases in PRI and CCI lead to cuts in brown investments and increases in green investment rates. Overall, the results of Table 3 confirm that the investment rates for green and brown capital align with economic priors and capture meaningful variation aligned with the green transition.

Table 3 about here.

## 4.2 Market-Based Firm Values

In this section, we structurally estimate market-based valuations of both green and brown capital stocks. Our objective is to discipline the relative valuation of green and brown capital using aggregate asset prices, rather than relying solely on physical measures of capital.

Our estimations build on Proposition 1 and Proposition 2, developed in Section 2. Combining the two propositions yields the following equilibrium relationship between aggregate market valuation and investment dynamics:

$$\frac{P_t + L_{t+1}}{G_{t+1} + B_{t+1}} = 1 + g(1 - \tau_t)\frac{I_t^G}{G_t}\frac{G_{t+1}}{G_{t+1} + B_{t+1}} + b(1 - \tau_t)\frac{I_t^B}{B_t}\frac{B_{t+1}}{G_{t+1} + B_{t+1}}. \tag{13}$$

This expression highlights that aggregate Tobin's $q$ can be interpreted as a weighted average of green and brown investment incentives, where the parameters $g$ and $b$ capture how marginal investment in each type of capital is capitalized into market values. Following Belo et al. (2022), we structurally estimate $g$ and $b$ using the time series regression implied by Equation (13).

<ins>FIGURE 4 ABOUT HERE.</ins>

Figure 4 shows the linear specification model's fitness. The second panel of Table 4 reports the estimation results. Using the FRED sample, we estimate $b = 20.86$ ($t$-statistic: 5.68) and $g = 28.83$ ($t$-statistic: 6.00). The estimation yields small mean absolute pricing errors, suggesting a good fit of the full time series of firm values.

<ins>TABLE 4 ABOUT HERE.</ins>

We use these parameter estimates to construct market-based valuations of brown and green capital. We substitute these parameter estimates back into Proposition 1 to get green capital $q$ ($q_t^G$) and brown capital $q$ ($q_t^B$). In order to check how the market value of green capital share has evolved over time, we calculate the following ratio,

$$\frac{q_t^B B_{t+1}}{q_t^B B_{t+1} + q_t^G G_{t+1}}. \tag{14}$$

Figure 5 shows how this market-based share has evolved over time. The market-based share has decreased over time. For instance, FRED-based market-based brown share is 94% in the year 1991 while it is only 22% in the year 2022.

We next compare these market-based valuations with the corresponding replacement cost measures of brown and green capital constructed in Section 4.1. This comparison allows us to assess how financial markets value green and brown capital relative to their physical cost and to examine whether market valuations amplify or attenuate the long-run shift away from carbon-intensive capital implied by replacement-cost dynamics. Early in the sample, the replacement-cost brown share is slightly lower than the market-based brown share (e.g., 0.91 versus 0.94 in 1991). In contrast, in the more recent period, the replacement-cost brown share is substantially higher than the market-based share (e.g. 0.37 versus 0.22 in 2022). This divergence indicates that green capital has become increasingly valuable relative to brown capital, with the valuation differential being more pronounced in market prices than in replacement costs.

FIGURE 5 ABOUT HERE.

## 4.3 Capital Adjustment Costs

We use the estimated parameters $g$ and $b$ to infer the adjustment costs implied by the model. Specifically, we substitute these estimates into Equations (4) and (5) to compute adjustment costs for green and brown capital, respectively.

TABLE 5 ABOUT HERE.

Table 5 reports the model-implied adjustment costs as a percentage of economic output (real GDP). Using the full sample, adjustment costs amount to 5.8% of GDP for brown capital and 16.7% of GDP for green capital. The larger adjustment cost associated with green capital primarily reflects its substantially higher investment intensity. As shown in Table 2, the average green investment rate is 19.22%, compared to 9.92% for brown investment. These numbers fall within the range of usual adjustment costs (Bloom (2009) and Cooper and Priestley (2016)).

Interestingly, the adjustment cost of brown capital (scaled by GDP) declines from 7.66% in the pre-2006 period to 3.94% in the post-2006 period, while the adjustment cost of green capital increases from 15.68% to 17.72% over the same periods. This divergence in capital adjustment costs over time is again largely driven by the persistently higher level of green investment relative to brown investment.

## 4.4 Robustness

Our results are robust to a battery of alternative implementations of our theoretical framework. The functional form of the emissions production function can include adjustments for capital utilization and lags via "time-to-emit". We can also choose alternative choices of the initial brown-capital share and the depreciation rate.

Our first robustness test generalizes the emissions production function from Equation (1) to

$$E_t = \xi U_t B_t, \tag{15}$$

where $U_t$ is the utilization rate of capital. We obtain the time series data, labeled "Capacity Utilization: Total Index", from FRED. Given this parametrization, we can infer the growth in brown capital from the growth in *utilization-adjusted* emissions. Given the new capital stocks, we repeat the structural estimation per Equation (13). We report the results in Table 6. Overall, our results remain robust. The model fit does not change (in terms of MAE), and green adjustment costs continue to dwarf adjustment costs for brown capital.

TABLE 6 ABOUT HERE.

Our next robustness test changes the emissions production function from Equation (1) to

$$E_t = \xi B_{t-1}, \tag{16}$$

This lagged specification recognizes that capital installation may occur with a delay, such that newly installed capital takes time before becoming operational and generating emissions, in the spirit of Kydland and Prescott (1982). This modeling choice allows us to infer the growth in *lagged* brown capital from the growth in emissions. With new green and brown capital stocks, we repeat the structural estimation per Equation (13) and present the results in Table 7. Our results are unchanged and continue to assign a high marginal value to green investments. The model continues to fit the data well, yielding small MAEs.

Table 7 about here.

In our baseline specification, we initialize the brown capital share in 1990 at 0.9. While we motivate this choice by the energy breakdown in 1990, we next confirm the robustness of our results to alternative initial conditions. Table 8 reports our main regression estimates when the initial brown-capital share is set to 0.75. The estimated parameters remain quantitatively similar and statistically significant, indicating that our main conclusions are not driven by the specific choice of the initial capital composition.

Table 8 about here.

Similarly, in the baseline analysis, we assume a depreciation rate of $\delta = 10\%$. Although this value is standard in the literature, we examine the robustness of our results to a higher depreciation rate. Table 9 reports the corresponding estimates for $\delta = 12\%$ (Cooper (2006) and Chen (2016)). The results remain stable and continue to support our main findings.

Table 9 about here.

# 5 Conclusion

This paper provides a transparent, market-based evaluation of the green transition by structurally estimating a neoclassical $q$-theory model that decomposes total capital into emissions-producing brown capital and emissions-free green capital. By explicitly tying brown capital dynamics to observed growth in aggregate emissions, our framework avoids reliance on firm-level classifications and self-reported measures of "greenness," thereby limiting measurement error and greenwashing concerns. Using comprehensive economy-wide data that cover both public and private firms and are not confined to particular industries, our approach also circumvents distortions arising from reallocation across sectors or corporate boundaries. The result is a disciplined, equilibrium-based assessment of how financial markets value green and brown capital.

Our findings indicate that the marginal value of green capital is high and that financial markets place a substantial premium on emissions-free capital while discounting emissions-producing brown capital relative to replacement costs. In particular, the divergence between market values and physical capital shares suggests that investors increasingly value green capital and penalize carbon-intensive assets. At the same time, the model-implied adjustment costs highlight the real frictions involved in scaling green investment. Together, these results suggest that markets are differentiating sharply between green and brown capital, offering evidence that asset prices embed meaningful signals about the direction and constraints of the green transition.

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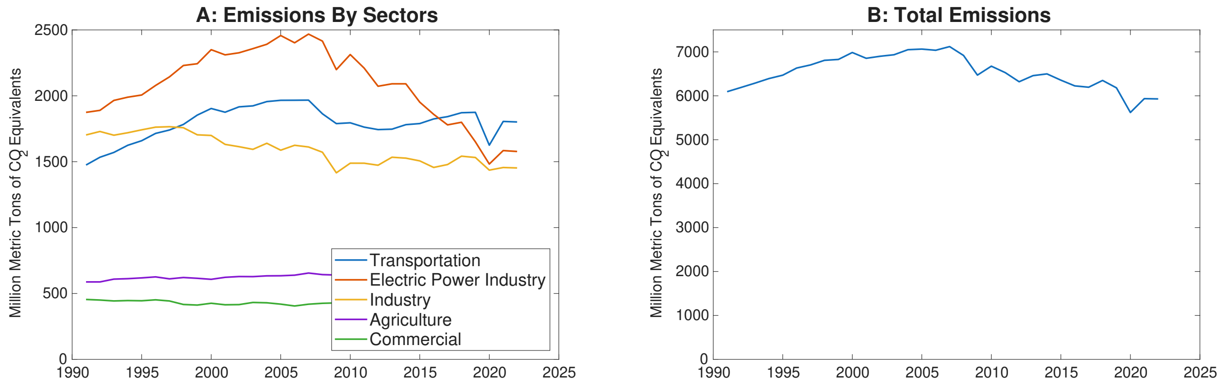


**Figure 1:** This figure plots annual U.S. greenhouse gas emissions from 1990 to 2022. Panel A displays emissions by sector—Transportation, Electric Power, Industry, Agriculture, and Commercial—measured in million metric tons of $CO_2$ equivalents. Panel B presents total emissions aggregated across these sectors. The data are obtained from the U.S. Environmental Protection Agency (EPA).

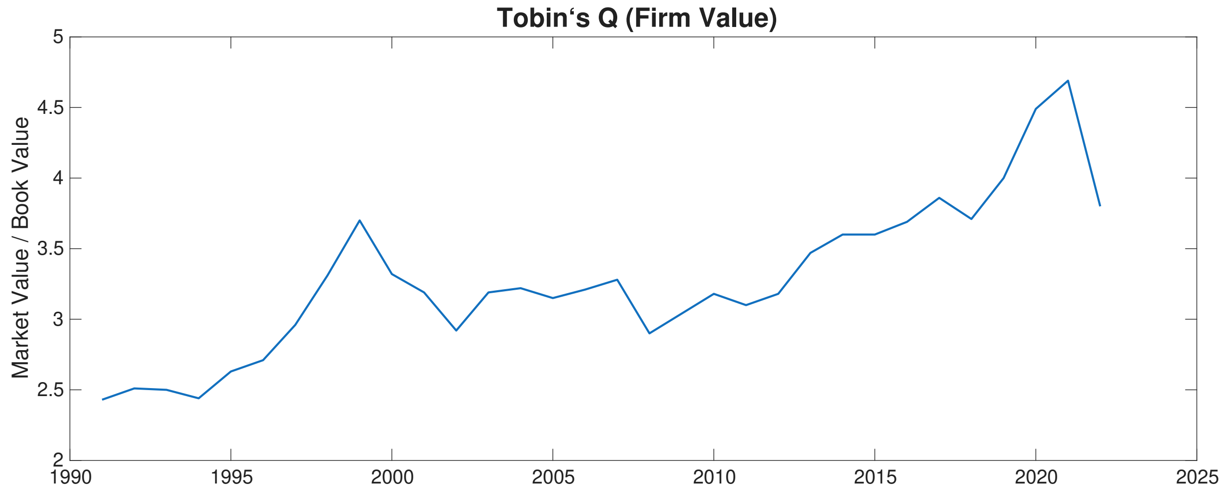


**Figure 2:** This figure plots the time series of aggregate Tobin's $q$ from 1990 to 2022. Tobin's $q$ is measured as the ratio of total market value (aggregate market equity plus aggregate debt) to the replacement cost of capital. The figure reports three versions based on alternative measures of equity market value: FRED (Flow of Funds–based aggregate equity), Compustat (public firms), and CRSP (public firms).

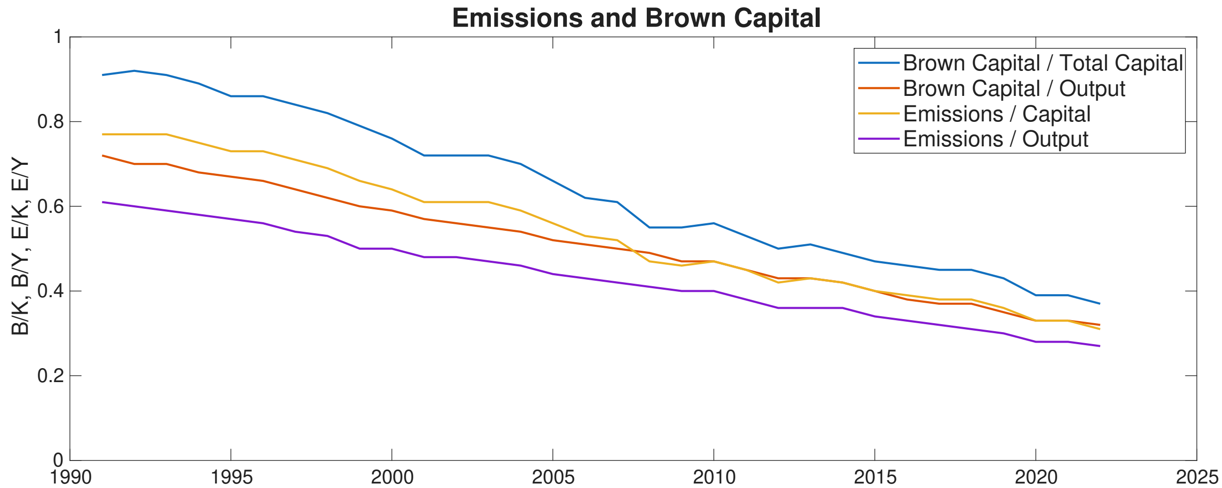


**Figure 3:** This figure plots four ratios from 1990 to 2022: brown capital to total capital $(B/K)$, brown capital to output $(B/Y)$, emissions to total capital $(E/K)$, and emissions to output $(E/Y)$. Brown capital is constructed using emissions growth. Total capital and output are obtained from FRED. Emissions are measured in $CO_2$ equivalents.

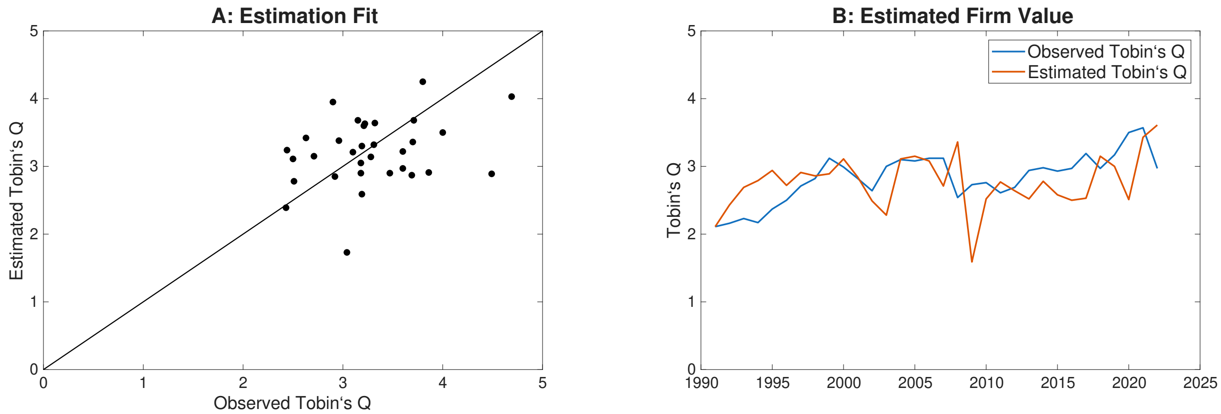


**Figure 4:** This figure visualizes the fit from our structural estimation in Equation (13). Panel A plots estimated Tobin's $q$ against observed Tobin's $q$. Panel B plots the time series of observed and model-implied Tobin's $q$ from 1990 to 2022. Estimation details are in Table 4.

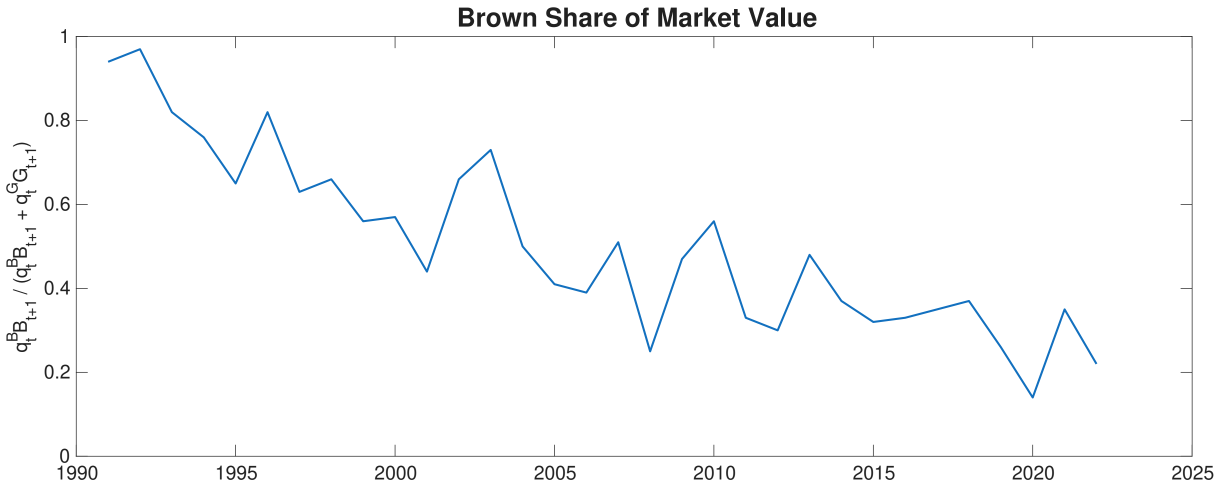


**Figure 5:** This figure plots the market-based share of brown capital from 1990 to 2022 from our structural estimation in Equation (13). The brown share is defined as $\frac{q_t^B B_{t+1}}{q_t^B B_{t+1}+q_t^G G_{t+1}}$, where $q_t^B$ and $q_t^G$ denote the marginal $q$ of brown and green capital, respectively. Estimation details are in Table 4.

**Table 1:** Summary Statistics for Emissions and Tobin's $Q$

This table reports summary statistics for total U.S. greenhouse gas emissions and aggregate Tobin's $q$. Emissions are measured in million metric tons of $CO_2$ equivalents, and growth denotes the annual percentage change. Tobin's $q$ is computed as the ratio of aggregate market value (equity plus debt) to the replacement cost of capital using alternative equity measures (FRED, CRSP, Compustat). Panel A reports the full sample (1991–2022). Panel B reports the early subsample (1991–2006). Panel C reports the late subsample (2007–2022).

| | Emissions | | Tobin's $Q$ | | |
|---|---|---|---|---|---|
| | Level | Growth | FRED | CRSP | Compustat |
| | (1) | (2) | (3) | (4) | (5) |
| Panel A: Full Sample (1991 – 2022) | | | | | |
| Mean | 6,531.71 | –0.08% | 3.28 | 3.49 | 2.84 |
| StdDev | 382.02 | 2.84% | 0.55 | 0.57 | 0.36 |
| Panel B: Early Sample (1991 – 2006) | | | | | |
| Mean | 6,701.89 | 0.83% | 2.96 | 3.19 | 2.68 |
| StdDev | 321.05 | 1.21% | 0.38 | 0.61 | 0.38 |
| Panel C: Late Sample (2007 – 2022) | | | | | |
| Mean | 6,361.53 | –1.00% | 3.60 | 3.77 | 2.98 |
| StdDev | 369.78 | 3.66% | 0.50 | 0.34 | 0.29 |

**Table 2:** Summary Statistics for Capital Stocks and Investment Rates

This table reports summary statistics for total, brown, and green investment rates, as well as ratios of emissions and brown capital to total capital and output. Brown capital is constructed from emissions growth. Green capital is defined as the residual of total capital minus brown capital. Investment rates are measured from the law of capital motion. Panel A reports the full sample (1991-–2022). Panels B and C report the early (1991–2006) and late (2007–2022) subsamples, respectively.

| | Investment Rates | | | Ratios | | | |
|---|---|---|---|---|---|---|---|
| | Total | Brown | Green | E/K | B/K | E/Y | B/Y |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Panel A: Full Sample (1991 – 2022) | | | | | | | |
| Mean | 12.73% | 9.92% | 19.22% | 0.54 | 0.64 | 0.43 | 0.51 |
| StdDev | 2.64% | 2.84% | 10.03% | 0.15 | 0.18 | 0.10 | 0.12 |
| Panel B: Early Sample (1991 – 2006) | | | | | | | |
| Mean | 13.21% | 10.83% | 22.75% | 0.67 | 0.79 | 0.52 | 0.61 |
| StdDev | 2.33% | 1.21% | 11.95% | 0.08 | 0.10 | 0.06 | 0.07 |
| Panel C: Late Sample (2007 – 2022) | | | | | | | |
| Mean | 12.25% | 9.00% | 15.69% | 0.41 | 0.48 | 0.34 | 0.41 |
| StdDev | 2.92% | 3.66% | 6.19% | 0.06 | 0.07 | 0.05 | 0.06 |

**Table 3:** Cyclicality of Investment Rates

This table reports correlations between total, brown, and green investment rates and macroeconomic and climate-related indicators: real GDP growth ($\Delta Y$), Baker et al.'s (2016) climate policy uncertainty (CPU), Bua et al.'s (2024) climate physical risk index (PRI), and Angelini et al.'s (2025) climate concern index (CCI). The sample covers 1991–2022.

| | Investment Rates | | |
|---|---|---|---|
| | Total | Brown | Green |
| | (1) | (2) | (3) |
| Corr(ΔY) | 0.59 | 0.79 | 0.26 |
| Corr(CPU) | –0.16 | –0.35 | –0.22 |
| Corr(PRI) | 0.12 | –0.06 | 0.29 |
| Corr(CCI) | 0.20 | –0.12 | 0.41 |

**Table 4:** Structural Estimation of Model Parameters

This table reports parameter estimates from the structural estimation of our $q$-theory model (Equation (13)). The coefficients $a$, $b$, and $g$ correspond to adjustment cost parameters for total, brown, and green capital, respectively. Columns report results using alternative measures of equity market value (FRED, Compustat, CRSP). Reported $t$-statistics in square brackets are based on Newey-West (1987) corrected standard errors. The sample covers 1991–2022. The table also reports implied adjustment costs as a share of GDP ($\Phi/Y$) and the mean absolute pricing error (MAE).

| | Physical Capital Model | | | Brown Capital Model | | |
|---|---|---|---|---|---|---|
| | FRED | Compustat | CRSP | FRED | Compustat | CRSP |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| $a$ | 25.77 | 28.03 | 20.64 | | | |
| | [15.66] | [17.87] | [22.06] | | | |
| $b$ | | | | 20.86 | 23.31 | 18.69 |
| | | | | [5.68] | [4.78] | [5.83] |
| $g$ | | | | 28.83 | 30.83 | 21.34 |
| | | | | [6.00] | [7.55] | [7.11] |
| $\Phi^K/Y$ | 17.62% | 19.16% | 14.11% | | | |
| $\Phi^B/Y$ | | | | 5.80% | 6.48% | 5.20% |
| $\Phi^G/Y$ | | | | 16.70% | 17.86% | 12.36% |
| MAE | 0.49 | 0.52 | 0.34 | 0.50 | 0.50 | 0.35 |

**Table 5:** Model-Implied Capital Adjustment Costs

This table reports model-implied capital adjustment costs as a percentage of real GDP for total capital, brown capital, and green capital. The adjustment costs are computed using parameter estimates from the structural estimation per Equation (13) summarized in Table 4. Panel A reports the full sample (1991-–2022). Panels B and C report the early (1991–2006) and late (2007–2022) subsamples.

| | Physical Capital Model | | | Brown Capital Model | | |
|---|---|---|---|---|---|---|
| | FRED | Compustat | CRSP | FRED | Compustat | CRSP |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Panel A: Full Sample (1991 – 2022) | | | | | | |
| $\Phi^K/Y$ | 17.62% | 19.16% | 14.11% | | | |
| $\Phi^B/Y$ | | | | 5.80% | 6.48% | 5.20% |
| $\Phi^G/Y$ | | | | 16.70% | 17.86% | 12.36% |
| Panel B: Early Sample (1991 – 2006) | | | | | | |
| $\Phi^K/Y$ | 17.98% | 19.55% | 14.40% | | | |
| $\Phi^B/Y$ | | | | 7.66% | 8.56% | 6.87% |
| $\Phi^G/Y$ | | | | 15.68% | 16.77% | 11.61% |
| Panel C: Late Sample (2007 – 2022) | | | | | | |
| $\Phi^K/Y$ | 17.26% | 18.77% | 18.77% | | | |
| $\Phi^B/Y$ | | | | 3.94% | 4.40% | 3.53% |
| $\Phi^G/Y$ | | | | 17.72% | 18.95% | 13.12% |

**Table 6:** Structural Estimation with Utilization-Adjusted Emissions

This table reports parameter estimates from the structural estimation of our $q$-theory model (Equation (13)) when the emissions production function includes a capital utilization adjustment (Equation (15)). The coefficients $a$, $b$, and $g$ correspond to adjustment cost parameters for total, brown, and green capital, respectively. Columns report results using alternative measures of equity market value (FRED, Compustat, CRSP). Reported $t$-statistics in square brackets are based on Newey-West (1987) corrected standard errors. The sample covers 1991–2022. The table also reports implied adjustment costs as a share of GDP ($\Phi/Y$) and the mean absolute pricing error (MAE).

| | Physical Capital Model | | | Brown Capital Model | | |
|---|---|---|---|---|---|---|
| | FRED | Compustat | CRSP | FRED | Compustat | CRSP |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| $a$ | 25.77 | 28.03 | 20.64 | | | |
| | [15.66] | [17.87] | [22.06] | | | |
| $b$ | | | | 25.13 | 27.50 | 21.44 |
| | | | | [7.95] | [6.06] | [7.80] |
| $g$ | | | | 24.32 | 26.38 | 18.35 |
| | | | | [6.72] | [8.68] | [8.84] |
| $\Phi^K/Y$ | 17.62% | 19.16% | 14.11% | | | |
| $\Phi^B/Y$ | | | | 7.55% | 8.26% | 6.44% |
| $\Phi^G/Y$ | | | | 16.56% | 17.97% | 12.50% |
| MAE | 0.49 | 0.52 | 0.34 | 0.53 | 0.55 | 0.37 |

**Table 7:** Structural Estimation with Lagged Emissions Specification

This table reports parameter estimates from the structural estimation of our $q$-theory model (Equation (13)) when the emissions production function includes time-to-emit (Equation (16)). The coefficients $a$, $b$, and $g$ correspond to adjustment cost parameters for total, brown, and green capital, respectively. Columns report results using alternative measures of equity market value (FRED, Compustat, CRSP). Reported $t$-statistics in square brackets are based on Newey-West (1987) corrected standard errors. The sample covers 1991–2022. The table also reports implied adjustment costs as a share of GDP ($\Phi/Y$) and the mean absolute pricing error (MAE).

| | Physical Capital Model | | | Brown Capital Model | | |
|---|---|---|---|---|---|---|
| | FRED | Compustat | CRSP | FRED | Compustat | CRSP |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| $a$ | 26.02 | 28.48 | 20.99 | | | |
| | [14.25] | [16.90] | [20.68] | | | |
| $b$ | | | | 25.94 | 27.51 | 21.86 |
| | | | | [5.81] | [4.77] | [5.74] |
| $g$ | | | | 23.85 | 26.94 | 18.45 |
| | | | | [5.65] | [6.92] | [6.76] |
| $\Phi^K/Y$ | 17.44% | 19.09% | 14.07% | | | |
| $\Phi^B/Y$ | | | | 7.54% | 7.99% | 6.35% |
| $\Phi^G/Y$ | | | | 16.02% | 18.09% | 12.39% |
| MAE | 0.49 | 0.51 | 0.33 | 0.54 | 0.55 | 0.37 |

**Table 8:** Structural Estimation with Alternative Initial Brown-Capital Share

This table reports parameter estimates from the structural estimation of our $q$-theory model (Equation (13)) when the initial brown-capital share is set to 0.75 instead of the baseline calibration of 0.90. The coefficients $a$, $b$, and $g$ correspond to adjustment cost parameters for total, brown, and green capital, respectively. Columns report results using alternative measures of equity market value (FRED, Compustat, CRSP). Reported $t$-statistics in square brackets are based on Newey-West (1987) corrected standard errors. The sample covers 1991–2022. The table also reports implied adjustment costs as a share of GDP ($\Phi/Y$) and the mean absolute pricing error (MAE).

| | Physical Capital Model | | | Brown Capital Model | | |
|---|---|---|---|---|---|---|
| | FRED | Compustat | CRSP | FRED | Compustat | CRSP |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| $a$ | 25.77 | 28.03 | 20.64 | | | |
| | [15.66] | [17.87] | [22.06] | | | |
| $b$ | | | | 19.24 | 21.81 | 18.18 |
| | | | | [3.87] | [3.46] | [4.34] |
| $g$ | | | | 29.42 | 31.43 | 21.74 |
| | | | | [6.31] | [7.89] | [7.46] |
| $\Phi^K/Y$ | 17.62% | 19.16% | 14.11% | | | |
| $\Phi^B/Y$ | | | | 4.46% | 5.05% | 4.21% |
| $\Phi^G/Y$ | | | | 15.76% | 16.85% | 11.66% |
| MAE | 0.49 | 0.52 | 0.34 | 0.49 | 0.49 | 0.34 |

**Table 9:** Structural Estimation with Alternative Depreciation Rate

This table reports parameter estimates from the structural estimation of our $q$-theory model (Equation (13)) when the depreciation rate is set to 12% instead of the baseline 10%. The coefficients $a$, $b$, and $g$ correspond to adjustment cost parameters for total, brown, and green capital, respectively. Columns report results using alternative measures of equity market value (FRED, Compustat, CRSP). Reported $t$-statistics in square brackets are based on Newey-West (1987) corrected standard errors. The sample covers 1991–2022. The table also reports implied adjustment costs as a share of GDP ($\Phi/Y$) and the mean absolute pricing error (MAE).

| | Physical Capital Model | | | Brown Capital Model | | |
|---|---|---|---|---|---|---|
| | FRED | Compustat | CRSP | FRED | Compustat | CRSP |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| $a$ | 22.50 | 24.45 | 18.01 | | | |
| | [16.14] | [18.05] | [22.63] | | | |
| $b$ | | | | 17.58 | 19.72 | 15.88 |
| | | | | [6.13] | [4.94] | [6.11] |
| $g$ | | | | 26.22 | 27.94 | 19.26 |
| | | | | [6.60] | [8.10] | [7.71] |
| $\Phi^K/Y$ | 20.38% | 22.16% | 16.32% | | | |
| $\Phi^B/Y$ | | | | 6.89% | 7.72% | 6.22% |
| $\Phi^G/Y$ | | | | 18.17% | 19.36% | 13.35% |
| MAE | 0.46 | 0.49 | 0.32 | 0.46 | 0.47 | 0.32 |