Innovation-Driven Contractions: A Key to Unravel Asset Pricing Puzzles [⋆]

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Abstract

We examine a perplexing phenomenon wherein technological innovations induce short-term contractions, using a two-sector New-Keynesian model. Pivotal to explaining the evidence are sticky prices, which alter the cyclicality of relative prices, impacting production during innovative phases. The model addresses key asset-pricing questions: Why is there a negative link between investment returns and stock returns? Why do valuations surge post adverse labor-market events? Why do both high book-to-market and high gross-profits forecast future returns positively, despite their divergent ties to technology? Why is the slope of the equity yield term structure procyclical? The mechanism of innovation-led contractions serves as a unifying thread, weaving together previously isolated puzzles, while offering a novel perspective.

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Technological innovations are primary catalysts for sustainable economic growth. While their long-term impact on the economy is unambiguously positive, prior macroeconomic literature indicates that these innovations can, surprisingly, lead to short-term production contractions.[1] However, quantitative theories explaining this critical empirical observation remain largely uncharted. What mechanisms drive these unexpected macroeconomic dynamics? And how do these short-term, technologically-driven downturns influence valuations and risk premia? This study delves into these pivotal questions, proposing that resolving the core macroeconomic issue also sheds light on several asset pricing puzzles.

We commence by expanding the evidence that technological innovations lead to short-term inputs' usage downturns, extending it to more recent years. Our findings indicate that in a short horizon, the contractionary impact of a rise in aggregate total factor productivity is concentrated within labor markets. Contrary to previous research, our extended sample analysis reveals that the immediate impact of these innovations on capital growth is insignificant.

Subsequently, we propose a general-equilibrium New-Keynsian model to explain the evidence. The model features two sectors: consumption and investment. The first produces final consumption goods, while the latter produces capital. Each sector faces nominal rigidities. The household model incorporates recursive preferences, facilitating a realistic examination of risk premia within this context.

In the absence of sticky prices, a technological innovation increases firms' current and expected marginal product of labor and capital. Consequently, firms ramp up their investments and hiring. This surge in capital demand also elevates the relative price of investment goods. With empirically-disciplined sticky prices, the short-term effect of positive shocks is more intricate. In particular, sticky prices imply that the marginal cost of production (relative to output price) falls more sharply, leading to increased markups. This dynamic curtails firms' labor demand, resulting in diminished hiring in the immediate term. As the capital is predetermined, near-term output also declines. While all firms capitalize on the

[1] See related literature for a comprehensive discussion.

heightened marginal productivity of capital by increasing investment rates, the relative price of investment goods decreases, thereby muting the impact on capital growth. These macro dynamics align with empirical findings.

Crucially, the model can shed new light on several empirical regularities, which a-priori suggest a potential *"disconnection"* between real economic activity and the stock market, but a-posteriori can be well-understood under fair pricing.

First, existing literature points to a fundamental challenge for production-based asset pricing frameworks. While stock-returns and returns on capital are positively correlated in expectation, the contemporaneous correlation between the two realized returns is negative in the data. The latter observation is quite perplexing, as under perfect competition, these returns should move in tandem. Our model, however, can reproduce this stylized fact. Following a positive innovation, firm valuations increase due to enhanced monopolistic rents. While investment returns might rise due to increased investment rates, they could also drop because of a reduced price per unit of capital. Quantitatively, the latter effect prevails, leading to a decrease in capital return. However, the influence of sticky prices on investment's relative price is transitory, suggesting that expected investment returns rise, consistent with empirical evidence.

Second, numerous studies have observed that deteriorating macro conditions, particularly those in the labor market, often coincide with elevated stock valuations, suggesting an apparent disjunction between fundamentals and prices. The prevailing resolution of the inverse relationship between labor market fluctuations and stock market shocks often hinges on compensatory monetary or fiscal policies. While this rationale is plausible, it does not fully explain why such policies do not merely mitigate the impact of adverse news on valuations but instead reverse the expected market reaction. Furthermore, extant research argues that a spike in (unexpected) unemployment signifies a "bad" state. Contrarily, we posit that unexpected employment is endogenous and should not be perceived as an external negative shock. Indeed, our model suggests that "good" shocks to technological innovation are associated with higher valuations but, in-line with the data, also with a pronounced unexpected drop in employment.

Thirdly, cross-sectional asset pricing research has demonstrated that firms characterized by high book-to-market ratios, low productivity, and high profitability all command a higher risk premium. Explaining these return spreads collectively poses a challenge. Growth firms are typically high-productivity entities. If such firms are deemed safer, then reconciling why high-profitability firms — which also traditionally exhibit high productivity — warrant a higher expected return becomes non-trivial. Our model offers a coherent explanation. A positive productivity shock reduces the book-to-market ratio, consistent with standard models, but also initially diminishes gross profits due to the contractionary nature of innovation in the short term. Consequently, both a lower book-to-market ratio and reduced profitability predict decreased future excess returns.

Lastly, we examine the implications of innovation-led contractions for the term structure of equity yields. In the benchmark model, the slope of the term structure is procyclical, as in the data, whereas in the absence of sticky prices the slope is countercyclical. Following a positive shock, input usage initially falls but is expected to revert and increase in the short-run, suggesting that in good states, the expected dividend growth is larger in shorter-horizons relative to the longer-horizons.

In all, we provide evidence that contractionary technological innovations, as corroborated by empirical evidence, offer an overarching resolution to multiple – and ostensibly unrelated – asset pricing anomalies, thereby forging a more cohesive link between macroeconomic dynamics and financial markets.

Related Literature. In a pivotal research by Basu, Fernald, and Kimball (2006), comprehensive empirical data delineates that when utilization-adjusted aggregate technology change rises, input metrics, encompassing labor hours and employment indices, counter-intuitively fall. While non-residential investment declines as well, the production of durable goods is unaffected. Several years subsequent to the inception of such technological advancements, inputs revert to their baseline, and output's trajectory rises.

Notwithstanding the first-order implications this evidence posits for macroeconomic dynamism, the ramifications pertaining to asset pricing remain unexplored. In our study, we extend this evidence, finding that the contractionary impact of technological innovations is primarily focused in labor markets. Furthermore, we theoretically show that this transient "disconnection" between macro aggregates and innovation, spills over to broader "disconnections" between macroeconomic variables and valuations in financial markets.

Liu, Whited, and Zhang (2009) uncover a production-based asset-pricing puzzle. Employing the generalized method of moments, they align average investment returns with average stock returns. The contemporaneous correlation between stock and investment returns is negative, which is incongruent with the canonical implications of q-theory. The authors postulate that temporal lags in investment might modulate the synchronicity of this correlation. Corroborating this hypothesis, Kuehn (2009) studies a production model wherein investment necessitates an extended time-to-build, offering a theoretical underpinning for these observations.

Our analytical suggests that while time-to-build might serve as a sufficient condition to reconcile this anomaly, it is not necessary. We construct a two-sector model of consumption and investment, in which time-to-build lasts only one period, analogous to the frameworks presented by Papanikolaou (2011) and Garlappi and Song (2017). We enhance these extant models by integrating monopolistic influence and nominal rigidities. In the presence of price stickiness, the relative price of investment goods declines subsequent to a technological innovation, which can account for the decline in investment returns, notwithstanding a simultaneous surge in stock returns. Crucially, the counter-cyclical nature of capital goods prices, as implied by our model, aligns with empirical findings by Greenwood, Hercowitz, and Krusell (1997) and Christiano and Fisher (2003), which underscore that investment goods prices exhibit an inverse correlation with the business cycle.

Several studies highlight an anomaly where "bad" macro news can be "good" news for equity markets. In particular, Boyd, Hu, and Jagannathan (2005), Elenev, Law, Song, and Yaron (2022) and Xu and You (2022) show that stock prices typically rise in response to announcements of higher unemployment. Our model is able to reconcile this puzzling observation, without any reliance on monetary or fiscal policy shocks.

Furthermore, firms with higher book-to-market and higher profitability both command a higher risk premium (see Fama and French, 1992; Hou, Mo, Xue, and Zhang, 2021; Novy-Marx, 2013). Reconciling these two observed phenomena concurrently presents a complex task for asset pricing models. Ai, Li, and Tong (2021) introduce a bifurcated paradigm, encompassing both transitory and permanent components. High profitability firms riskiness emerges from the transitory component of productivity, while that of value firms from the permanent component. Kogan, Li, and Zhang (2022) postulate that variable production costs create an operating hedging mechanism, thereby explaining both the value and profitability risk premiums. Zhu (2023) argues that the connection between investment options and disinvestment options may also explain both premiums. Our contribution to this corpus of literature is the proposition of a more streamlined solution, given that our framework encapsulates both spreads within a single first-moment shock paradigm.

Lastly, Bansal, Miller, Song, and Yaron (2021) document that in the US, Europe and Japan, the equity yield (expected dividend growth) term-structure slope is positive (negative) during economic expansions, while it turns negative (positive) in recessions. Gormsen (2021) confirms this finding, providing evidence that the term-structure of equity yields negatively comoves with the dividend-to-price ratio. The former recession dynamics also align with findings by Binsbergen, Brandt, and Koijen (2012). Bansal et al. (2021) accounts for the procyclical slope with a regime-switching model that dictates the cyclicality of expected dividend growth. Li and Xu (2023) rely on a financial-intermediary-based asset pricing model in an endowment economy. Our model also generates the procyclicality of the slope, but with dividends being endogenous and their growth cyclicality dependent on innovation-led contractions.

In a broader context, our manuscript is related to studies that connect production economies to expected returns (e.g., Belo and Lin (2012), Jones and Tuzel (2013), Kuehn and Schmid (2014), Belo, Li, Lin, and Zhao (2017), Kilic (2017), Tuzel and Zhang (2017), Ai, Li, Li, and Schlag (2019), Dou, Ji, Reibstein, and Wu (2019), Gofman, Segal, and Wu

Table 1: **Technological Innovations and Macroeconomic Growth: Data**

	Dependent variable (growth rate)						
Regressor	(1) Hours	(2) Payroll	(3) Composition-adjusted Labor	(4) Capital	(5) Investment	(6) Consumption	(7) Output
b	-0.34	-0.25	-0.27	0.04	0.12	0.12	0.21
t-stat	-4.68	-2.15	-3.11	1.51	0.28	2.06	2.86

The table reports the slope coefficients and the t-statistics for the regression: $\Delta y_t = const + b \cdot dz_t + \varepsilon_t$. dz_t is quarterly aggregate technological innovation. Δy_t is the log-growth rate of the macroeconomic variables, which include (1) Hours; (2) All Employees in Manufacturing; (3) Composition-adjusted labor input as in Fernald (2014); (4) Capital; (5) Investment; (6) Consumption; (7) Output. The sample is quarterly from 1968Q1 to 2019Q4.

(2020) and Kogan, Li, Zhang, and Zhu (2023). For instance, Belo, Lin, and Bazdresch (2014) discern that firms with restrained hiring yield higher expected returns. Analogously, disparities in intangible assets (e.g., Eisfeldt and Papanikolaou (2013)) or financial mechanisms (e.g., Belo, Lin, and Yang (2018)) predict expected returns.

1 Motivating Evidence and Model

Evidence. In alignment with the methodology presented by Basu et al. (2006), we furnish updated empirical findings pertaining to the immediate ramifications of technological advancements on factors of production. Our dataset encompasses a quarterly span from 1968Q1 to 2019Q4. We source real per-capita consumption expenditures (encompassing non-durables and services), gross domestic product, and investment expenditures from the Bureau of Economic Analysis (BEA). Employment metrics are procured from the Bureau of Labor Statistics (BLS). The utilization-adjusted productivity data, adhering to the methodology delineated by Fernald (2014), are obtained from the Federal Reserve Bank of San Francisco.

We employ a simple projection:

$$\Delta y_t = const + b \cdot dz_t + \varepsilon_t, \tag{1}$$

wherein dz_t is quarterly aggregate technological innovation, and Δy_t represents the log-growth rate of the macroeconomic variable of interest. The findings are tabulated in Table 1.

Consistent with the findings of Basu et al. (2006), we find technology innovations are associated with a significant reduction in hours worked, composition-adjusted labor input, and lower employment in good-producing sectors. However, in the extended sample, the impact of these innovations on capital usage is inconclusive. Both measures of investment expenditures and capital growth load positively on dz, but the slope coefficient is statistically insignificant. In congruence, the immediate impact on consumption and output is positive, yet, muted in the short-run (amounting to approximately 4% standard deviation increase).

Model. Conventional single-sector RBC (Real Business Cycle) models are unable to replicate the aforementioned empirical observations. Following a positive technological innovation, the marginal productivity of labor increases, leading to augmented employment. Given the persistent nature of technological shifts, the marginal productivity of capital also sees a commensurate enhancement, resulting in an unambiguous rise in investment expenditures.

Subsequently, we introduce a quantitative two-sector New-Keynesian model to reconcile the evidence. Production is bifurcated into a consumption sector and an investment sector, with the latter producing investment goods. Each sector comprises a multitude of firms operating under monopolistic competition and experiencing nominal price rigidity. This rigidity implies that markups vary endogenously over time. The intermediate inputs from these firms are amalgamated to produce a final investment good, which is sold to firms, and a final consumption good, which is sold to households. The household, owner of all firms, supplies labor elastically for production while optimizing its lifetime recursive utility. A monetary authority, adhering to a standard Taylor rule, sets interest rates, thereby influencing endogenous inflation. The dual-sector structure is pivotal in reconciling the data, as it facilitates the segregation of capital expenditures into two potentially counteracting components: the quantity of investment and the price of investment.

1.1 Aggregation

The aggregator in the consumption (investment) sector produces composite or "final" consumption (investment) goods, denoted $Y_{c,t}$ ($Y_{i,t}$). $Y_{c,t}$ will be used for consumption by the household, while $Y_{i,t}$ will be equal to aggregate investment goods in the economy. Production of the composite consumption (investment) good requires a continuum of differentiated intermediate goods as inputs, denoted by $\{y_{c,t}(n)\}_{\{n\in[0,1]\}}$ $\left(\{y_{i,t}(n)\}_{\{n\in[0,1]\}}\right)$. The production of the composite good $Y_{j,t}$, in sector $j \in \{c,i\}$, converts the sector's intermediate goods into a final good using a constant elasticity of substitution (CES) technology:

$$Y_{j,t} = \left[\int_0^1 \left(y_{j,t}(n)\right)^{\frac{\mu_j-1}{\mu_j}} dn\right]^{\frac{\mu_j}{\mu_j-1}}, \quad j \in \{c,i\}. \tag{2}$$

The parameter $\mu_j, \quad j \in \{c,i\}$, controls the substitutability among the intermediate goods. Perfect competition between the intermediate good producers requires $\mu_j \to \infty$. When μ_j is finite, the intermediate goods in sector j are not perfect substitutes, and thus each intermediate good producer has some degree of monopolistic power. Each final good producer (aggregator) in sector j sells its output $Y_{j,t}$ at nominal price $P_{j,t}$. Each intermediate good producer sells its intermediate good to the aggregator at a nominal price $p_{j,t}(n)$. The aggregator in each sector $j \in \{c,i\}$ faces perfectly competitive market, thus solving

$$\max_{\{y_{j,t}(n)\}} P_{j,t}Y_{j,t} - \int_0^1 p_{j,t}(n)y_{j,t}(n)dn, \quad j \in \{c,i\}, \tag{3}$$

where $Y_{j,t}$ is given by Eq (2), and the prices are taken as given. The first-order condition of Eq. (3) yields the demand for differentiated intermediate good of type n in sector j:

$$y_{j,t}(n) = \left[\frac{p_{j,t}(n)}{P_{j,t}}\right]^{-\mu_j} Y_{j,t}, \quad j \in \{c,i\}. \tag{4}$$

As the market for final goods is perfectly competitive, the final good producing firm (aggregator) in sector j earns zero profits in equilibrium. This condition, along with Eq. (3) and (4), yields the aggregate price index in sector j, given by

$$P_{j,t} = \left[\int_0^1 \left(p_{j,t}(n)\right)^{1-\mu_j} dn\right]^{\frac{1}{1-\mu_j}}, \quad j \in \{c,i\}. \tag{5}$$

1.2 Intermediate good production

1.2.1 Sectoral intermediate good producers

Intermediate goods in sector $j \in \{c,i\}$ are differentiated, and each type is denoted by $n \in [0,1]$. Each intermediate good producer n in sector j rents labor $n_{j,t}(n)$ from the household and owns capital stock $k_{j,t}(n)$. The intermediate good producer n in sector j produces an intermediate good $y_{j,t}(n)$, using a constant returns-to-scale Cobb-Douglas production function over capital and labor and subject to sectoral technology shocks $Z_{j,t}$:

$$y_{j,t}(n) = Z_{j,t} k_{j,t}(n)^{\alpha_j} n_{j,t}(n)^{1-\alpha_j}, \quad j \in \{c, i\}, \tag{6}$$

where α_j is the capital share of output of intermediaries in sector j, and $Z_{j,t}, \quad j \in \{c, i\}$, are the sectoral technology shocks.

Each intermediate good producer who wishes to invest an amount $i_{j,t}(n)$, where $i_{j,t}(n)$ is the investment, must purchase $\Phi_{j,k}\left(i_{j,t}(n), k_{j,t}(n)\right) k_{j,t}(n)$ units of capital goods under an equilibrium price of investment goods $P_{i,t}$. The convex adjustment cost function $\Phi_{j,k}(.)$ is given by:

$$\Phi_{j,k}\left(i_{j,t}(n), k_{j,t}(n)\right) = \frac{i_{j,t}(n)}{k_{j,t}(n)} + \frac{\phi_{k,j}}{2}\left(\frac{i_{j,t}(n)}{k_{j,t}(n)} - \bar{\delta}_j\right)^2 \tag{7}$$

where $\phi_{k,j}$ is the adjustment cost parameter and $\bar{\delta}_j$ is the investment ratio at the deterministic steady state for each sector j. Capital of each producer of type n in sector j evolves as:

$$k_{j,t+1}(n) = (1-\delta)\, k_{j,t}(n) + i_{j,t}(n). \tag{8}$$

Intermediate good producers in both sectors are monopolistic competitors in the product market and price takers in the input market. They face a quadratic costs of changing their nominal output price $p_{j,t}(n)$ each period, similar to Rotemberg (1982), given by

$$\Phi_{P,j}\left(p_{j,t}(n), p_{j,t-1}(n)\right) = \frac{\phi_{P,j}}{2}\left[\frac{p_{j,t}(n)}{\Pi_j p_{j,t-1}(n)} - 1\right]^2 p_{j,t}(n) Y_{j,t}, \quad j \in \{c, i\}, \tag{9}$$

where $Y_{j,t}$ is the final composite good in sector j, Π_j is the steady state inflation in the j sector, and $\phi_{P,j}$ governs the degree of price rigidity in sector j. In all, the period nominal dividend of intermediate good producer of type n in sector $j \in \{c, i\}$, $d^{\$}_{j,t}(n)$, in terms of nominal consumption goods, is given by

$$d^{\$}_{j,t}(n) = p_{j,t}(n) y_{j,t}(n) - W_t n_{j,t}(n) - P_{i,t}\Phi_{j,k}\left(\frac{i_{j,t}(n)}{k_{j,t}(n)}\right) k_{j,t}(n) - \Phi_{P,j}\left(p_{j,t}(n), p_{j,t-1}(n)\right). \tag{10}$$

Each intermediate good producer n chooses optimal hiring, investment, and nominal output price to maximize the firm's market value, taking as given nominal wages W_t, the nominal price of investment goods $P_{i,t}$, the demand for differentiated intermediate good n in sector j given by Eq. (4), and the nominal stochastic discount factor of the household $M^{\$}_{t,t+1}$. Specifically, the intermediate good producers maximize

$$V^{\$}_{j,t}(n) = \max_{\{n_{j,s}(n), k_{j,s}(n), p_{j,s}(n)\}} E_t \Sigma_{s=t}^{\infty} M^{\$}_{t,t+s} d^{\$}_{j,t+s}(n), \tag{11}$$

subject to Eq. (8), Eq. (10), and the demand constraint

$$\left[\frac{p_{j,t}(n)}{P_{j,t}}\right]^{-\mu_j} Y_{j,t} \leq Z_{j,t} k_{j,t}(n)^{\alpha_j} n_{j,t}(n)^{1-\alpha_j}, \quad j \in \{c, i\}. \tag{12}$$

Note that $V_{j,t}^{\$}(n), \quad j \in \{i, c\}$, is in nominal consumption units. Define the real firm value $V_{j,t}(n)$ and real dividend $d_{j,t}(n)$ (in terms of real consumption goods) by

$$V_{j,t}(n) = V_{j,t}^{\$}(n)/P_{c,t}; \quad d_{j,t}(n) = d_{j,t}^{\$}(n)/P_{c,t}. \tag{13}$$

Lastly, define the real growth rate in aggregate investment expenditures (in terms of real consumption goods) as $\triangle I_t = \frac{(P_{i,t}/P_{c,t})Y_{i,t}}{(P_{i,t-1}/P_{c,t-1})Y_{i,t-1}}$ and the growth rate in the relative price of investment goods by $\triangle P_{i,t} = \frac{P_{i,t}/P_{c,t}}{P_{i,t-1}/P_{c,t-1}}$.

1.2.2 Technology

The production in the investment (consumption) sector is subject to a sectoral technology shock, denoted $Z_{i,t}$ ($Z_{c,t}$). The technical growth rates are characterized as follows:

$$\frac{Z_{j,t}}{Z_{j,t-1}} = g_{z,j} + x_{j,t} + \sigma_{z,j}\varepsilon_{z,t}^{j}, \quad j \in \{c, i\}$$

$$x_{j,t} = \rho_{x,j} x_{j,t-1} + \sigma_{x,j}.\varepsilon_{x,t}^{j},$$

where $\rho_{x,j} \in (-1, 1)$ measures the persistence of long-term productivity growth, similar to Croce (2014), and $\sigma_{x,j}$ denotes long-run shocks' standard deviation. The shocks $\varepsilon_{z,t}^{c}$, $\varepsilon_{z,t}^{i}$, $\varepsilon_{x,t}^{i}$ and $\varepsilon_{x,t}^{c}$ are standard normal and independent over time.

1.3 Household

The economy is populated by a representative household that supplies total labor N_t, which flows to the both sectors. It derives utility from an Epstein and Zin (1991) and Weil (1989) utility over a stream of consumption goods C_t and disutility from labor N_t:

$$U_t = \left\{ (1-\beta)\left[C_t\left(1-\xi N_t^{\eta}\right)\right]^{1-1/\psi} + \beta\left(E_t U_{t+1}^{1-\gamma}\right)^{\frac{1-1/\psi}{1-\gamma}} \right\}^{\frac{1}{1-1/\psi}} \tag{14}$$

where β is the time discount rate, γ is the relative risk aversion, ψ is the IES, ξ is the amount of disutility from labor, and η is the sensitivity of disutility to working hours. When $\gamma > (<)\frac{1}{\psi}$, the household has preferences exhibiting early (late) resolution of uncertainty. The household derives income from labor and from the dividends of intermediate consumption and investment good producers. She chooses labor supply and consumption to maximize her lifetime utility, subject to the budget constraint:

$$\max_{\{C_s,N_s\}} U_t, \quad \text{s.t. } P_{c,t}C_t = W_tN_t + \int_0^1 d^{\$}_{c,t}(n)dn + \int_0^1 d^{\$}_{i,t}(n)dn \tag{15}$$

where $P_{c,t}$ is the nominal price of final consumption goods, and W_t is the nominal market wage. The consumer problem derives the nominal SDF used to discount the nominal dividend of intermediate good producing firms in both sectors:

$$M^{\$}_{t+1} = \beta\left(\frac{C_{t+1}}{C_t}\right)^{-1/\psi}\left(\frac{1-\xi N^{\eta}_{t+1}}{1-\xi N^{\eta}_t}\right)^{1-1/\psi}\left(\frac{U_{t+1}}{\left(E_tU^{1-\gamma}_{t+1}\right)^{\frac{1}{1-\gamma}}}\right)^{1/\psi-\gamma}\frac{P_{c,t}}{P_{c,t+1}} \tag{16}$$

1.4 Monetary authority

A monetary authority sets the nominal log-interest rate $r^{\$}_t$ according to a Taylor (1993) rule:

$$r^{\$}_t = \rho_r r^{\$}_{t-1} + (1-\rho_r)\left(r^{\$}_{ss} + \rho_\pi(\pi_t - \pi_{ss}) + \rho_y(\Delta Y_t - \Delta Y_{ss})\right) \tag{17}$$

where π_t is log inflation (in the consumption sector) defined as $\pi_t = \log\left(\frac{P_{c,t}}{P_{c,t-1}}\right)$, and ΔY_t is log-growth of real total output, $\Delta Y_t = \log\left(\frac{Y_{c,t}+P_{i,t}/P_{c,t}Y_{i,t}}{Y_{c,t-1}+P_{i,t-1}/P_{c,t-1}Y_{i,t-1}}\right)\cdot$ $r^{\$}_{ss}, \pi_{ss}$, and Δy_{ss} are the steady state log-levels of nominal interest rate, inflation, and output growth.

1.5 Equilibrium

In equilibrium, $W_t, P_{i,t}$, and π_t are set to clear all markets:

- Labor market clearing:

$$\int_0^1 n_{c,t}(n)dn + \int_0^1 n_{i,t}(n)dn = N_t. \tag{18}$$

- Consumption good market clearing:

$$C_t + \int_0^1 \frac{\phi_{P,c}}{2}\left[\frac{p_{c,t}(n)}{\Pi_c p_{c,t-1}(n)} - 1\right]^2 Y_{c,t}dn = Y_{c,t}. \tag{19}$$

- Investment good clearing:

$$\int_0^1 \Phi_{c,k}\left(\frac{i_{c,t}(n)}{k_{c,t}(n)}\right)k_{c,t}(n)dn + \int_0^1 \Phi_{i,k}\left(\frac{i_{i,t}(n)}{k_{i,t}(n)}\right)k_{i,t}(n)dn \tag{20}$$

$$+\int_0^1 \frac{\phi_{P,i}}{2}\left[\frac{p_{i,t}(n)}{\Pi_i p_{i,t-1}(n)} - 1\right]^2 Y_{i,t}dn = Y_{i,t} \tag{21}$$

- Zero net supply of nominal bonds:

$$\frac{1}{R_t^{\$}} = E_t\left[M_{t+1}^{\$}\right] \tag{22}$$

An equilibrium consists of prices and allocations s.t. taking prices as given, (i) household's allocation solves Eq. (15); (ii) firms' allocations solve Eq. (11); (iii) labor, consumption good, investment good and bond markets clear. We solve for a symmetric equilibrium in which intermediate good firms in both sectors employ the same amount $n_{j,t}(n) = n_{j,t}$, choose to hold the same amount of capital $k_{j,t}(n) = k_{j,t}$, and select the same price $P_{j,t}(n) = P_{j,t}$.

1.6 Returns

1.6.1 Stock Returns

The (real) realized stock return for each sector $j \in \{c, i\}$ is

$$R_{j,t+1}^{S(unlevered)} = \frac{d_{j,t+1} + V_{j,t+1}}{V_{j,t}} = \frac{d_{j,t+1}^{\$}/P_{c,t+1} + V_{j,t+1}^{\$}/P_{c,t+1}}{V_{j,t}^{\$}/P_{c,t}},$$

where dividend $d_{j,t+1}^{\$}$ and firm value $V_{j,t+1}^{\$}$ are defined in equations (10) and (11).

Define the unlevered market return as the value weighted return of both sectors, i.e.,

$$R_{M,t}^{S(unlevered)} = \frac{V_{c,t-1}}{V_{c,t-1} + V_{i,t-1}} R_{c,t}^{S(unlevered)} + \frac{V_{i,t-1}}{V_{c,t-1} + V_{i,t-1}} R_{i,t}^{S(unlevered)}. \tag{23}$$

Our model does not feature financial debt, operating leverage, or non-systematic payouts. We therefore define the excess returns as follows:

$$R_{j,t}^{e} = \phi_{lev}(R_{j,t}^{S(unlevered)} - R_t^f) + \sigma_d \varepsilon_{j,d,t} \quad j \in \{c, i, m\}, \tag{24}$$

where ϕ_{lev} is the degree of (total) financial and operating leverage, σ_d captures the volatility of idiosyncratic dividend shocks, and $\frac{1}{R_t^f} = E_t\left[M_{t+1}\right]$. This suggests that the equity premium in each sector is $E_t\left[R_{j,t+1}^{e}\right]$. The implied levered market gross return $R_{j,t}^{S}$ is defined as the sum of the excess return and the risk-free rate. Importantly, the leverage parameter does not affect the cyclicality of the market return, and the shocks, $\varepsilon_{j,d,t}$, do not covary with the SDF.

1.6.2 Investment Returns

The first order conditions of each sector are detailed in the Appendix. Optimality imply that the marginal real value of capital in sector $j \in \{c, i\}$ is given by:

$$\partial V/\partial k_{j,t} = \frac{P_{c,t-1}}{P_{c,t}} \left[-P_{i,t} \left(\Phi_{j,k}(i_{j,t}, k_{j,t}) + \frac{\partial \Phi_{j,k}\left(i_{j,t}, k_{j,t}\right)}{\partial k_{j,t}} k_{j,t} \right) + q_{j,t}(1-\delta) + \alpha_j \theta_{j,t} Z_{j,t} k_{j,t}^{\alpha_j - 1} n_{j,t}^{1-\alpha_j} \right],$$

where $q_{j,t}$ is the price of a marginal unit of installed capital in sector j, and $\theta_{j,t}$ is the marginal cost of producing an additional unit of intermediate good in sector $j \in \{c, i\}$ (inverse of markup). Consequently, the investment return in each sector is given by:

$$R^I_{j,t+1} = \frac{\partial V/\partial k_{j,t+1}}{q_{j,t}}.$$

The market investment return is therefore defined as:

$$R^I_{M,t} = \frac{V_{c,t-1}}{V_{c,t-1} + V_{i,t-1}} R^I_{c,t} + \frac{V_{i,t-1}}{V_{c,t-1} + V_{i,t-1}} R^I_{i,t}. \tag{25}$$

2 Quantification

2.1 Calibration

The model is calibrated at the quarterly frequency. The parameters are details in Table 2. We divide these to several categories.

Technology. We set the technological drift of both sectors, $g_{z,i} = g_{z,c}$, to match the mean of per-capita real consumption growth of about 2%. The parameter $\sigma_{z,c}$ ($\sigma_{z,i}$), which governs the volatility of short-run sectoral productivity growth, is set to target the the standard deviation of annual consumption (investment) growth. Notably, short-run investment shocks are about 30% more volatile than consumption shocks, in-line with Fernald (2014). The long-run productivity growth parameters follow Croce (2014). Specifically, the persistence, $\rho_{x,c} = \rho_{x,i}$, is 0.93, while the sectoral standard deviations of long-run productivity shocks is 10% of the volatility of sectoral short-run productivity shocks. For parsimony, all shocks in the model are perfectly correlated such that the model collapses to a single-shock framework (Z_{agg}), though all implications follow when shocks are orthogonal.

Table 2: **Model Parametrization**

Symbol	Parameter	Value
A. Technology		
$g_{z,i}$	Technological drift - investment sector	1.0035
$g_{z,c}$	Technological drift - consumption sector	1.0035
$\sigma_{z,i}$	Volatility of short-run growth - investment sector(%)	1.62
$\sigma_{z,c}$	Volatility of short-run growth - consumption sector (%)	1.23
$\rho_{x,i}$	Persistence of long-run growth - investment sector	0.93
$\rho_{x,c}$	Persistence of long-run growth - consumption sector	0.93
$\sigma_{x,i}$	Volatility of long-run growth - investment sector (%)	0.1*σ_{zi}
$\sigma_{x,c}$	Volatility of long-run growth - investment sector (%)	0.1*σ_{zc}
B. Production		
α_i	Capital share of output - investment sector	0.33
α_c	Capital share of output - consumption sector	0.33
δ	Capital depreciation rate	0.02
$\phi_{k,i}$	Capital adjustment cost - investment sector	2.1
$\phi_{k,c}$	Capital adjustment cost - consumption sector	2.1
μ_i	Elasticity of good substitution - investment sector	4
μ_c	Elasticity of good substitution - consumption sector	2.4
$\phi_{p,i}$	Rotemberg adjustment cost - investment sector	15
$\phi_{p,c}$	Rotemberg adjustment cost - consumption sector	15
C. Preferences and Rates		
γ	Relative risk aversion	10
ψ	Intertemporal elasticity of substitution	1.4
ξ	Disutility from labor	2
η	Sensitivity of disutility to working hours	4
β	Time discount factor	0.997
ϕ_{lev}	Combined Financial and Operating Leverage	2
D. Monetary Policy		
π_{ss}	Steady state inflation	0.005
ρ_r	Smoothing coefficient of Taylor rule	0.5
ρ_π	Weight on inflation gap	1.5
ρ_y	Weight on output gap	0.5

The table presents parameter choice of the model (in quarterly frequency) in the benchmark case.

Production. Capital's share of output in both sectors, $\alpha_c = \alpha_i$ is 33%, as in the data. The capital depreciation rate is 2%, implying an annual compounded depreciation of 8.2%. Capital adjustment costs in both sectors, $\phi_{k,c} = \phi_{k,i}$, are set to 2.1, as estimated by Basu and Bundick (2017). We set μ_i and μ_c to 4 and 2.4, respectively. The first implies that the average markup in the investment sector is 33%, identical to Bilbiie, Ghironi, and Melitz (2012) and close to Garlappi and Song (2017), while the latter implies that the average ratio of investment-sector markup to consumption-sector markup is 46%, consistent with De Loecker, Eeckhout, and Mongey (2021). The Rotemberg adjustment costs, $\phi_{p,c}$ and $\phi_{p,i}$, are set to 15, a conservative value when compared to Basu and Bundick (2017). This parameter matches the slope coefficient β of projection (1), when the dependent variable is hours growth, to the data.

Preferences and rates. We adopt a standard preference parameter configuration in the production-based asset-pricing literature. Specifically, γ is set to a conservative value of 10, while the IES, ψ, is calibrated to 1.4, in-line with Croce, Nguyen, Raymond, and Schmid (2019), suggesting an early resolution of uncertainty. The degree of disutility to working hours ξ is chosen such that in the deterministic steady state, the household works roughly 20% of its time. η, the Frisch elasticity of labor supply is 4, consistent with Keane and Neal (2023). The time discount factor β is 0.997, targeting the real risk free rates. Consistent with the total degree of leverage (joint operating and financial leverage) estimated in García-Feijóo and Jorgensen (2010), we set ϕ_{lev} to 2, which is similar to the leverage parameter used by Bansal and Yaron (2004).

Monetary Policy. The monetary policy parameters are standard, and identical to Basu and Bundick (2017). Specifically, π_{ss} implies an annual inflation rate of 2%. The weights on inflation gap and output gap are 1.5 and 0.5, respectively. The smoothing parameter of the nominal policy rule, ρ_r, is 0.5.

We solve the model using a third order perturbation method.

Table 3: **Model-Implied Aggregate Moments**

	Data	Benchmark	No-LRR	No-LRR & No-Sticky	No-LRR & Perfect-Comp
$E(\Delta C)(\%)$	1.80	2.04	2.01	2.01	2.01
$\sigma(\Delta Y)(\%)$	3.05	2.77	2.44	2.64	2.86
$\sigma(\Delta C)/\sigma(\Delta Y)$	0.83	0.81	0.78	0.80	0.69
$\sigma(\Delta I)/\sigma(\Delta Y)$	2.61	2.22	1.95	1.77	1.63
$\sigma(\Delta N)/\sigma(\Delta Y)$	0.73	0.29	0.28	0.06	0.07
$E(R^e_M)(\%)$	4.71	3.78	1.72	2.09	1.44
$\sigma(R^e_M)(\%)$	20.89	19.40	4.48	5.40	0.87
$E(r^f)(\%)$	0.65	1.36	2.05	1.88	1.91
$\sigma(r^f)(\%)$	1.86	0.74	0.44	0.22	0.23

The table presents annual moments from the data and the model simulation. We report four alternative calibrations: (I) The benchmark model with parameters from Table 2, referred to as 'Benchmark', (II) A model excluding long-term productivity shocks, with $\sigma_{x,c} = \sigma_{x,i} = 0$, labeled as 'No-LRR', (III) A model void of long-term risk shocks and price stickiness, where $\phi_{p,c} = \phi_{p,i} = 0$, termed as 'No-LRR & No-Sticky', (IV) A model devoid of long-term risk shocks, sticky prices, and markups, signifying perfect competition where $\mu_c = \mu_i \to \infty$, designated as 'No-LRR & Perfect-Comp'. The model-implied moments are based on the average across a thousand finite paths simulations, each of 160 quarters (after dropping the first 400 quarters).

2.2 Aggregate Moments

Table 3 reports annual macroeconomic and asset-prices moments in the data and the model. The model-implied moments are based on the average across a thousand simulations for 560 quarters. We drop the first 400 quarters to neutralize the impact of the initial condition and match the length of the empirical paths used for projection (1). Each quarterly model path is converted into annual non-overlapping observations by compounding the last four quarters.

We distinguish between four cases: (I) the benchmark model (henceforth 'Benchmark'), (II) a model without long-run productivity shocks, where $\sigma_{x,c} = \sigma_{x,i} = 0$ (henceforth 'No-

LRR'), (III) a model without long-run risk shocks and without price stickiness, $\phi_{p,c} = \phi_{p,i} = 0$ (henceforth 'No-LRR & No-Sticky'), (IV) a model without long run risk shocks, no sticky prices, and no markups, that is perfect competition where $\mu_c = \mu_i \to \infty$ (henceforth 'No-LRR & Perfect-Comp').

In the benchmark framework, both the model and empirical data exhibit an output growth volatility of approximately 3%. Similarly, the proportion of consumption growth volatility to output growth volatility is 0.81, and for investment growth to output growth volatility, it is 2.2. The model represents a more subdued volatility in hours' growth relative to the data. Empirically, the hours-to-output growth volatility ratio is 0.73, whereas in the model, it is 0.29. Intriguingly, within our model, an increased hours' growth volatility amplifies the asset pricing implications, which will be elaborated in the subsequent section. The asset pricing metrics inferred from the Benchmark model align closely with empirical observations. The model predicts an equity premium of 3.8% and a modest risk-free rate of 1.4%. Consistent with the data, the model's excess return displays a volatility of 19.4%, and the risk-free rate displays a volatility of roughly 1%.

In juxtaposition with the 'No-LRR' configuration, the Benchmark elucidates that long-term technological innovations exert a minimal influence on aggregate macroeconomic moments. The primary contribution of long-term productivity shocks is to amplify the equity premium. In their absence, the equity premium contracts to 1.72%.

The moments implied by both 'No-LRR & No-Sticky' and 'No-LRR & Perfect-Comp' configurations exhibit marked congruence. The presence of sticky prices is instrumental in engendering realistic business cycle oscillations of input variables. Within both configurations, the volatility of both investment and labor hours is notably attenuated in comparison to empirical data. Subsequent sections will further expound upon the influence of sticky prices on the conditional dynamics of these inputs post technological innovations.

3 Macro and Prices Dynamics

3.1 Macro Dynamics

3.1.1 Inputs response to technological innovations

Utilizing paths simulated from the model, we execute the projections delineated in Eq (1) within the model's framework. Specifically, we conduct regressions of annualized growth in hours, capital, output, and consumption against the aggregate technical change, denoted as Z_{agg}. It is imperative to note that the duration of each path is congruent with its empirical analogue. Table 4 shows the median slope coefficient derived from a thousand finite sample simulations, accompanied by the model-implied confidence interval.

Several salient insights emerge from Table 4. Firstly, the benchmark model adeptly emulates the contractionary or tepid reactions of inputs subsequent to technological innovations. Post positive innovations, there is a marked decline in hours growth, with a slope coefficient of -0.32, juxtaposed against -0.34 in the data. The model's response of capital growth to technological innovations is subdued, evidenced by slope coefficients of 0.02 and 0.04 in the model and empirical data, respectively. Notably, this slope is not a direct target of our calibration, and its insignificance within the model mirrors the empirics. Both output and consumption responses to innovations align positively with the data.

Secondly, the contractionary ramifications of innovations on inputs are not contingent upon long-term risks. Specifically, long-term technological innovations do not substantially modulate the dynamics of inputs or outputs. The slope coefficients under both the Benchmark and 'No-LRR' configurations exhibit remarkable similarity, with a pronounced decline in hours growth and an insignificant capital growth correlation with short-term technological innovations. This echoes the negligible influence of these long run risks on unconditional moments, as delineated in Table 3.

Lastly, the presence of sticky prices is pivotal in engendering a contractionary influence on input utilization. Under both 'No-LRR & No-Sticky' and 'No-LRR & Perfect-Comp'

Table 4: **Technological Innovations and Macroeconomic Growth: Model**

	Benchmark	No-LRR	No-LRR & No-Sticky	No-LRR & Perfect-Comp
(1) $b_{N,t}$	-0.32 [-0.36, -0.27]	-0.34 [-0.37, -0.30]	0.05 [0.05, 0.05]	0.07 [0.06, 0.07]
(2) $b_{K,t}$	0.02 [-0.01, 0.06]	0.02 [-0.01, 0.04]	0.03 [0.02, 0.05]	0.03 [0.02, 0.05]
(3) $b_{C,t}$	0.68 [0.64, 0.72]	0.66 [0.66, 0.67]	0.83 [0.83, 0.84]	0.73 [0.72, 0.73]
(4) $b_{Y,t}$	0.77 [0.74, 0.80]	0.75 [0.73, 0.78]	1.03 [1.03, 1.04]	1.05 [1.05, 1.06]

The table reports the model-implied slope coefficients for the regression: $\Delta y_t = const + b_{y,t} \cdot dZ_{agg,t} + \varepsilon_t$. $dZ_{agg,t}$ is the quarterly aggregate technological innovation. Δy_t is the log-growth rate of the quarterly macroeconomic variables in the model simulation, which include (1) Hours (ΔN_t); (2) Capital (ΔK_t); (3) Consumption (ΔC_t); (4) Output (ΔY_t). We report four alternative calibrations: (I) The benchmark model with parameters from Table 2, referred to as 'Benchmark', (II) A model excluding long-term productivity shocks, with $\sigma_{x,c} = \sigma_{x,i} = 0$, labeled as 'No-LRR', (III) A model void of long-term risk shocks and price stickiness, where $\phi_{p,c} = \phi_{p,i} = 0$, termed as 'No-LRR & No-Sticky', (IV) A model devoid of long-term risk shocks, sticky prices, and markups, signifying perfect competition where $\mu_c = \mu_i \to \infty$, designated as 'No-LRR & Perfect-Comp'. All regression results are based on a thousand simulations, each of 160 quarters (after dropping the first 400 quarters). We report the average across all simulations as well as the 90% confidence interval.

configurations, hours growth counterfactually surges in the wake of enhanced technology. Additionally, the slope coefficient associated with capital growth is both positive and statistically significant. While the benchmark model's slope coefficients for consumption and output growth slightly exceed empirical data, these coefficients are reduced by approximately 25% under the 'Benchmark' relative to configurations devoid of sticky prices. In essence, in the absence of sticky prices, technological innovations exert a disproportionately expansionary influence on output variables when juxtaposed against the Benchmark or the data.

3.1.2 Inspecting the mechanism

To distill the mechanism responsible for the contractionary influence of innovations on inputs within the benchmark model, we strategically shut-down the long-run productivity component. Subsequently, we delineate the model-implied impulse responses stemming from short-run technological shocks to macroeconomic aggregates, contrasting scenarios with sticky prices (represented in blue) against those devoid of such rigidity (illustrated in red), as depicted in Fig 1.

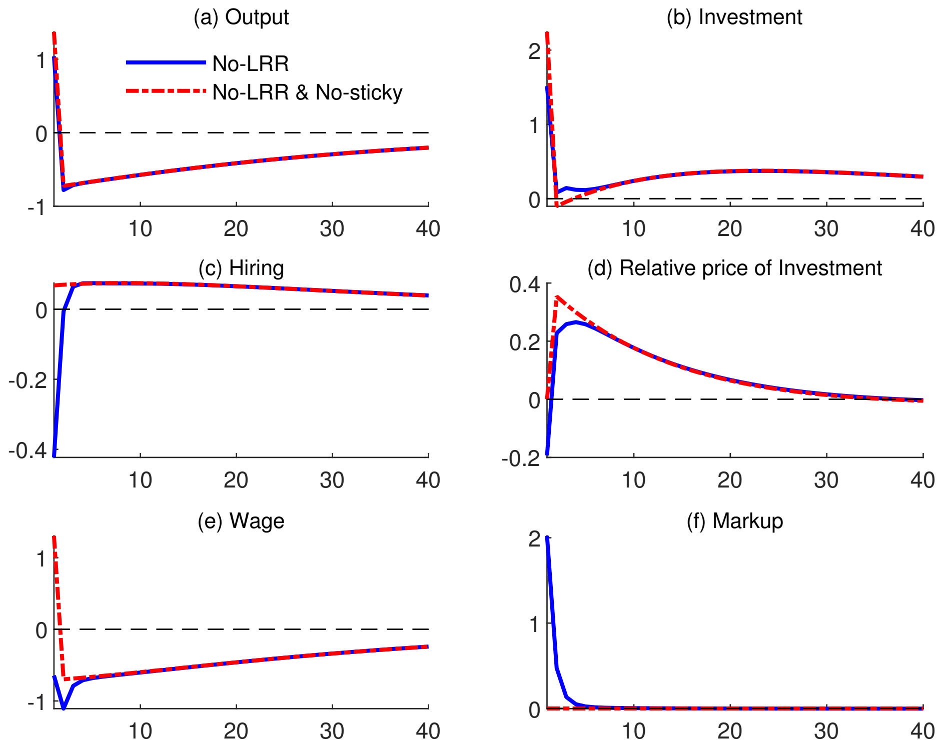
Upon a positive technological innovation, output under-reacts to the supply shock, especially when juxtaposed against the scenario with flexible prices (as evidenced in panel (a) of Fig 1). This muted output response occurs as price levels are unable to fully react to the shock because of nominal rigidities, and it renders a contraction in the output gap. The diminished output gap, in turn, precipitates a decline in inflation gap, a relationship articulated by the New-Keynesian Phillips curve (as formalized in Eq (A.3)).

In a model devoid of sticky prices, a technological innovation augments firms' contemporaneous and future marginal productivity of both labor and capital. This prompts firms to bolster their investment and hiring, as reflected by the red trajectories in panels (b) and (c) of Fig 1. The latter observation, however, is incongruent with empirical observations, mirroring the positive slope coefficient for hours in Table 4. This amplified demand for capital and labor raises wages and also increases the relative price of investment goods (red line in panels (d) and (e) Fig 1), thereby elevating firms' marginal production costs.

The introduction of sticky prices substantially modulates the repercussions of innovations on these marginal costs. Within the New-Keynesian paradigm, inflation is proportionate to the expected discounted valuation of future marginal costs. In our model, the marginal cost for output is contingent upon expected wages and the contemporaneous price of capital goods – attributable to the one-period time-to-build stipulation. Put together, the decline in inflation gap under sticky prices implies a downward pressure on both wages and the relative price of investment.

If the degree of price stickiness is sufficiently large, the price of capital goods can decline subsequent to a positive technological innovation, as illustrated by the blue trajectory in panel (d). This counter-cyclical behavior of capital goods prices, as inferred from our model, resonates with empirical findings by Greenwood et al. (1997) and Christiano and Fisher (2003), which emphasize a negative correlation between investment goods prices and output.

Figure 1: **Model-Implied Impulse-Responses of Macro Variables**



The figure shows impulse responses of model-detrended real output, investment expenditures, hiring, the relative price of investment, wage, and markup to one standard deviation shock of aggregate technology. The solid blue line shows impulse responses from the 'No-LRR' model. The dash-dotted red line shows impulse responses from a 'No-LRR & No-Sticky', which is identical to the former calibration but without price stickiness ($\phi_{p,c} = \phi_{p,i} = 0$). The horizontal axis represents quarters. The vertical axis represents percent deviations from the steady state.

Analogously, wages exhibit a decline post the positive innovation, as portrayed in the blue line of panel (e).

The decline in output gap suggests that hours should decline in response to the positive technology shock. Put differently, the drop in firms' marginal costs raises markups as output prices are rigid in the short run (panel (f) Fig 1). The elevated markups induce a rationing effect on the desired hiring, and in sharp contrast to flexible prices, total employment contracts in the short-run (blue line in panel (c)). This is consistent with the evidence of Basu et al. (2006), and our updated evidence in Table 1.

The contraction in the output gap implies a decline in hours in the aftermath of the positive technological shock. To expound, the reduction in firms' marginal costs amplifies markups, given the rigidity of output prices in the immediate term, as illustrated in panel (f) of Fig 1. The positive response of markups to a supply-side technology shock is consistent with Kollmann (1997) and recent evidence by Nekarda and Ramey (2013). These augmented markups engender a rationing effect on hiring, leading to, in stark contrast to the flexible price case, a contraction in total employment in the short term. This observation aligns with the findings of Basu et al. (2006) and our empirical evidence.

The two-sector structure of the model is instrumental in delineating the impact of innovations on capital growth, which is more intricate. On the one hand, elevated markups ration production, rendering investment more subdued compared to the flexible price scenario, albeit it remains positive, consistent with the data (refer to Table 1). On the other hand, the relative price of investment experiences a drop. This counteracting dynamic is absent in a single-sector model. The cumulative effect manifests as a muted effect on capital growth expenditures, which turn statistically insignificant in finite samples, mirroring empirical data (as evidenced in Tables 1 and 4).

3.2 Asset Prices Dynamics and Implications

In this section, we show how the transitory contractionary effects of technological innovations cascade into expansive 'disconnections' between macroeconomic conditions and financial market valuations.

3.2.1 The relation of investment and stock returns

Cochrane (1991) demonstrates that the forecasted returns of stocks and investments exhibit a high correlation. Driven by this empirical finding, Liu et al. (2009) unveil an asset pricing anomaly. Utilizing the generalized method of moments approach, they match mean investment returns with mean equity returns. The simultaneous correlation between equity and investment returns is found to be negative. However, there exists a positive correlation between investment returns and subsequent equity returns. Notably, the former observation contradicts the conventional predictions of q-theory as postulated by Hayashi (1982).

Our model proficiently addresses this anomaly. As depicted in Panel (A) of Table 5, both the Benchmark and the 'No-LRR' configurations exhibit a negative contemporaneous

Table 5: **Investment and Stock Returns Correlations**

	Data	Benchmark	No-LRR	No-LRR & No-Sticky	No-LRR &Perfect-Comp
			Panel A: Data and market moments		
Corr($R^I_{M,t}, R^S_{M,t}$)	-0.1	-0.16	-0.18	0.77	1.00
Corr($R^I_{M,t+1}, R^S_{M,t}$)	0.2	0.12	0.60	0.08	0.17
Corr($\frac{I_{t+1}}{I_t}, R^S_{M,t}$)	0.1	0.11	0.27	0.22	0.10
			Panel B: Consumption-sector moments		
Corr($R^I_{c,t}, R^S_{c,t}$)		-0.17	-0.34	0.63	1.00
Corr($R^I_{c,t+1}, R^S_{c,t}$)		0.11	0.56	0.10	0.50
			Panel C: Investment-sector moments		
Corr($R^I_{i,t}, R^S_{i,t}$)		-0.08	-0.82	0.98	1.00
Corr($R^I_{i,t+1}, R^S_{i,t}$)		0.11	0.39	0.01	0.02

The table shows correlations in the data (obtained from Liu et al. (2009)) and in the simulated model. We report the simultaneous correlation between investment returns (R^I) and stock returns (R^S), and the correlation between investment returns and subsequent equity returns for the market (Panel A), the consumption sector (Panel B), and the investment sector (Panel C). We also report the correlation between investment growth (I_{t+1}/I_t) and stock returns for the market. For each moment, we compare four alternative calibrations: (I) The benchmark model with parameters from Table 2, referred to as 'Benchmark', (II) A model excluding long-term productivity shocks, with $\sigma_{x,c} = \sigma_{x,i} = 0$, labeled as 'No-LRR', (III) A model void of long-term risk shocks and price stickiness, where $\phi_{p,c} = \phi_{p,i} = 0$, termed as 'No-LRR & No-Sticky', (IV) A model devoid of long-term risk shocks, sticky prices, and markups, signifying perfect competition where $\mu_c = \mu_i \to \infty$, designated as 'No-LRR & Perfect-Comp'. The model-implied moments are based on the average across annualized finite sample paths.

correlation between market stock returns and investment returns. Specifically, under the benchmark, the correlation is statistiaclly significant and stands at -0.1 in the data from Liu et al. (2009), compared to -0.16 in the model. Moreover, the correlation between market stock returns and either one-year ahead investment returns or one-year ahead investment growth is positive, mirroring empirical observations. Conversely, in configurations devoid of sticky prices, the contemporaneous correlation between investment and stock returns is incongruously positive, reaching a unit correlation under perfect competition. Panels (B) and (C) further substantiate this pattern for individual sectors, namely consumption and investment.

To elucidate the anomaly's resolution, we neutralize long-run risks and delineate impulse-response functions from technological innovations onto investment rates, market stock returns, and investment returns, as showcased in Figure 2.

First, both under flexible and sticky price regimes, technological shocks raise firms' valuations, as illustrated in panel (a) of Fig 2. In the latter case, the higher valuation arises due to elevated markups and monopolistic rents. Second, within a two-sector New Keynesian framework featuring monopolistic power, stock and investment returns do not exhibit equality state-by-state. Specifically, two predominant, yet opposing, forces influence investment returns. On the one hand, technological shocks bolster the forecasted marginal productivity of capital, thereby elevating investment rates across sectors, as evidenced in panels (d) and (e) of Fig 2. This aligns with the technological shock's impact on investment, as delineated in Table 1. In the presence of capital frictions, heightened investment rates should also increase the shadow price of capital and the return on investment. This dynamic, inherent to a conventional competitive single-sector model, induces a counterfactual positive correlation between stock and investment returns, as depicted by the red trajectory in panel (b).

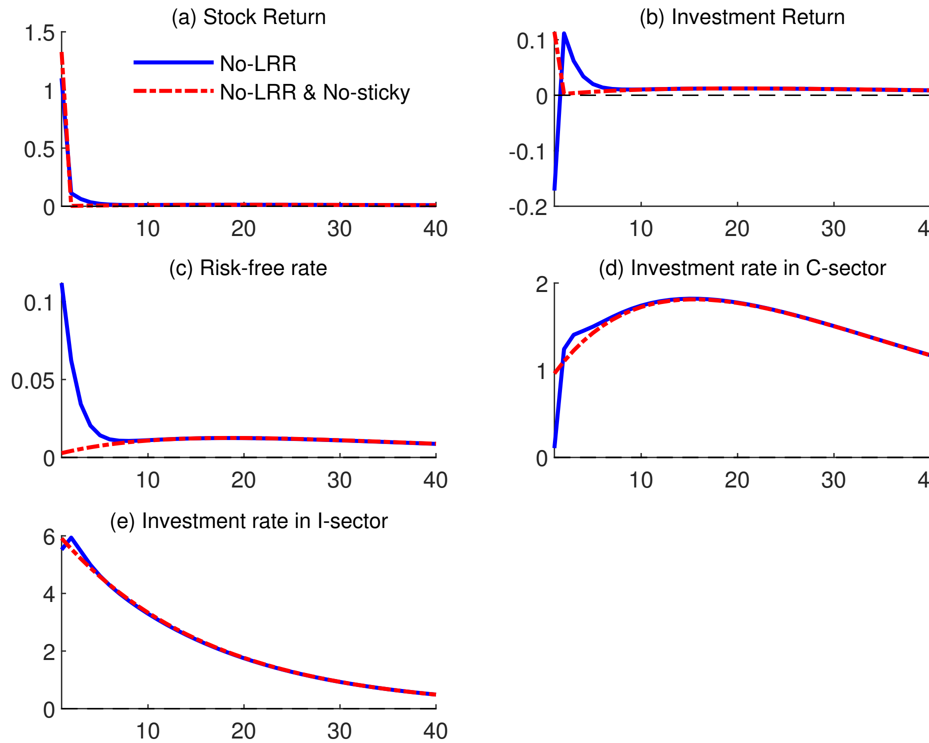
On the other hand, as previously discussed, technological shocks can depress the relative price of capital when consumption prices exhibit rigidity. Ceteris paribus, this diminishes the shadow price of capital in the short term, and consequently, the investment returns. When price rigidity is empirically-disciplined, this latter force predominates, as indicated by the blue trajectory in panel (b), culminating in a negative comovement between investment returns and stock returns, consistent with empirical data.

However, the impact of sticky prices on the relative price of investment is transient. In subsequent periods, this relative price spikes, akin to the flexible price scenario, rendering elevated investment returns. This reconciles the observed positive lead-lag relationship between market and investment returns in both the model and the data.

3.2.2 Labor markets and stock returns

Numerous research studies have identified a paradoxical phenomenon where negative macroeconomic indicators can have a positive impact on equity market performance. Boyd et al. (2005) and Elenev et al. (2022) show equity valuations typically ascend in response to

Figure 2: **Model-Implied Impulse-Responses of Returns and Investment Rates**



The figure shows impulse responses of stock return, investment return, risk-free rate, the investment rate in the consumption sector, and the investment rate in the investment sector to one standard deviation aggregate technology shock. The solid blue line shows impulse responses from the 'No-LRR' model. The dash-dotted red line shows impulse responses from a 'No-LRR & No-Sticky', which is identical to the former calibration but without price stickiness ($\phi_{p,c} = \phi_{p,i} = 0$). The horizontal axis represents quarters. The vertical axis represents percent deviations from the steady state.

announcements of heightened unemployment. The underlying premise posited by these papers is that greater unemployment is indicative of an impending decrement in interest rates. Xu and You (2022) provide similar empirical evidence during the COVID period, and argue that following greater unemployment, investors anticipates augmented fiscal interventions by the Federal Government, culminating in an elevation of stock valuations.

In all of the aforementioned studies the resolution to this anomaly is predominantly attributed to either monetary or fiscal policy dynamics. We postulate that while such channels can certainly play a role, the foundational empirical observations might not inherently be "anomalous" if technological advancements bolster stock prices while simultaneously precipitating transient contractions in labor market.

Our model adeptly reconciles this puzzle without resorting to exogenous policy shocks.

Table 6: **Labor Market Surprises and Stock Returns**

	Benchmark	No-LRR	No-LRR & No-Sticky	No-LRR & Perfect-Comp
Corr($N_t^{\text{surprise}}, R_{M,t}^S$)	-0.30	-0.99	1.00	0.87
Corr($N_t^{\text{surprise}}, R_t^f$)	-0.38	-0.77	-0.06	-0.13

The table shows the model-implied correlation between labor market surprises, N^{surprise}, and the stock market return, R_m^S, or the risk-free interest rate, R_f. We define the labor market surprises as $N_t^{\text{surprise}} = N_t - E_{t-1}[N_t]$. We compare four alternative calibrations: (I) The benchmark model with parameters from Table 2, referred to as 'Benchmark', (II) A model excluding long-term productivity shocks, with $\sigma_{x,c} = \sigma_{x,i} = 0$, labeled as 'No-LRR', (III) A model void of long-term risk shocks and price stickiness, where $\phi_{p,c} = \phi_{p,i} = 0$, termed as 'No-LRR & No-Sticky', (IV) A model devoid of long-term risk shocks, sticky prices, and markups, signifying perfect competition where $\mu_c = \mu_i \to \infty$, designated as 'No-LRR & Perfect-Comp'. The model-implied moments are based on the average across annualized finite sample paths.

We derive labor surprises within the model framework by subtracting anticipated hiring from actualized hiring. As presented in Table 6, under both the Benchmark and 'No-LRR' configurations, the correlation between labor surprises and either market stock returns or the risk-free rate is negative, mirroring the "average" empirical scenario as documented by Boyd et al. (2005). However, in scenarios devoid of sticky prices, this correlation inverts to a positive value.

The origin of this negative correlation can be directly attributed to the inherent dynamics of our model. Technological innovations precipitate a hiring contraction due to amplified markups, as illustrated in panel (b) of Fig 1, while concurrently enhancing valuations via monopolistic rents, as depicted in panel (a) of Fig 2. Additionally, given the initial subdued response of output, coupled with an anticipated future surge in the output gap, the real interest rate exhibits an initial increase, as evidenced in panel (c) of Fig 2. This dynamic suggests a negative comovement between the risk-free rate and labor surprises. It is imperative to recognize that within this framework, labor or employment metrics are endogenously determined and, as such, cannot be directly interpreted as indicators of favorable or adverse underlying economic conditions.

It is noteworthy that the correlation between labor market surprises and the stock market might exhibit temporal variations, contingent upon prevailing markup levels. Specifically, within our model's purview, the correlation between unemployment and equity markets skews more negatively (or positively) when average markups are elevated (or diminished). Markups, when influenced by technological shocks, exhibit procyclicality, as delineated by Nekarda and Ramey (2013): prices manifest greater rigidity during economic expansions, given firms' reluctance to escalate prices, thereby aiming to augment market share and capitalize on heightened consumer demand. This insight aligns with the empirical observations of Boyd et al. (2005), which emphasize a more pronounced inverse correlation between equity and labor markets during economic expansions.

3.2.3 B/M, profits and stock returns

The studies of Fama and French (1992); Hou et al. (2021); Novy-Marx (2013) show that firms with higher book-to-market and higher profitability both predict higher expected returns. Studies such as Zhang (2005) and İmrohoroğlu and Tüzel (2014) offer reconciliation for the former observation. Specifically, value firms, characterized by diminished productivity, face escalated capital adjustment costs, thereby amplifying their riskiness. However, this rationale poses a conundrum when attempting to explain why elevated gross profits, typically also associated with higher productivity, are concomitant with increased risk premiums.

To address this intricate puzzle, we commence by enhancing our benchmark model with an element of stochastic volatility. In particular, we postulate that the conditional log-volatility of the aggregate technology shocks adheres to an AR(1) process, characterized by an autocorrelation coefficient of 0.98 and a standard deviation amounting to 0.004%. This parametrization mirrors the specifications delineated by Bansal and Yaron (2004). Furthermore, we posit a perfectly negative correlation between aggregate technology innovations and volatility shocks, ensuring that the time-varying volatility exhibits a countercyclical pattern, consistent with empirical observations.

The incorporation of stochastic volatility into our model framework is pivotal for engendering temporal variations in the risk premium. As depicted in Panel C of Table 7, the model, once augmented with this volatility component, continues to produce macro moments that

Table 7: **Correlation between Risk Premia, B/M, and Gross Profits**

Panel A: Relation between risk premia and characteristics			
Moments	$\text{Corr}(GP_t^M, E_t[R^e_{M,t+1}])$	$\text{Corr}(GP_t^c, E_t[R^e_{c,t+1}])$	$\text{Corr}(GP_t^i, E_t[R^e_{i,t+1}])$
Value	0.44	0.40	0.22
Moments	$\text{Corr}(BM_t^M, E_t[R^e_{M,t+1}])$	$\text{Corr}(BM_t^c, E_t[R^e_{c,t+1}])$	$\text{Corr}(BM_t^i, E_t[R^e_{i,t+1}])$
Value	0.71	0.68	0.74

Panel B: Predictive regressions for future excess returns	(1)	(2)	(3)
GP_t^M	0.11		0.02
t-stat	[14.80]		[2.12]
BM_t^M		2.70	2.45
t-stat		[20.87]	[13.80]

Panel C: Other moments

Moments	Value	Moments	Value	Moments	Value
$E(\Delta C)(\%)$	2.06	$b_{N,t}$	-0.36	$\text{Corr}(R^I_{M,t}, R^S_{M,t})$	-0.23
$\sigma(\Delta Y)(\%)$	2.78	$b_{K,t}$	0.01	$\text{Corr}(R^I_{M,t+1}, R^S_{M,t})$	0.09
$\sigma(\Delta C)/\sigma(\Delta Y)$	0.96	$b_{C,t}$	0.86	$\text{Corr}(\frac{I_{t+1}}{I_t}, R^S_{M,t})$	0.15
$\sigma(\Delta I)/\sigma(\Delta Y)$	2.10	$b_{Y,t}$	0.76	$\text{Corr}(R^I_{c,t}, R^S_{c,t})$	-0.24
$\sigma(\Delta N)/\sigma(\Delta Y)$	0.34			$\text{Corr}(R^I_{c,t+1}, R^S_{c,t})$	0.10
$E(R^e_M)(\%)$	3.89			$\text{Corr}(R^I_{i,t}, R^S_{i,t})$	-0.25
$\sigma(R^e_M)(\%)$	20.28			$\text{Corr}(R^I_{i,t+1}, R^S_{i,t})$	0.09
$E(r^f)(\%)$	1.39			$\text{Corr}(N_t^{\text{surprise}}, R^S_{M,t})$	-0.38
$\sigma(r^f)(\%)$	0.97			$\text{Corr}(N_t^{\text{surprise}}, R^f_t)$	-0.18

The table shows model-implied moments for the framework augmented with stochastic countercyclical volatility. In Panel A, we report the correlations between conditional annual risk premia ($E_t[R^e_{j,t+1}]$) and either annual gross profits (GP_t^j) or the annual book-to-market ratio (BM_t^j) for the market and both sectors, where $j \in \{M, c, i\}$. In Panel B, we run the predictive regressions at the market level and report the slope coefficients and the t-statistics, where the dependent variable is the annualized next year's realized excess return $R^e_{M,t+1}$. The set of explanatory variables includes: (1) the current annual gross profits (GP_t^M); (2) the current annual book-to-market ratio (BM_t^j); (3) both of them. In Panel C, we report other model-implied moments as in Table 3 - Table 6, under the augmented model.

align closely with empirical data, while preserving the previously established correlations between stock returns, investment returns, and labor surprises.

To compute the model-implied temporal variations in the risk premium, we calculate the conditional expected excess returns for each state, adjusted for the risk-free rate. Panel A of Table 7 reports the model-derived correlations between risk premia and either gross profits or the book-to-market ratio. Notably, both the book-to-market and gross profits exhibit a positive correlation with risk premia, mirroring empirical patterns. This pattern holds at the aggregate and sectoral levels.

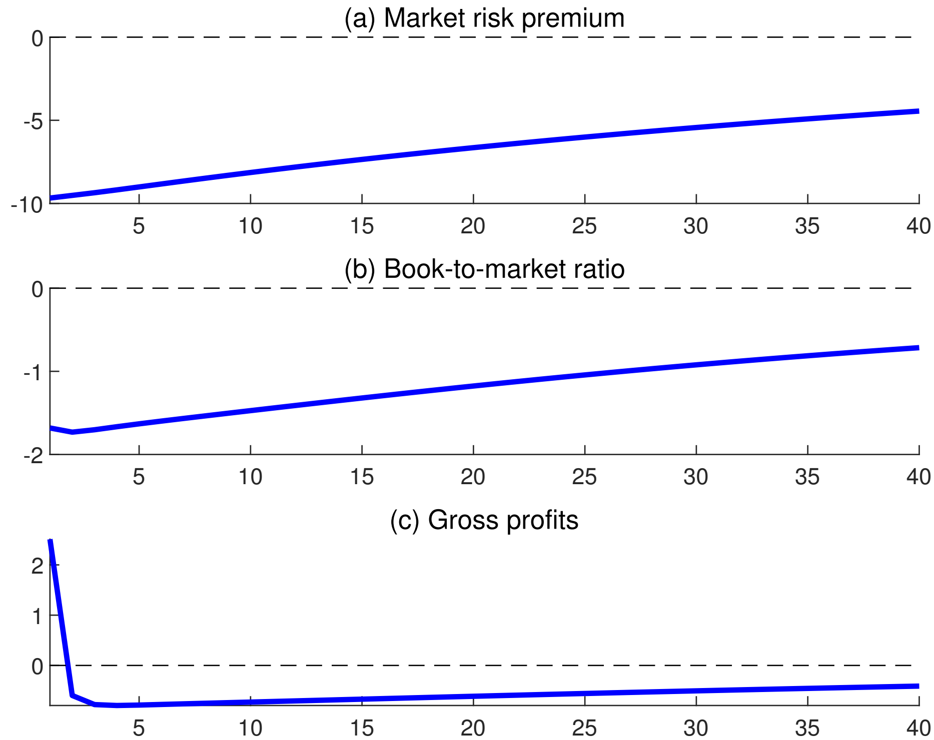
In addition, we conduct predictive regressions using model-simulated data. We project annualized next year's realized excess returns on current annualized gross profits or/and annualized book-to-market ratios. All slope coefficients are positive and significant as shown in Panel B of Table 7. Importantly, book-to-market and gross profits do not crowd each other out in the model: both *jointly* predict future excess returns positively.

To explain how our single shock model can account for the concurrent positive predictive power of both book-to-market and gross profits, we present in Fig 3 the impulse-response trajectories originating from technological innovations, against aggregate gross profits, book-to-market ratios, and the market risk premium. A positive technological innovation precipitates a decline in the risk premium, an immediate consequence of the countercyclical volatility, as illustrated in panel (a). Concurrently, this innovation amplifies firm valuations by augmenting monopolistic rents, while leaving the predetermined capital stock unaffected. This dynamic suggests a sustained reduction in the book-to-market ratio, as portrayed in panel (b), thereby yielding a positive correlation with the conditional risk premium.

Furthermore, the technological shock exerts an immediate and positive impact on gross profits, attributable to enhanced productivity. In a standard flexible-price model, these gross profits would persistently remain elevated, leading to a counterfactual negative correlation between profitability and risk premia.

However, within our model's architecture, a counteracting dynamic emerges that suppresses gross profits beyond the initial shock, as depicted in panel (c). Specifically, technological innovations trigger a transient contraction in labor, which, in subsequent periods, outweighs the benefits of heightened productivity, culminating in sub-trend output and profitability from the quarter following the initial shock. Consequently, technological advancements are linked with diminished (annual) gross profits in the short term. This dynamic ensures that the correlation between profitability and the conditional risk premium remains positive, congruent with the data.

Figure 3: **Model-Implied Impulse-Responses of Risk Premium, B/M, and Profits**



The figure shows model-implied impulse responses of the market risk premium, book-to-market ratio, and the aggregate gross profit to one standard deviation positive aggregate technology innovation, using the augmented stochastic volatility framework. The horizontal axis represents quarters. The vertical axis represents percent deviations from the steady state.

3.2.4 Term structure of equity yields

Using the augmented model from the previous section we define the price of a dividend strip at time t maturing in n periods, $P_{t,n}$, recursively as follows:

$$P_{t,0} = d_t \tag{26}$$

$$P_{t,n} = \mathbb{E}_t \left[M_{t,t+1} P_{t+1,n-1} \right]. \tag{27}$$

As a result, the the equity yield for maturity n is given by:

$$e_{t,n} = \frac{1}{n} \log \left(\frac{d_t}{P_{t,n}} \right)$$

We define the slope of the term structure as the n-quarters to maturity equity yield net of next period's maturing equity yield: $\text{Slope}_{t,n} = e_{t,n} - e_{t,1}$. To examine the cyclicality of the slope, we run the following regression:

$$\text{Slope}_{t,n} = const + \phi_n \cdot dp_t + error,$$

where dp_t is the (log) market dividend yield. A procyclical slope implies that $\phi_n < 0$. Table 8 provides the regression results using model-simulated data, for maturity $n \in \{8, 12, 16, 20\}$ quarters.

Table 8: **Cyclicality of the Equity Yield Term Structure**

	Data	Benchmark	No LRR	No LRR & No sticky
ϕ_8	N.A.	-0.279 [-0.470, -0.111]	-0.408 [-0.589, -0.225]	0.004 [0.002, 0.005]
ϕ_{12}	N.A.	-0.295 [-0.498, -0.116]	-0.432 [-0.624, -0.237]	0.006 [0.004, 0.008]
ϕ_{16}	N.A.	-0.302 [-0.512, -0.118]	-0.443 [-0.641, -0.243]	0.008 [0.006, 0.011]
ϕ_{20}	-0.33	-0.306 [-0.525, -0.121]	-0.450 [-0.658, -0.247]	0.011 [0.010, 0.017]

The table reports the model-implied slope coefficients for the regression: $\text{Slope}_{t,n} = const + \phi_n \cdot dp_t + error$. dp_t is the (log) market dividend yield and $n \in \{8, 12, 16, 20\}$ is the maturity (quarters). The data moment is taken from Gormsen (2021). We report three alternative calibrations: (I) The benchmark model with parameters from Table 2 with stochastic countercyclical volatility as in subsection 3.2.3, referred to as 'Benchmark', (II) A model excluding long-term productivity shocks, with $\sigma_{x,c} = \sigma_{x,i} = 0$, labeled as 'No-LRR', (III) A model void of long-term risk shocks and price stickiness, where $\phi_{p,c} = \phi_{p,i} = 0$, termed as 'No-LRR & No-Sticky', All regression results are based on a thousand simulations, each of 160 quarters (after dropping the first 400 quarters). We report the average across all simulations as well as the 90% confidence interval.

In the context of the benchmark and the 'No-LRR' specification, the model produces negative regression coefficients between the slopes at different maturities and the dividend yield. Qualitatively, the slope's procyclicality is consistent with the evidence presented by Bansal et al. (2021). Quantitatively, at the five year horizon, the regression coefficient matches the empirical evidence by Gormsen (2021). Conversely, in a theoretical framework devoid of price stickiness, the slopes' correlation with the dividend yield is positive, implying a counterfactual countercyclical behavior of the slope.

The reconciliation of the slope's cyclicality arises directly from the macro dynamics outlined in Section 3.1. A positive technological innovation results in an immediate contraction in labor. This means that, relative to the no price-rigidity case, the expected (realized) dividend growth is higher (lower) in the short term, as future cash flows "catch up" to the flexible price scenario in the near horizon. The converse happens in response to a negative innovation. Therefore, the slope of expected dividend growth becomes more (less) negative during expansions (recessions), which in turn influences the dynamics of the equity yields slope.

4 Conclusion

We illuminate the intricate relationship between technological innovations and their immediate macroeconomic implications. While technological advancements undeniably foster long-term economic growth, they can, paradoxically, lead to short-term contractions. Through our general-equilibrium New-Keynesian model, we elucidate the mechanisms underlying these dynamics, with a particular emphasis on the role of sticky prices.

Central to our findings is the resolution of several empirical anomalies, underscoring the pivotal role of contractionary technological innovations. Firstly, we address the enigmatic negative contemporaneous correlation between stock returns and returns on capital. Secondly, our model offers insights into the counterintuitive inverse relationship between labor market fluctuations and stock market valuations, challenging prevailing interpretations. We also reconcile observed return spreads in cross-sectional asset pricing, shedding light on why certain firms, characterized by seemingly contradictory traits (specifically, high book-to-market ratios and high profits), command higher risk premiums. Lastly, unlike the flexible-price case, the framework produces a procyclical slope for the equity yield term structure. These anomalies, previously perceived as distinct challenges in the literature, are cohesively explained through our model, highlighting the complex interplay between technological innovations, macroeconomic factors, and financial dynamics.

Future research should further explore the implications of short-term technological contractions on the term structure of bond yields, and delve into the endogeneity of sticky prices via menu costs. This latter exploration can elucidate the time-varying correlation between fundamentals and equity prices, especially pertinent in an era of rapidly accelerating technological advancements.

Appendix

A Details of the numerical solution

A.1 Characterization of model's solution

This section describes the equilibrium first-order conditions of the model. The first-order condition of firm $n \in [0,1]$ in sector $j \in \{c,i\}$

$$0 = q_{j,t} - P_{it}\frac{\partial \Phi_{j,k}(i_{j,t}(n), k_{j,t}(n))}{\partial i_{j,t}(n)} k_{j,t}(n) \tag{A.1}$$

$$0 = W_t n_{j,t}(n) - (1-\alpha_j)\theta_{j,t} Z_{j,t} k_{j,t}(n)^{\alpha_j} (n_{j,t}(n))^{1-\alpha_j} \tag{A.2}$$

$$\begin{aligned} 0 = -q_{j,t} + E_t\Big[M^{\$}_{t+1}\Big\{ - P_{i,t+1}\left(\Phi_{j,k}\left(i_{j,t+1}, k_{j,t+1}(n)\right) + \frac{\partial \Phi_{j,k}\left(i_{j,t+1}(n), k_{j,t+1}(n)\right)}{\partial k_{j,t+1}(n)} k_{j,t+1}(n)\right) + q_{j,t+1}\left(1-\delta\right) \\ + \theta_{j,t+1} Z_{j,t+1} \alpha_j k_{j,t+1}(n)^{\alpha_j - 1} (n_{j,t+1}(n))^{1-\alpha_j}\Big\}\Big] \end{aligned} \tag{A.3}$$

$$\begin{aligned} 0 = (1-\mu_j)\left[\frac{p_{j,t}(n)}{P_{j,t}}\right]^{-\mu_j} + \theta_{j,t}\mu_j\left[\frac{p_{j,t}(n)}{P_{j,t}}\right]^{-\mu_j - 1}\frac{1}{P_{j,t}} + \phi_{P,j} E_t\left[M^{\$}_{t+1}\left(\frac{Y_{j,t+1}}{Y_{j,t}}\right)\left[\frac{p_{j,t+1}(n)}{\Pi_j p_{j,t}(n)} - 1\right]\frac{p^2_{j,t+1}(n)}{\Pi_j p^2_{j,t}(n)}\right] \\ - \phi_{P,j}\left\{\left[\frac{p_{j,t}(n)}{\Pi_j p_{j,t-1}(n)} - 1\right]\frac{p_{j,t}(n)}{\Pi_j p_{j,t-1}(n)} + \frac{1}{2}\left[\frac{p_{j,t}(n)}{\Pi_j p_{j,t-1}(n)} - 1\right]^2\right\} \end{aligned} \tag{A.4}$$

$$0 = k_{j,t+1}(n) - (1-\delta)\, k_{j,t}(n) - i_{j,t}(n) \tag{A.5}$$

$$0 = y_{j,t}(n) - Z_{j,t} k_{j,t}(n)^{\alpha_j} (n_{j,t}(n))^{1-\alpha_j}, \tag{A.6}$$

where $q_{j,t}$ is the price of a marginal unit of installed capital in sector j, the Lagrange multiplier of constraint (8), and $\theta_{j,t}$ is the marginal cost of producing an additional unit of intermediate good in sector $j \in \{c,i\}$, the Lagrange multiplier of constraint (12).

The first-order condition of the household

$$0 = \frac{W_t}{P_{c,t}} - \frac{C_t}{1-\xi N_t^{\eta}}\xi\eta N_t^{\eta-1}. \tag{A.7}$$

The nominal SDF, nominal interest rate, as well as the household utility, are given in Eq. (16), (17), and (14), respectively. The last equilibrium conditions include four market clearing conditions (labor, investment goods, consumption goods, and bond market) specified in Eq. (18), (19), (21), and (22), respectively. We are looking for a symmetric equilibrium in which $p_{j,t}(n) = P_{j,t}$, $n_{j,t}(n) = n_{j,t}$, and $k_{j,t}(n) = k_{j,t}$ for all $n \in [0,1]$ and $j \in \{c,i\}$. Thus, the above equations can be rewritten in terms of only aggregate quantities. There are 32 endogenous variables:

$\{C_t, N_t, Y_{c,t}, Y_{i,t}, N_{c,t}, N_{i,t}, K_{c,t}, K_{i,t}, i_{c,t}, i_{i,t}, q_{c,t}, q_{i,t}, \theta_{c,t}, \theta_{i,t}, P_{i,t}, P_{c,t}, W_t, R^{\$}_t, U_t, M^{\$}_t, R^{S(unlevered)}_{j,t}, R^{S(unlevered)}_{M,t}, R^e_{j,t}, d^{\$}_{j,t}, V^{\$}_{j,t}, R^I_{j,t}, R^I_{M,t}\}$.

In turn, there are 28 equations: 13 equations for household's and firms' first-order conditions (in both sectors), 12 definitions of return and dividends, four market clearing conditions, and three definitions of SDF, utility, and Taylor rule). Other quantities, such as the real SDF and firm valuations, are derived from the endogenous decision variables, see, e.g., Eq. (11).

A.1.1 Detrended problem

Covariance-stationary first-order conditions can be achieved by rescaling the nonstationary variables of the problem as follows: (a) divide $k_{c,t}, k_{i,t}, i_{c,t}, i_{i,t}, Y_{i,t}$ by $Z_{i,t-1}^{\frac{1}{1-\alpha_i}}$; (b) divide $C_t, Y_{c,t}, U_t$ by $Z_{c,t-1} Z_{i,t-1}^{\frac{\alpha_c}{1-\alpha_i}}$; (c) divide $W_t, d^{\$}_{i,t}, d^{\$}_{c,t}, V^{\$}_{i,t}, V^{\$}_{c,t}$ by $P_{c,t} Z_{c,t-1} Z_{i,t-1}^{\frac{\alpha_c}{1-\alpha_i}}$; (d) divide $\theta_{c,t}$ by $P_{c,t}$; (e) divide $\theta_{i,t}, q_{i,t}, q_{c,t}, P_{i,t}$ by $P_{c,t} Z_{c,t-1} Z_{i,t-1}^{\frac{\alpha_c-1}{1-\alpha_i}}$. After plugging the rescaled variables in the first-order equations, the equilibrium conditions can be written using stationary variables (in particular, using the rescaled variables and using the growth rates of $Z_{i,t}$, $Z_{c,t}$, and of $P_{c,t}$).

Therefore, we can rewrite the first-order conditions of firm $n \in [0,1]$ in sector $j \in \{c, i\}$:

$$0 = \widetilde{q_{i,t}} - \widetilde{P_{it}} \frac{\partial \Phi_{i,k}\left(\widetilde{i_{i,t}}(n), \widetilde{k_{i,t}}(n)\right)}{\partial \widetilde{i_{i,t}}(n)} \widetilde{k_{i,t}}(n) \tag{A.8}$$

$$0 = \widetilde{q_{c,t}} - \widetilde{P_{it}} \frac{\partial \Phi_{c,k}\left(\widetilde{i_{c,t}}(n), \widetilde{k_{c,t}}(n)\right)}{\partial \widetilde{i_{c,t}}(n)} \widetilde{k_{c,t}}(n) \tag{A.9}$$

$$0 = \widetilde{W_t} n_{i,t}(n) - (1-\alpha_i) \frac{Z_{i,t}}{Z_{i,t-1}} \widetilde{\theta_{i,t}} \widetilde{k_{i,t}}(n)^{\alpha_i} n_{i,t}(n)^{1-\alpha_i} \tag{A.10}$$

$$0 = \widetilde{W_t} n_{c,t}(n) - (1-\alpha_c) \frac{Z_{c,t}}{Z_{c,t-1}} \widetilde{\theta_{c,t}} \widetilde{k_{c,t}}(n)^{\alpha_c} n_{c,t}(n)^{1-\alpha_c} \tag{A.11}$$

$$\begin{aligned} 0 = -\widetilde{q_{i,t}} + E_t\Big[& \Big(\frac{P_{c,t+1}}{P_{c,t}} \frac{Z_{c,t}}{Z_{c,t-1}} \Big(\frac{Z_{i,t}}{Z_{i,t-1}}\Big)^{\frac{\alpha_c-1}{1-\alpha_i}}\Big) M^{\$}_{t+1} \Big\{ -\widetilde{P_{i,t+1}} \Phi_{i,k}\left(\widetilde{i_{i,t+1}}(n), \widetilde{k_{i,t+1}}(n)\right) \\ & - \widetilde{P_{i,t+1}} \frac{\partial \Phi_{i,k}\left(\widetilde{i_{i,t+1}}(n), \widetilde{k_{i,t+1}}(n)\right)}{\partial \widetilde{k_{i,t+1}}(n)} \widetilde{k_{i,t+1}}(n) + \widetilde{q_{i,t+1}}(1-\delta) + \widetilde{\theta_{i,t+1}} \alpha_i \frac{Z_{i,t+1}}{Z_{i,t}} \widetilde{k_{i,t+1}}(n)^{\alpha_i - 1} n_{i,t+1}(n)^{1-\alpha_i} \Big\} \Big] \end{aligned} \tag{A.12}$$

$$0 = -\widetilde{q_{c,t}} + E_t\Big[(\frac{P_{c,t+1}}{P_{c,t}}\frac{Z_{c,t}}{Z_{c,t-1}}(\frac{Z_{i,t}}{Z_{i,t-1}})^{\frac{\alpha_c-1}{1-\alpha_i}})M_{t+1}^{\$}\Big\{-\widetilde{P_{i,t+1}}\Phi_{c,k}\left(\widetilde{i_{c,t+1}}(n),\widetilde{k_{c,t+1}}(n)\right)$$

$$-\widetilde{P_{i,t+1}}\frac{\partial\Phi_{c,k}\left(\widetilde{i_{c,t+1}}(n),\widetilde{k_{c,t+1}}(n)\right)}{\partial\widetilde{k_{c,t+1}}(n)}\widetilde{k_{c,t+1}}(n) + \widetilde{q_{c,t+1}}(1-\delta) + \widetilde{\theta_{c,t+1}}\alpha_c\frac{Z_{c,t+1}}{Z_{c,t}}\widetilde{k_{c,t+1}}(n)^{\alpha_c-1}n_{c,t+1}(n)^{1-\alpha_c}\Big\}\Big] \tag{A.13}$$

$$0 = (1-\mu_i)\left[\frac{\widetilde{p_{i,t}}(n)}{\widetilde{P_{i,t}}}\right]^{-\mu_i} + \widetilde{\theta_{i,t}}\mu_i\left[\frac{\widetilde{p_{i,t}}(n)}{\widetilde{P_{i,t}}}\right]^{-\mu_i-1}\frac{1}{\widetilde{P_{i,t}}}$$

$$+\phi_{P,i}E_t\left[M_{t+1}^{\$}\left(\frac{(\frac{Z_{i,t}}{Z_{i,t-1}})^{\frac{1}{1-\alpha_i}}\widetilde{Y_{i,t+1}}}{\widetilde{Y_{i,t}}}\right)\left[\frac{\frac{P_{c,t+1}}{P_{c,t}}\frac{Z_{c,t}}{Z_{c,t-1}}(\frac{Z_{i,t}}{Z_{i,t-1}})^{\frac{\alpha_c-1}{1-\alpha_i}}\widetilde{p_{i,t+1}}(n)}{\Pi_i\widetilde{p_{i,t}}(n)}-1\right]\frac{(\frac{P_{c,t+1}}{P_{c,t}}\frac{Z_{c,t}}{Z_{c,t-1}}(\frac{Z_{i,t}}{Z_{i,t-1}})^{\frac{\alpha_c-1}{1-\alpha_i}})^2\widetilde{p_{i,t+1}}^2(n)}{\Pi_i\widetilde{p_{i,t}}^2(n)}\right]$$

$$-\phi_{P,i}\left\{\left[\frac{\frac{P_{c,t}}{P_{c,t-1}}\frac{Z_{c,t-1}}{Z_{c,t-2}}(\frac{Z_{i,t-1}}{Z_{i,t-2}})^{\frac{\alpha_c-1}{1-\alpha_i}}\widetilde{p_{i,t}}(n)}{\Pi_i\widetilde{p_{i,t-1}}(n)}-1\right]\frac{\frac{P_{c,t}}{P_{c,t-1}}\frac{Z_{c,t-1}}{Z_{c,t-2}}(\frac{Z_{i,t-1}}{Z_{i,t-2}})^{\frac{\alpha_c-1}{1-\alpha_i}}\widetilde{p_{i,t}}(n)}{\Pi_i\widetilde{p_{i,t-1}}(n)}+\frac{1}{2}\left[\frac{\frac{P_{c,t}}{P_{c,t-1}}\frac{Z_{c,t-1}}{Z_{c,t-2}}(\frac{Z_{i,t-1}}{Z_{i,t-2}})^{\frac{\alpha_c-1}{1-\alpha_i}}\widetilde{p_{i,t}}(n)}{\Pi_i\widetilde{p_{i,t-1}}(n)}-1\right]^2\right\} \tag{A.14}$$

$$0 = (1-\mu_c)\left[\frac{p_{c,t}(n)}{P_{c,t}}\right]^{-\mu_c} + \widetilde{\theta_{c,t}}\mu_c\left[\frac{p_{c,t}(n)}{P_{c,t}}\right]^{-\mu_c-1} + \phi_{P,c}E_t\left[M_{t+1}^{\$}\left(\frac{\frac{Z_{c,t}}{Z_{c,t-1}}(\frac{Z_{i,t}}{Z_{i,t-1}})^{\frac{\alpha_c}{1-\alpha_i}}\widetilde{Y_{c,t+1}}}{\widetilde{Y_{c,t}}}\right)\left[\frac{\frac{P_{c,t+1}}{P_{c,t}}}{\Pi_c}-1\right]\frac{(\frac{P_{c,t+1}}{P_{c,t}})^2}{\Pi_c}\right]$$

$$-\phi_{P,c}\left\{\left[\frac{\frac{P_{c,t}}{P_{c,t-1}}}{\Pi_c}-1\right]\frac{\frac{P_{c,t}}{P_{c,t-1}}}{\Pi_c}+\frac{1}{2}\left[\frac{\frac{P_{c,t}}{P_{c,t-1}}}{\Pi_c}-1\right]^2\right\} \tag{A.15}$$

$$0 = (\frac{Z_{i,t}}{Z_{i,t-1}})^{\frac{1}{1-\alpha_i}}\widetilde{k_{i,t+1}}(n) - (1-\delta)\widetilde{k_{i,t}}(n) - \widetilde{i_{i,t}}(n) \tag{A.16}$$

$$0 = (\frac{Z_{i,t}}{Z_{i,t-1}})^{\frac{1}{1-\alpha_i}}\widetilde{k_{c,t+1}}(n) - (1-\delta)\widetilde{k_{c,t}}(n) - \widetilde{i_{c,t}}(n) \tag{A.17}$$

$$0 = \widetilde{y_{i,t}}(n) - \frac{Z_{i,t}}{Z_{i,t-1}}\widetilde{k_{i,t}}(n)^{\alpha_i}n_{i,t}(n)^{1-\alpha_i}, \tag{A.18}$$

$$0 = \widetilde{y_{c,t}}(n) - \frac{Z_{c,t}}{Z_{c,t-1}}\widetilde{k_{c,t}}(n)^{\alpha_c}n_{c,t}(n)^{1-\alpha_c}, \tag{A.19}$$

where $\widetilde{q_{j,t}}$ is the detrended price of a marginal unit of installed capital in sector j, the Lagrange multiplier of constraint (8), and $\widetilde{\theta_{j,t}}$ is the detrended marginal cost of producing an additional unit of intermediate good in sector $j \in \{c, i\}$, the Lagrange multiplier of constraint (12).

The detrended first-order condition of the household

$$0 = \widetilde{W_t} - \frac{\widetilde{C_t}}{1-\xi N_t^{\eta}}\xi\eta N_t^{\eta-1}. \tag{A.20}$$

And the detrended equations of definitions of the nominal SDF, nominal interest rate, as well as the household utility are as follows:

$$M^{\$}_{t+1} = \beta(\frac{Z_{c,t}}{Z_{c,t-1}}(\frac{Z_{i,t}}{Z_{i,t-1}})^{\frac{\alpha_c}{1-\alpha_i}})^{-1/\psi}(\frac{\widetilde{C_{t+1}}}{\widetilde{C}_t})^{-1/\psi}(\frac{1-\xi N^{\eta}_{t+1}}{1-\xi N^{\eta}_t})^{1-1/\psi}(\frac{\widetilde{U_{t+1}}}{(E_t\widetilde{U_{t+1}}^{1-\gamma})^{\frac{1}{1-\gamma}}})^{1/\psi-\gamma}\frac{P_{c,t}}{P_{c,t+1}} \tag{A.21}$$

$$r^{\$}_t = \rho_r r^{\$}_{t-1} + (1-\rho_r)\left(r^{\$}_{ss} + \rho_\pi(\pi_t - \pi_{ss}) + \rho_y(\Delta y_t - \Delta y_{ss})\right) \tag{A.22}$$

$$\widetilde{U}_t = \left\{(1-\beta)\left[\widetilde{C}_t(1-\xi N^{\eta}_t)\right]^{1-1/\psi} + \beta(E_t\widetilde{U_{t+1}}^{1-\gamma})^{\frac{1-1/\psi}{1-\gamma}}(\frac{Z_{c,t}}{Z_{c,t-1}}(\frac{Z_{i,t}}{Z_{i,t-1}})^{\frac{\alpha_c}{1-\alpha_i}})^{1-1/\psi}\right\}^{\frac{1}{1-1/\psi}} \tag{A.23}$$

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