Market Power and Capital Flexibility: A New Perspective on the Pricing of Technology Shocks*

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Abstract

In this paper we show that firms' market power and flexibility in the utilization of capital crucially affect how investment-specific technology (IST) shocks impact asset prices. We develop a two-sector general equilibrium model in which households have recursive preferences and obtain three main results. First, the equilibrium price of risk for IST shocks changes sign from *negative*, under fixed capital utilization, to *positive*, when firms are allowed to optimally choose the intensity of capital utilization. Variable capital utilization provides flexible capital service input in the production of the consumption good and hence alters the intertemporal trade-off between current and future consumption ("discount rate effect"). Second, the firms' equilibrium IST loadings change sign from *negative*, for perfectly competitive firms, to *positive*, for monopolistically competitive firms. Market power allows firms to benefit from the reduction in capital investment costs induced by a positive technology shock ("cash flow effect"). Finally, preference for early resolution of uncertainty, together with flexible capital utilization and high market power, can generate simultaneously *positive* price of risk and *positive* risk premium for IST shocks. These results indicate that variable capital utilization and market power are critical ingredients for production-based models that rely on IST shocks to explain observed properties of both asset prices and macroeconomic quantities.

JEL Classification Codes: E22; G12; O30

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1 Introduction

Technological innovations are important determinants of business cycle fluctuations and economic growth. Macroeconomists refer to such innovations as *investment-specific technological (IST) shocks*, i.e., investment shocks that affect the price of new capital goods.[1] A growing macro finance literature relies on these type of shocks to overcome the well known difficulties of production-based models in generating the level of market risk premia observed in the data.[2] In these models, a positive IST shock, by reducing the marginal cost of new capital goods, affects asset prices through two main channels: (i) it spurs investment at the expense of consumption, and (ii) it reduces the value of firms' capital. The risk premium the market demands for holding an asset exposed to IST shocks is the product of the market price of IST risk and the asset's exposure, or loading, to IST risk. High risk premia are hence achieved by a combination of a *negative* market price of IST risk (marginal utility increases following a positive IST shock) and a *negative* loading on IST risk (firm value drops after a positive IST shock). Although successful in obtaining high level of risk premia, both channels are at odds with macro data. Specifically, the first channel is at odds with the pro-cyclicality of consumption and investment, a salient fact of business cycles. The second channel is at odds with the fact that existing firms are the major source of technological innovation.

In this paper we show that one can overcome the above shortcomings within a tractable general equilibrium model with production and IST shocks whose implications are consistent with observed properties of both asset prices and macroeconomic quantities. Our argument rests on two key observations. The first observation is that the countercyclical nature of consumption and investment in existing asset pricing models with IST shocks is a consequence of ignoring flexibility in the utilization of capital in response to technology shocks. The second observation is that the negative impact of IST shocks on firms' value is the consequence of assuming that firms operate in a perfectly competitive environment. We show that relaxing both assumptions, i.e., allowing for both capital flexibility and firms' market power, can generate simultaneously a *positive* price of IST risk and a *positive* firm value loading on such risk. These two effects, jointly,

[1] IST shocks were originally introduced in the macroeconomics literature to capture the Keynesian idea that variations in "investment efficiency," as opposed to Total Factor Productivity (TFP), could act as a driver of the business cycle.

[2] We review the literature in Section 2.

help generate higher aggregate risk premia in an economy where consumption and investment are procyclical, and existing firms benefit from technological progress. We now elaborate more on these two specific channels.

In existing asset pricing models, IST shocks affect the accumulation of *new* capital stock, implying that higher future consumption is achieved at the expense of lower current consumption. This mechanism, however, ignores the fact that IST shocks also alter the intensity of utilization of the *old* capital stock. If, in response to a positive IST shock, capital becomes cheaper to replace, there is an incentive to utilize existing capital more intensively. Hence, under flexible capital utilization, it may no longer be the case that higher future consumption can only be achieved at the expense of lower current consumption. By affecting the trade-off between current and future consumption, capital flexibility is therefore an important "discount rate" channel through which technological innovations may affect asset prices.[3]

Another important channel through which IST shocks could affect asset prices is the firm's competitive environment. In perfectly competitive markets, positive IST shocks reduce the value of the marginal unit of existing capital, and therefore firms' market value. In a micro-founded model of technological innovation, the assumption of perfectly competitive markets would be hard to reconcile with the empirical fact that large part of innovating activity originates within incumbent firms.[4] If firms retain some degree of market power in the product market, then a positive IST shock can have a positive impact on firm value because the rents originating from reduced investment costs are not fully eroded by competition. The degree of firms' market power is therefore a potentially important "cash flow" channel through which technological innovations may affect asset prices.

We develop a two-sector general equilibrium model with IST shocks in which capital utilization is determined endogenously and firms retain some degree of market power in their respective sector. The two sectors, labeled 'consumption' and 'investment', produce consumption and investment goods, respectively. These final goods are produced by combining intermediate goods that are obtained from monopolistically competitive firms in the consumption and investment

[3]Capacity utilization rates are important indicators of economic activity and are commonly used by academics and policymakers to explain the behavior of investment, inflation, productivity, profits, and output. See, e.g., the Industrial Production and Capacity Utilization index utilized by the Federal Reserve.

[4]Recent research on disaggregated data shows that large part of new innovating activity is conducted by existing firms. See for example, Bernard, Redding, and Schott (2010), and Broda and Weinstein (2010).

sectors. Importantly, the final investment good is an input of production for intermediate good producers in both sectors. We solve for an equilibrium allocation in this economy and derive implications for the market price of risk of IST shocks, and for the risk premium demanded by these shocks in sectoral and aggregate portfolios.

We begin our analysis by considering the standard case of exogenously fixed capital utilization, time-separable CRRA preferences and perfectly competitive markets. In this case, the market price of risk for IST shocks is *negative*, and the risk premia demanded by these shocks in the sectoral and aggregate portfolios are positive. This happens because a positive IST shock increases the productivity of the investment sector, which, in turn, increases the total labor supply and diverts labor from the consumption to the investment sector. With fixed capital utilization, the drop in labor in the consumption sector induces a drop in consumption. This, in turn, leads to an increase in the household's marginal utility and hence to a negative price of risk for the IST shock. Furthermore, in perfectly competitive markets, firm values drop in response to a positive IST shock, i.e., firm values load negatively on IST shocks. A negative price of risk and negative loadings imply a *positive* risk premium for IST shocks.

Remaining within the class of CRRA preferences and perfectly competitive markets, we then allow for capital utilization to be determined endogenously in equilibrium. In this case, we find that, under a wide range of parameter values consistent with empirically observed variations in capital utilization, the market price of risk for IST shocks is *positive*. This happens because, with variable capital utilization, a positive IST shock makes capital cheaper to replace and hence increases utilization of existing capital at the expense of faster capital depreciation. As in the case of fixed capital utilization, labor supply in the consumption sector drops. But, this decline in labor is counterbalanced by an increase in capital utilization. When capital utilization is sufficiently responsive to IST shocks, the latter effect dominates, causing a net increase in consumption, a decline in marginal utility, and hence a positive price of risk for IST shocks. Because of perfectly competitive markets, portfolio returns load negatively on IST shocks. A positive price of risk and negative loadings imply a *negative* risk premium for IST shocks.

In the most general version of the model we consider, we allow for endogenous capital utilization in an equilibrium production economy where households have recursive preferences and firms are monopolistically competitive in their respective sector as in Dixit and Stiglitz (1977).

This allows us to highlight two other channels, besides flexible capital utilization, that are important for understanding the pricing implication of IST shocks: (i) firms market power, and (ii) households' attitudes towards the temporal resolution of uncertainty, i.e., the relationship between their elasticity of intertemporal substitution (EIS) and their risk aversion. Firms' market power affects directly the sign of the risk premium associated with IST shocks. In the model, under moderate degree of market power, i.e., moderate markups, the risk premium associated with IST shock can be positive. This happens because, following a positive IST shock, the monopolistic rents originating from lower investment cost can more than compensate the decline in value of installed capital. EIS affects both the market price of risk and the risk premium of IST shocks because, with recursive utility, the stochastic discount factor depends both on current consumption and on future utility. Following a positive IST shock, households with high (low) EIS will value the uncertainty in future utility less (more) favorably, leading to lower (higher) marginal utility and hence a positive (negative) price of risk for IST shocks. When combined with firms' market power and flexible capital utilization, we show that the risk premium demanded by IST shocks is positive in two cases: (1) households have a preference for *late* resolution of uncertainty and firms cannot vary their capital utilization; or (2) households have a preference for *early* resolution of uncertainty, firms can flexibly adjust their capital utilization, and benefit from monopoly power.[5] The first case has been emphasized by the existing literature. The second case is a novel perspective on the asset pricing implications of technology shocks.

It is important to emphasize that although both variable capital utilization and high EIS can generate a positive price of risk for IST shocks, the two channels are conceptually quite different: the former is a property of the production technology and has direct impact on both macroeconomic quantities and asset prices, while the latter is a property of households' preferences and mainly impacts asset prices. As our analysis shows, variable capital utilization can "undo" part of the effect of EIS and generate a positive price of risk for IST shocks even when the household have strong preference towards consumption smoothing across time (i.e.,

[5]The EIS effect is well known. For example, Papanikolaou (2011) shows that, with fixed capital utilization, the sign of the price of risk for IST shocks depends on the preferences towards consumption smoothing. Low (high) values of EIS induce household to attach high (low) values to securities that hedge against the drop in consumption caused by an IST shock, thus leading to a negative (positive) price of risk for IST shock. EIS has a similar qualitative effect on the aggregate risk premium in the long-run risk literature (see for example, Bansal and Yaron (2004)). We emphasize the effect of EIS on risk premia through the market power channel, which is absent in most existing studies.

low EIS). Furthermore, while the sign of the market price of risk depends on capital flexibility and households' EIS, the sign and magnitude of the risk premium is determined jointly by firms' market power, capital flexibility, and households' EIS. In summary, higher market power and more flexible capital utilization, together with high EIS, can generate a positive risk premium for IST shocks. The combination of these three channels provides therefore a mechanism that can improve the ability of production-based models to match observed levels of the equity risk premium, without generating counterfactual dynamics in aggregate macroeconomic quantities.

Our paper makes three contributions. First, we provide a new perspective to assess the pricing implication of IST shocks. Specifically, we focus not only on the effect of IST shocks on the accumulation of *new* capital, as is done in the existing literature, but also on the effect of these shocks on the utilization of existing *old* capital. Second, we show that the firms' competitive environment is important in determining the impact of IST shocks on firm value and asset risk premia. Third, we document that equilibrium models that allow for variable capital utilization and firms' market power generate theoretical implications on asset prices that are *qualitatively* different from those obtained in models with fixed capital utilization and perfectly competitive markets.

The rest of the paper proceeds as follows. In Section 2 we review the related literature. In Section 3 we describe our two-sector general equilibrium model. We present the main results in Section 4. In Section 5 we provide a qualitative analysis of the main mechanisms of the model. Section 6 concludes. Appendix A contains details of the numerical procedure used to solve the model.

2 Related literature

Our work is related to a large literature that studies the macroeconomic and asset pricing implications of IST shocks. Since the work of Solow (1960), IST shocks have become an important feature of the macroeconomic literature. Representative works in this area are Greenwood, Hercowitz, and Krusell (1997, 2000) and Fisher (2006), who show that IST shocks can account for a large fraction of growth and variations in output, and Justiniano, Primiceri, and Tambalotti (2010) who study the effect of investment shocks on business cycles. Greenwood, Hercowitz, and Huffman (1988) are the first to introduce capital utilization in a neoclassical real business cycle model with IST shocks. They show how capacity utilization is important to avoid the counterfactual negative correlation between consumption and investment. Jaimovich and Rebelo (2009) use IST shocks and capital utilization in a two-sector economy similar to ours, in order to study the effect of news on the business cycle. Christiano and Fisher (2003) is the first paper to explore the implications of IST shocks for aggregate asset prices and business cycle fluctuations.

Several recent studies link IST shocks to aggregate and cross-sectional return patterns. Papanikolaou (2011) is the first to study the implications of these shocks for asset prices in both the aggregate and the cross-section of stocks. Papanikolaou (2011) introduces IST shocks in a two-sector general equilibrium model and shows how financial data can be used to measure IST shocks at a higher frequency. Kogan and Papanikolaou (2012a,b) explore how IST shocks can explain the value premium as well as other cross sectional return patterns associated with firm characteristics, such as Tobin's Q, past investment, earnings-price ratios, market betas, and idiosyncratic volatility of stock returns. Li (2012) uses IST shocks to explain the momentum effect, while Yang (2013) uses IST shocks to explain the commodity basis spread. Bazdresch, Belo, and Lin (2013) study the impact of labor market frictions on asset prices when the growth opportunities in the economy are time-varying. Their model features an aggregate adjustment cost shock which operates similarly to an IST shock affecting both labor and capital inputs. To the best of our knowledge ours is the first paper that investigates the equilibrium implications of capital utilization and market power on the relationship between technology shocks and asset prices.

More broadly, our paper is also related to the recent literature that explores the general equilibrium implications of technology innovations on asset prices.[6] For example, Garleanu, Kogan, and Panageas (2012) study the role of "displacement risk" due to innovation in a general equilibrium overlapping-generations economy, and Garleanu, Panageas, and Yu (2012) study the asset pricing implications of technological growth in a model with "small," disembodied, productivity shocks, and "large," infrequent, technological innovations embodied into new capital vintages.

[6] Neutral productivity shocks are the main driving force in the large literature that explores the implications of real business cycles on asset prices (see, for example, Jermann (1998), Tallarini (2000), Boldrin, Christiano, and Fisher (2001), Gomes, Kogan, and Yogo (2009)), and in the investment-based asset pricing literature (see, for example, Cochrane (1991, 1996), Berk, Green, and Naik (1999), Gomes, Kogan, and Zhang (2003), Carlson, Fisher, and Giammarino (2004), Zhang (2005), Liu, Whited, and Zhang (2009)).

Lin (2012) studies the cross section of stock return by emphasizing how intangible capital (R&D) affects both the creation of new products and the productivity of physical investment devoted to the production of new capital. In his model, R&D capital can hence be interpreted as a determinant of IST shocks.

Finally, our modelling device for introducing firms' market power borrows from the endogenous growth literature in macroeconomics that employs the monopolistically competitive equilibrium structure pioneered by Dixit and Stiglitz (1977). Several recent papers employs a similar channel in studying the equilibrium asset pricing implication of innovation, such as, for example Kung and Schmid (2012), who link innovation to long-run risks, Loualiche (2012), who studies the role of industry entry and exit on asset prices, and Kogan, Papanikolaou, and Stoffman (2013), who emphasize the role of innovation in affecting intergenerational risk sharing. Our work differs from this literature in that we focus explicitly on the impact of market power on the pricing mechanism associated with IST shocks.

3 A two-sector general equilibrium model

In this section, we build a two-sector general equilibrium model to study the pricing impact of technological innovations on asset prices. The modelling framework builds on the two-sector models in Jaimovich and Rebelo (2009) and Papanikolaou (2011). Jaimovich and Rebelo (2009) focus on the macroeconomic impact of technology shocks on business cycles in discrete time when households have time-separable utility. Papanikolaou (2011) studies the pricing implications of investment shocks in continuous time and under recursive utility. We model an economy in discrete time where agents have recursive utility and production is undertaken by firms operating in two sectors: the consumption sector (C-sector) and the investment sector (I-sector). We also allow firms to flexibly adjust their capital utilization and to retain some degree of market power in their product market. Our model nests the cases of fixed capital utilization and perfectly competitive markets as limiting cases.

3.1 Households

The economy is populated by a continuum of identical households that maximize their lifetime utility (U) derived from consumption (C) and hours worked (L) according to the following Epstein-Zin recursive structure (Epstein and Zin (1989)):

$$U_t = \left\{ (1-\beta) \left[C_t (1 - \psi L_t^{\theta}) \right]^{1-\rho} + \beta (E_t U_{t+1}^{1-\gamma})^{\frac{1-\rho}{1-\gamma}} \right\}^{\frac{1}{1-\rho}}, \tag{1}$$

where β is the time discount rate, $1/\rho$ is the elasticity of intertemporal substitution (EIS), and γ is the coefficient of relative risk aversion. The parameters ψ and θ measure, respectively, the degree and sensitivity of disutility to working hours. The recursive utility (1) reduces to time-separable CRRA utility when $\rho = \gamma$, and, in particular, it belongs to the class of preference for consumption and leisure discussed in King, Plosser, and Rebelo (1988), which we refer to as KPR preferences. Households supply labor L^c and L^i to the C- and I-sector respectively. The total working hours L is the sum of the working hours in the two sectors, that is, $L_t = L_t^c + L_t^i$. The labor market is perfectly competitive and frictionless.[7]

Households choose consumption and labor supply to maximize utility in (1), taking the wage and firms' dividends as given. Specifically, they solve the following problem:

$$V_t = \max_{\{C_s, L_s\}_{s=t}^{\infty}} U_t, \qquad \text{s.t.} \;\; P_s^c C_s = W_s L_s + D_s^c + D_s^i, \;\; s \geq t, \tag{2}$$

where P^c is the price of consumption good,[8] W is the market wage, D^c and D^i are the dividends paid by, respectively, the C- and I-firms, defined formally in (14) and (21) below.

From the household optimization, by a standard argument, we obtain the stochastic discount factor (SDF) in the economy. The one-period SDF $\mathbb{M}_{t,t+1}$ at time t is the marginal rate of substitution between time t and time $t+1$, i.e.,

$$\mathbb{M}_{t,t+1} = \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\rho} \left(\frac{1 - \psi L_{t+1}^{\theta}}{1 - \psi L_t^{\theta}} \right)^{1-\rho} \left(\frac{V_{t+1}}{(\mathbb{E}_t V_{t+1}^{1-\gamma})^{\frac{1}{1-\gamma}}} \right)^{\rho-\gamma}. \tag{3}$$

[7] Extending the model to allow for wage rigidity as a friction in the labor market (see for example, Favilukis and Lin (2013)) does not change our results.

[8] For convenience, we choose the final consumption good as numeraire by setting $P_t^c = 1$ for all t.

3.2 Firms and technology

There are two productive sectors in the economy: the C-sector, producing the consumption good and the I-sector, producing the capital good. Labor and the capital good are inputs for both sectors.

3.2.1 Consumption sector

There is an infinite number of final good producers, who take intermediate goods as input and produce final consumption good as output. The final consumption good is produced according to the following constant elasticity of substitution (CES) technology:

$$Y_t^c = \left[\sum_{f=1}^{N^c} (x_{f,t}^c)^{\frac{\sigma_c - 1}{\sigma_c}} \right]^{\frac{\sigma_c}{\sigma_c - 1}}, \tag{4}$$

where $x_{f,t}^c$ is the input of type f good, N^c is the total number of types of intermediate consumption goods, and σ_c is the elasticity of substitution between any two intermediate goods. All the final output in C-sector is used for consumption ($C_t = Y_t^c$). We assume that the final good producers are competitive and so they make zero net profit in equilibrium.[9] The final good producer's demand $x_{f,t}^c$ of intermediate good of type f at time t is determined by an intratemporal profit maximization, i.e.,

$$\max_{x_{f,t}^c} P_t^c Y_t^c - \sum_{f=1}^{N^c} p_{f,t}^c x_{f,t}^c, \tag{5}$$

where Y_t^c is given by (4) and the prices P_t^c and $p_{f,t}^c$ of, respectively, the final and intermediate consumption good of type f are taken as given. Solving (5) yields the following demand for each type of intermediate good:

$$x_{f,t}^c = \left(\frac{p_{f,t}^c}{P_t^c} \right)^{-\sigma_c} C_t, \tag{6}$$

where the price of the final consumption good is $P_t^c = \left[\sum_{f=1}^{N^c} (p_{f,t}^c)^{1-\sigma_c} \right]^{\frac{1}{1-\sigma_c}}$.

[9] An equivalent interpretation is that consumers have CES preferences over intermediate consumption goods in the spirit of Dixit and Stiglitz (1977). We then can think of the final good producers are the consumers themselves.

The CES parameter σ_c measures the degree of substitutability among intermediate goods and provides a tractable way to model intermediate good firms' market power. Perfect competition corresponds to the limiting case $\sigma_c \rightarrow \infty$. In this case the intermediate goods are perfect substitute, and we have only one type of intermediate good which is also the final good. For finite value of σ_c, the intermediate goods are not perfect substitutes. As a result, each monopolistic firm has some degree of market power in the product market. As we show in Appendix A, each intermediate good firm charges a constant markup equal to $1/\sigma_c$, which represents the firm's monopolistic rent. Therefore, a lower value of σ_c implies more market power for the monopolistic firms.

Each intermediate good firm f in the C-sector (C-firm hereafter) produces good f by using capital, $k^c_{f,t}$, and labor, $l^c_{f,t}$, according to the following Cobb-Douglas production technology:

$$y^c_{f,t} = A_t Z^c_t (u^c_{f,t} k^c_{f,t})^{1-\alpha} (l^c_{f,t})^{\alpha}, \tag{7}$$

where A_t is the total factor of productivity (TFP), Z^c_t is the sector-specific factor of productivity for C-firms, and $u^c_{f,t} > 0$ is the intensity of capital utilization.

The capital utilization intensity variable $u^c_{f,t} > 0$ captures the duration or speed in operating existing machines. For example, a high level of $u^c_{f,t}$ may represent less maintenance time or longer working hours. If we normalize the capital utilization to be $u^c_{f,t} = 1$ at "normal" times (steady state), then a capital utilization higher than one means that the machines are more intensively used comparing to normal times.

The technology shocks A_t and Z^c_t follow geometric random walks with growth:

$$\ln A_t = \mu^A + \ln A_{t-1} + \varepsilon^A_t, \qquad \varepsilon^A_t \sim \ i.i.d.\ \mathcal{N}(0, \sigma^A), \tag{8}$$

$$\ln Z^c_t = \mu^{Z^c} + \ln Z^c_{t-1} + \varepsilon^{Z^c}_t, \qquad \varepsilon^{Z^c}_t \sim \ i.i.d.\ \mathcal{N}(0, \sigma^{Z^c}). \tag{9}$$

Each C-firm f can purchase the investment good and increase its capital stock. The evolution of capital for C-firm f is given by

$$k^c_{f,t+1} = k^c_{f,t}(1 + i^c_{f,t} - \delta(u^c_{f,t})), \tag{10}$$

where $i^c_{f,t}$ denotes the investment rate and the depreciation rate $\delta(u^c_f)$ depends explicitly on the intensity $u^c_{f,t}$ of capital utilization. The dependence of depreciation on the capital utilization captures the cost of increasing utilization and ensures that firms only choose a finite intensity of utilization of their capital.

We follow Jaimovich and Rebelo (2009) and specify a depreciation function that has a constant elasticity of marginal depreciation with respect to capital utilization, i.e.,

$$\delta(u) = \delta_0 + \delta_1 \frac{u^{1+\xi} - 1}{1+\xi}, \quad \xi > 0, \tag{11}$$

where δ_0 corresponds to the depreciation rate under unit capital utilization, i.e., $\delta(1) = \delta_0$. The parameter ξ measures the elasticity of marginal depreciation with respect to capital utilization, i.e., $\xi = \delta''(u)u/\delta'(u)$. A higher ξ means that capital depreciation, i.e., the marginal cost of capital utilization, is very sensitive to the degree of utilization. In other words, a higher ξ makes increasing capital utilization more costly. In contrast, a lower ξ, implies that capital utilization is very responsive to exogenous shocks. Therefore, the parameter ξ measures the inflexibility of firms' capital service in responses to shocks.

The investment in new capital is subject to a convex capital adjustment cost. To increase capital by an amount $i^c k^c$, firms need to purchase $\varphi(i^c)k^c$ units of capital goods. Following Papanikolaou (2011), we parameterize the adjustment cost function as

$$\varphi(i) = \frac{1}{\phi}(1+i)^{\phi} - \frac{1}{\phi}, \quad \phi \geq 1, \tag{12}$$

where ϕ captures the degree of the adjustment cost. The cases $\phi = 1$ and 2 correspond, respectively to, no adjustment cost and quadratic adjustment cost.

Each C-firm f makes optimal hiring, investment and capital utilization decisions in order to maximize the firm's market value, i.e., the present value of dividends obtained by taking wages W_t, the price of capital good P^i_t, and the stochastic discount factor $\mathbb{M}_{t,t+1}$ as given. Importantly, in solving its maximization problem, the C-firm takes as given the demand $x^c_{f,t}$ of intermediate good f derived in (6). Specifically, the C-firm producing intermediate good f solves the following problem:

$$V_{f,t}^c = \max_{\{l^c,i^c,u^c\}} \mathbb{E}_t \sum_{s=t}^{\infty} \mathbb{M}_{t,s} d_{f,s}^c, \qquad \text{s.t.} \;\; d_{f,s}^c = p_{f,s}^c y_{f,s}^c - W_s l_{f,s}^c - P_s^i \varphi(i_{f,s}^c) k_{f,s}^c, \tag{13}$$

where $d_{f,s}^c$ is firm f's dividend at time s, P_s^i is the price of investment good, $y_{f,s}^c = x_{f,s}^c$, and $\mathbb{M}_{t,s}$ is the time-t SDF for time-s payoffs, obtained from the one-period SDF in (3) as $\mathbb{M}_{t,s} = \prod_{k=0}^{s-t-1} \mathbb{M}_{t+k,t+k+1}$.

Aggregating across all C-firms we obtain the aggregate market value of the C-sector

$$V_t^c = \sum_{f=1}^{N^c} V_{f,t}^c = \max_{\{l^c,i^c,u^c\}} \mathbb{E}_t \sum_{s=t}^{\infty} \mathbb{M}_{t,s} D_s^c, \qquad \text{s.t.} \;\; D_s^c = \sum_{f=1}^{N^c} d_{f,s}^c, \tag{14}$$

where $d_{f,s}^c$ is given by (13).

3.2.2 Investment sector

The final investment good is also produced by an infinite number of perfectly competitive investment good producers that aggregate the intermediate investment goods according to the following CES technology:[10]

$$Y_t^i = \left[\sum_{f=1}^{N^i} (x_{f,t}^i)^{\frac{\sigma_i - 1}{\sigma_i}} \right]^{\frac{\sigma_i}{\sigma_i - 1}}. \tag{15}$$

In (15), $x_{f,t}^i$ is the input of type f intermediate investment good, N^i is the total number of types of intermediate investment goods, and σ_i is the elasticity of substitution between any two intermediate investment goods. Similar to the consumption sector, a lower value of σ_i implies higher market power for intermediate investment good producers (see discussions for σ_c in subsection 3.2.1). All the final output in I-sector is used for investment ($I_t = Y_t^i$). Similar to the C-sector, the investment good producers' demand $x_{f,t}^i$ of intermediate good f is given by:

$$x_{f,t}^i = \left(\frac{p_{f,t}^i}{P_t^i} \right)^{-\sigma_i} I_t, \tag{16}$$

[10] A similar argument as in footnote 9 applies to the I-sector. We can think of the final investment good producers as the intermediate goods producers themselves, using the same CES technology in transforming intermediate investment goods to the final productive capital.

where p^i_f is the price for type f intermediate investment good, and the price of final investment good $P^i_t = \left[\sum_{f=1}^{N^i}(p^i_{f,t})^{1-\sigma_i}\right]^{\frac{1}{1-\sigma_i}}$.

Each intermediate good firm f in the I-sector (I-firm hereafter) produces good f by using capital, $k^i_{f,t}$, and labor, $l^i_{f,t}$, according to the following Cobb-Douglas production technology:[11]

$$y^i_{f,t} = A_t Z^i_t (u^i_{f,t} k^i_{f,t})^{1-\alpha} (l^i_{f,t})^{\alpha}, \tag{17}$$

where A_t is the same TFP shock affecting the C-sector production function (7), Z^i_t is the sector-specific factor of productivity for I-firms, and $u^i_{f,t} > 0$ is the intensity of capital utilization. We refer to the sector-specific shock Z^i_t as the investment-specific technology (IST) shock. This shock affects directly the I-sector and, because it impacts the C-sector through investment in new capital, it is also referred to as a *capital-embodied* technological shock.

The IST shock follows a geometric random walk:

$$\ln Z^i_t = \mu^{Z^i} + \ln Z^i_{t-1} + \varepsilon^{Z^i}_t, \;\; \varepsilon^{Z^i}_t \sim \; i.i.d.\; \mathcal{N}(0, \sigma^{Z^i}). \tag{18}$$

The main focus of our study is the impact of this shock on asset prices.

The evolution of capital in the I-sector is similar to that in the C-sector, described in (10). Specifically, given the current level of capital $k^i_{f,t}$, the investment rate i^i_t, and capital utilization $u^i_{f,t}$, the next period capital $k^i_{f,t+1}$ is given by

$$k^i_{f,t+1} = k^i_{f,t}(1 + i^i_{f,t} - \delta(u^i_{f,t})), \tag{19}$$

where the depreciation rate $\delta(u^i_{f,t})$ depends on capital utilization according to equation (11). Similar to C-firms, an I-firm that wants to increase capital by an amount $i^i k^i$ needs to purchase $\varphi(i^i)k^i$ units of capital goods at the unit price P^i_t, where the adjustment cost function $\varphi(\cdot)$ is given by (12).

Similar to C-firms, I-firms make optimal hiring, investment and capital utilization decisions in order to maximize their market value by taking wages W_t, the price of capital good P^i_t, and the stochastic discount factor $\mathbb{M}_{t,t+1}$ as given. In solving its maximization problem, the I-firm

[11]Our results are qualitatively the same if we use a constant elasticity of substitution (CES) technology between labor and capital for the production of intermediate investment goods.

f takes as given the demand $x^i_{f,t}$ of intermediate good f derived in (16). Specifically, the I-firm producing good f solves the following problem:

$$V^i_{f,t} = \max_{\{l^i, i^i, u^i\}} \mathbb{E}_t \sum_{s=t}^{\infty} \mathrm{M}_{t,s} d^i_{f,s}, \qquad \text{s.t.} \;\; d^i_{f,s} = p^i_{f,s} y^i_{f,s} - W_s l^i_{f,s} - P^i_s \varphi(i^i_{f,s}) k^i_{f,s}, \tag{20}$$

where $d^i_{f,s}$ is the type f firm's dividend at time s and $y^i_{f,s} = x^i_{f,s}$.

Aggregating across all I-firms we obtain the aggregate market value of the I-sector

$$V^i_t = \sum_{f=1}^{N^i} V^i_{f,t} = \max_{\{l^i, i^i, u^i\}} \mathbb{E}_t \sum_{s=t}^{\infty} \mathrm{M}_{t,s} D^i_s, \qquad \text{s.t.} \;\; D^i_s = \sum_{f=1}^{N^i} d^i_{f,s}, \tag{21}$$

where $d^i_{f,s}$ is given by (20).

3.3 Equilibrium

In equilibrium, all markets have to clear. For the C-sector, the market clearing condition is $C_t = Y^c_t$, where Y^c_t is given in (4). For the I-sector, we need to account for the fact that the final investment good is used for capital investment in both sectors. This implies the following market clearing condition for the final investment good:

$$\sum_{f=1}^{N^c} \varphi(i^c_{f,t}) k^c_{f,t} + \sum_{f=1}^{N^i} \varphi(i^i_{f,t}) k^i_{f,t} = Y^i_t, \tag{22}$$

where Y^i_t is given in (15).

Since all the monopolistic firms in each sector are affected by the same technological shocks, in equilibrium they have identical product prices, quantities, investment, labor, capital utilization choices, and values. This symmetry helps us to construct the following measures of aggregate capital, labor and output in the economy:

$$K_t^j = N^j \cdot k_{f,t}^j, \quad j = c, i, \tag{23}$$

$$L_t^j = N^j \cdot l_{f,t}^j, \quad j = c, i, \tag{24}$$

$$Y_t^j = \left(N^j\right)^{\frac{\sigma_j}{\sigma_j - 1}} \cdot y_{f,t}^j = A_t \left(\left(N^j\right)^{\frac{1}{\sigma_j - 1}} Z_t^j\right) \left(u_t^j K_t^j\right)^{1-\alpha} \left(L_t^j\right)^{\alpha}, \quad j = c, i, \tag{25}$$

$$P_t^j Y_t^j = N^j \cdot p_{f,t}^j y_{f,t}^j, \quad j = c, i. \tag{26}$$

The equilibrium of the economy is determined by the solution of the households' problem (2), the C-firm's problem (13), and the I-firm's problem (20). The equilibrium conditions derived from these problems are given in Appendix A, where we also show that the equilibrium is stationary after a suitable renormalization of all variables.

3.4 Asset prices

In this section, we describe our approach to study the implications of technology shocks to equilibrium asset prices. We focus our analysis on two specific quantities of interests for asset pricing. The first quantity is the market price of risk of technological shocks. This quantity is the Sharpe ratio of a security whose returns are perfectly correlated with the shock. The second quantity is the risk premium demanded in equilibrium for holding sectoral or aggregate portfolios that are exposed to technology shocks.

3.4.1 Market price of risk of technology shocks

The economy we consider features three aggregate shocks, a neutral TFP shock A_t and two sector specific shocks, Z_t^c and Z_t^i. Projecting the log SDF process (3) on the space spanned by these shocks we can write:

$$m_{t,t+1} = \ln(M_{t,t+1}) = \mathbb{E}_t m_{t,t+1} - \gamma_{t+1}^A \frac{\varepsilon_{t+1}^A}{\sigma^A} - \gamma_{t+1}^{Z^c} \frac{\varepsilon_{t+1}^{Z^c}}{\sigma^{Z^c}} - \gamma_{t+1}^{Z^i} \frac{\varepsilon_{t+1}^{Z^i}}{\sigma^{Z^i}}, \tag{27}$$

where ε_{t+1}^A, $\varepsilon_{t+1}^{Z^c}$ and $\varepsilon_{t+1}^{Z^i}$ are orthogonal to each other. The quantities γ_{t+1}^A, $\gamma_{t+1}^{Z^c}$, and $\gamma_{t+1}^{Z^i}$ are the market prices of risk for, respectively, the TFP shock A_t, the C-sector specific shock Z_t^c and the I-sector specific shock Z_t^i. To see this, consider a similar projection of the log return $r_{j,t+1}$

of a generic asset j on the space spanned by these shocks, i.e.,

$$r_{j,t+1} = \mathbb{E}_t r_{j,t+1} + \beta^{A}_{j,t+1}\varepsilon^{A}_{t+1} + \beta^{Z^c}_{j,t+1}\varepsilon^{Z^c}_{t+1} + \beta^{Z^i}_{j,t+1}\varepsilon^{Z^i}_{t+1}. \tag{28}$$

where $\beta^{\mathrm{X}}_{j,t+1} = Cov(\varepsilon^{\mathrm{X}}_{t+1}, r_{j,t+1})/(\sigma^{\mathrm{X}})^2$, $\mathrm{x} = A, Z^c, Z^i$. Accounting for the Jensen's inequality adjustment, the log risk premium on asset j can be written as

$$\begin{aligned}\mathbb{E}_t(r_{j,t+1} - r_{f,t+1} + \sigma^2_j/2) &= -Cov(m_{t,t+1}, r_{j,t+1}) \\ &= \beta^{A}_{j,t+1}\sigma^{A}\gamma^{A}_{t+1} + \beta^{Z^c}_{j,t+1}\sigma^{Z^c}\gamma^{Z^c}_{t+1} + \beta^{Z^i}_{j,t+1}\sigma^{Z^i}\gamma^{Z^i}_{t+1}, \end{aligned} \tag{29}$$

where $r_{f,t+1}$ is the log risk-free rate from t to $t+1$, σ_j is the volatility of asset j's log returns, and the second equality follows from (27) and (28) and the orthogonality of the shocks ε^{A}_{t+1}, $\varepsilon^{Z^c}_{t+1}$, and $\varepsilon^{Z^i}_{t+1}$. If an asset j is perfectly correlated with the IST shock Z^i, $\beta^{Z^i}_{j,t+1} = \sigma_j/\sigma^{Z^i}$ and $\beta^{A}_{j,t+1} = \beta^{Z^c}_{j,t+1} = 0$. Hence, from (29) the Sharpe ratio of this asset is given by

$$\frac{\mathbb{E}_t(r_{j,t+1} - r_{f,t+1} + \sigma^2_j/2)}{\sigma_j} = \frac{\beta^{Z^i}_{j,t+1}\sigma^{Z^i}\gamma^{Z^i}_{t+1}}{\beta^{Z^i}_{j,t+1}\sigma^{Z^i}} = \gamma^{Z^i}_{t+1}, \tag{30}$$

proving that the quantity $\gamma^{Z^i}_{t+1}$ in the parameterization (27) is the market price of risk for the IST shock Z^i_t, i.e., the risk premium per unit volatility of the IST shock.

From the SDF equation (27), the market price of risk $\gamma^{Z^i}_{t+1}$ is given by

$$\gamma^{Z^i}_{t+1} = -\sigma^{Z^i}\frac{\partial m_{t,t+1}}{\partial \varepsilon^{Z^i}_{t+1}}. \tag{31}$$

Hence, the market price of risk of IST shock is positive (negative) if a positive IST shock $\varepsilon^{Z^i}_{t+1} > 0$ causes a decrease (increase) in the marginal utility of consumption of the representative household.

Similarly, from the SDF equation (27) we obtain the market prices of risk for TFP shocks, γ^A, and for C-sector specific shocks, γ^{Z^c}:

$$\gamma^{A}_{t+1} = -\sigma^{A}\frac{\partial m_{t,t+1}}{\partial \varepsilon^{A}_{t+1}}, \quad \text{and} \quad \gamma^{Z^c}_{t+1} = -\sigma^{Z^c}\frac{\partial m_{t,t+1}}{\partial \varepsilon^{Z^c}_{t+1}}. \tag{32}$$

3.4.2 Aggregate and sectoral risk premia

To analyze risk premia associated with IST shocks, we first define the time $t+1$ realized return of C-firms, $R_{c,t+1}$, as the return of an infinitely-lived security whose payoff is the dividend D_t^c, defined in (14). Similarly, we define the realized return $R_{i,t+1}$ of I-firms. The log return $r_{c,t+1}$ of C-firms is,

$$r_{c,t+1} = \ln(R_{c,t+1}) = \ln\left(\frac{V_{t+1}^c}{V_t^c - D_t^c}\right). \tag{33}$$

From equation (28), the loading of the return of C-firm on the IST shock is given by

$$\beta_{c,t+1}^{Z^i} = \frac{\partial r_{c,t+1}}{\partial \varepsilon_{t+1}^{Z^i}} = \frac{\partial \ln(V_{t+1}^c)}{\partial \varepsilon_{t+1}^{Z^i}}. \tag{34}$$

Using the risk premium definition in (29), we obtain that the risk premium $\lambda_{c,t+1}^{Z^i}$ associated to IST shocks that the market demands for holding a sectoral portfolio of C-firms is given by:

$$\lambda_{c,t+1}^{Z^i} = \beta_{c,t+1}^{Z^i} \sigma^{Z^i} \gamma_{t+1}^{Z^i}, \tag{35}$$

where the loading $\beta_{c,t+1}^{Z^i}$ is obtained through (34) and the market price of risk for IST shock $\gamma_{t+1}^{Z^i}$ is given by (31). Similarly, $\lambda_{i,t+1}^{Z^i}$ associated to IST shocks that the market demands for holding a sectoral portfolio of I-firms is given by:

$$\lambda_{i,t+1}^{Z^i} = \beta_{i,t+1}^{Z^i} \sigma^{Z^i} \gamma_{t+1}^{Z^i}, \tag{36}$$

where the loading on the IST shock is given by

$$\beta_{i,t+1}^{Z^i} = \frac{\partial r_{i,t+1}}{\partial \varepsilon_{t+1}^{Z^i}} = \frac{\partial \ln(V_{t+1}^i)}{\partial \varepsilon_{t+1}^{Z^i}}. \tag{37}$$

At each time t, the aggregate market value V_t^m is the sum of the market values of C- and I-firms,

$$V_t^m = V_t^c + V_t^i, \tag{38}$$

where the cum-dividend market values V_t^c and V_t^i are defined in (14) and (21), respectively.

Following a similar logic as that used to derive sectoral risk premia $\lambda^{Z^i}_{c,t+1}$ and $\lambda^{Z^i}_{i,t+1}$, the risk premium $\lambda^{Z^i}_{m,t+1}$ associated to IST shocks that the market demands for holding the aggregate portfolio of C- and I-firms is given by:

$$\lambda^{Z^i}_{m,t+1} = \beta^{Z^i}_{m,t+1} \sigma^{Z^i} \gamma^{Z^i}_{t+1}, \tag{39}$$

where the loading on the IST shock is given by

$$\beta^{Z^i}_{m,t+1} = \frac{\partial r_{m,t+1}}{\partial \varepsilon^{Z^i}_{t+1}} = \frac{\partial \ln(V^m_{t+1})}{\partial \varepsilon^{Z^i}_{t+1}}, \tag{40}$$

and the aggregate cum dividend market value V^m_{t+1} is defined in (38).

The betas and risk premia associated with the other two technological shocks (A_t and Z^c_t) can be derived in a similar fashion as in equations (34)–(40), by replacing the IST shock $\varepsilon^{Z^i}_{t+1}$ with either the TFP, ε^A_{t+1}, or the C-sector-specific shock, $\varepsilon^{Z^c}_{t+1}$.

4 Results

To highlight the important role played by capital flexibility and firms' market power, we analyze the implication of the model under both fixed ($\xi \to \infty$) and variable ($0 < \xi < \infty$) capital utilization , and under both perfectly competitive ($\sigma_c, \sigma_i \to \infty$) and monopolistically competitive ($0 < \sigma_c, \sigma_i < \infty$) sectors.

In addition, because of the flexibility of the Epstein-Zin framework, we also explore the role of the elasticity of intertemporal substitution and contrast it to that of capital utilization and market power. This allows us to analyze, both qualitatively and quantitatively, the effect on asset prices of the three main channels of our model: technology (variable capital utilization), industry structure (market power) and preferences (elasticity of intertemporal substitution).

4.1 Parameters

The model parameters belong to three groups: preference, production, and technology shocks. We report our parameter choices in Table 1, where values are calibrated to a quarterly frequency.

Preference parameters. We choose a relative risk aversion coefficient $\gamma = 2$ and a time discount factor $\beta = 0.995$. Following Jaimovich and Rebelo (2009) we set the sensitivity of disutility to working hours to $\theta = 1.4$. The value ψ for the degree of disutility to working hours is chosen in such a way as to insure that in the deterministic steady state the value L of working hours is equal to 0.2, i.e., households work for 20% of their time.[12] We provide results for three different values of EIS ($1/\rho$): low (0.2), medium (0.5), and high (1.2). Note that, given a relative risk aversion of $\gamma = 2$, the medium case (EIS=0.5) corresponds to the case of time-separable CRRA utility.

Production parameters. The capital adjustment cost parameter is set to $\phi = 1.2$, as in Papanikolaou (2011). Following Jaimovich and Rebelo (2009), we set the labor share of output to $\alpha = 0.64$, and the deterministic steady state depreciation rate in (11) to $\delta_0 = 1.25\%$. For the case of fixed capital utilization ($\xi \to \infty$), the capital utilizations u_t^c and u_t^i are fixed at 1, so the depreciation rate (11) is a constant $\delta_0 = 1.25\%$. For the case of variable capital utilization ($0 < \xi < \infty$), the curvature parameter of the depreciation in capital utilization is set to $\xi = 0.5$, higher than the value of $\xi = 0.15$ in Jaimovich and Rebelo (2009). Note that a higher value of ξ implies less flexibility in adjusting capital utilization in equilibrium. The other depreciation parameter in (11), δ_1, is chosen such that the capital utilization in the deterministic steady state of the general case is also equal to 1. When considering monopolistically competitive firms ($0 < \sigma_c, \sigma_i < \infty$), we choose market power parameters $\sigma_c = \sigma_i = 4$, which imply a 25% markup for firms in both sectors. This markup value is lower than the 36% markup value calibrated by Bilbiie, Ghironi, and Melitz (2012).

Technology shocks parameters. The quarterly growth rate (volatility) is set to 0.25% (1%) for the TFP shock A_t, to 0.5% (2%) for the C-sector specific productivity shock Z_t^c, and to 1% (5%) for the I-sector specific productivity (IST) shock Z_t^i.

Using these parameter values we solve the model numerically through third order perturbations around the stochastic steady state.

[12]For a representative worker who works for 8 hours per day and 255 days a year, the working time accounts for roughly 23% of the time in a year. In our calibration, we use a slightly lower value of 20% in order to take into account other factors affecting working hours such as sick-leaves or unemployment.

4.2 Macroeconomic quantities

In this section we analyze the responses of macroeconomic quantities of interest (consumption, labor, capital utilization, and investment rate) and of the relative price of the capital good, to a positive one standard deviation shock to each of the three technology shocks, A_t, Z_t^c, and Z_t^i. We measure the response of a quantity of interest to a shock as the relative deviation from the steady state value following a positive one standard deviation change in the log of the technology shock.

Panel A of Table 2 reports responses of macroeconomic quantities to a positive 1% shock to the TFP A_t. We consider first the case in which firms are perfectly competitive. Upon a positive TFP shock, consumption C increases, labor L^c in the C-sector drops while labor L^i in the I-sector increases. The overall effect of positive TFP shock on total labor supply L is positive. As we discuss in Section 5, under KPR preferences the labor in the two sectors cannot move in the same direction in response to a technology shock. Variable capital utilization, investment rate in the I-sector and the price of investment good respond positively to a positive TFP shock. The investment rate of the C-sector is however sensitive to the level of EIS. For EIS<1 a positive TFP shock results in a positive response of investment rate in both sectors while for EIS>1 the response of C-sector investments to TFP shocks is negative. This happens because for lower level of EIS, the household would like to smooth consumption by consuming more in the near future and this induces an increase in capital investment in the C-sector. For high levels of EIS the household is relatively less concerned about consumption smoothing over time. This leads to lower investment in the C-sector and relatively more investment in the I-sector in order to take advantage of the increase in productivity implied by the TFP shock. The capital good price P^i increases in response to a positive shock to A_t because of the increased demand from the investment sector. The responses are qualitatively the same for cases in which firms have some degree of monopoly power in their product market.

Panel A of Table 3 reports responses of macroeconomic quantities to the C-sector specific shock Z_t^c. The results are similar for cases under perfect competition and monopolistic competition. Not surprisingly, consumption is positively affected by a consumption specific shock. The responses of variable capital utilization are all positive. The capital good price P^i increases in response to a positive shock to Z_t^c because of the increased demand from the consumption sector.

Finally, Panel A of Table 4 reports responses of macroeconomic quantities to the IST shock Z_t^i. The results are qualitatively the same for cases under perfect and monopolistic competition. Comparing this panel to the corresponding panels in the previous tables reveals the unique nature of IST shocks. In particular, the panel reveals the important role played by capital utilization in the dynamics of macroeconomic quantities. For example, under fixed capital utilization, a positive IST shock leads to a drop in consumption, independent of the level of EIS. The opposite is true for the case of variable capital utilization. This fact has important implications for asset pricing quantities as we discuss in the next section. In response to a positive IST shock, labor in the I-sector increases while labor in the C-sector decreases. Capital utilization increases in both sectors, while investment rates increase much more in the I-sector than in the C-sector. Investment responses in the C-sector decline, and can turn negative as EIS increases. This happens because for low level of EIS the household's preference for consumption smoothing over time induces more investment in the C-sector relative to the I-sector; for higher level of EIS the household is willing to give up consumption in the short-run (i.e., reduce investment in the C-sector) for more consumption in the future. Consistent with the interpretation that a positive IST shocks makes the capital good cheaper, the price of the capital good P^i reacts negatively to a shock in Z_t^i, independent of the level of EIS.

4.3 Asset pricing quantities

Following the analysis in Section 3.4, we derive asset pricing quantities of interest from the response to a positive one standard deviation change to each of the three technology shocks. In what follows, we discuss the results related to the market price of risk of the three technology shocks (Subsection 4.3.1) and the risk premia of sectoral and aggregate portfolios (Subsection 4.3.2).

4.3.1 Market price of risk of technology shocks

As discussed in Section 3.4, the market price of risk for a technology shock is the Sharpe ratio of an asset that is perfectly correlated with the shock. To construct the market price of risk γ^{X}, x $= A, Z^c, Z^i$, from the solution of our model, we rely on equations (31) and (32), which indicate that this quantity is the (negative of the) response of the log SDF to a technology shock.

Panel B of Table 2 reports results for the TFP shock A_t. The market price of risk for the TFP shock is positive for different values of EIS and under either fixed or variable capital utilization. The magnitude, however, is higher for large values of EIS and for variable capital utilization, ranging from 1.45% to 2.99% quarterly under perfect competition (and from 1.46% to 3.08% under monopolistic competition). For high value of EIS, i.e., preference for early resolution of uncertainty ($\rho < \gamma$), the household dislikes the uncertainty of their future utility. Because a positive TFP shocks increases both current consumption C_t and future utility V_{t+1}, the household's marginal utility, i.e., the SDF in (3) becomes lower when $\rho < \gamma$. Hence the higher price of risk observed for high EIS. The increase in capital utilization u_t^c induced by the TFP shocks further magnifies the impact on current consumption and increase the market price of risk γ^A relative to the case of fixed capital utilization. Different degree of market power do not alter these results, as can be seen by comparing the right and left sides of Table 2.

Panel B of Table 3 reports results for the C-sector specific shock Z_t^c. Similar to the TFP shock, the market price of risk for the Z_t^c shock is positive for different values of EIS, under either fixed or variable capital utilization, and under either perfect or monopolistic competition. The magnitude is higher for higher EIS but not very sensitive to variable capital utilization or degree of competition. It ranges from 3.89% to 4.46% quarterly. These results are not affected by the degree of market power.

Panel B of Table 4 reports results for the IST shock Z_t^i. In sharp contrast with the previous two panels, we see that variable capital utilization can change the sign of the market price of risk γ^{Z^i}. Specifically, for low level of EIS (either 0.2 or 0.5) the market price of risk for the Z^i shock is negative under fixed capital utilization but positive under variable capital utilization. This result is important because it shows that a purely technological aspect of the production process such as the intensity of capital utilization, can have qualitatively implications for the compensation of investment-specific technology risk. The existing literature has primarily focused on the effect of preferences on the sign of the price of risk, suggesting that only a large value of EIS can induce a positive price of risk for IST shock. Our result indicates that a positive price of risk for IST shocks is possible also for low value of EIS if one allows for variable utilization of capital.

Confirming the conjecture of the existing literature, we find that the price of risk turns positive for large values of EIS. Importantly, we note that, even for high EIS value, variable capital utilization amplifies the price of risk γ^{Z^i}. For example, when EIS $= 1.2$, allowing for variable capital utilization increases the market price of IST shocks from 2.77% to 3.71% under perfect competition and from 3.00% to 4.14% under monopolistic competition. These results are not affected by the degree of market power. In summary, capital utilization and preferences towards early vs. late resolution of uncertainty have important qualitative implication for the sign of the price of risk for IST shocks, while the impact of market power is relatively negligible. As we show in the next section, market power plays instead a crucial role in the determination of the market risk premium.

4.3.2 Aggregate and sectoral risk premia

We now consider the risk premia associated with the technological shocks for the aggregate portfolios composed of C-firms, I-firms, and for the market portfolio comprising both sectors. According to equation (29), the risk premia λ^{X} associated to a shock $\mathrm{x} = A, Z^c, Z^i$ are given by $\lambda^{\mathrm{X}} = \beta^{\mathrm{X}} \cdot \sigma^{\mathrm{X}} \cdot \gamma^{\mathrm{X}}$, where β^{X} is the factor loading of the asset on shock x, σ^{X} is shock x volatility and and γ^{X} the market price of risk of shock x. Given the exogenous shock volatility σ^{X} and the market prices of risk γ^{X} obtained in the previous subsection, to compute risk premia λ^{X} we need the beta loadings β^{X} of the portfolios of interest. Following the definition in equation (34), we construct the beta loading to a technology shock for a C-firm as the response of the firm's log market value to a one standard deviation shock. For example, β_c^A refers to the response of a C-firm's log market value to a one standard deviation TFP shock A_t. We follow similar steps to construct betas with respect to other technology shocks for all portfolios considered.

Panel B of Table 2 reports results for the TFP shock. The loadings on the TFP shock for the portfolio of C-firms, I-firms, and the market, are positive, i.e., $\beta_j^A > 0$, $j = c, i, m$. This fact, combined with a positive market price of risk $\gamma^A > 0$, leads to a positive risk premia for these portfolios, i.e., $\lambda_j^A > 0$, $j = c, i, m$. The patterns are qualitatively the same under perfect and monopolistic competition. The magnitude of the risk premia are however tiny, in the order of 0.04% quarterly.

Panel B of Table 3 reports results for the C-sector specific shock. The loadings $\beta_j^{Z^c} > 0$, $j = c, i, m$, which, together with a positive market price of risk $\gamma^{Z^c} > 0$, also leads to positive risk premia $\lambda_j^{Z^c}$, $j = c, i, m$. The premia are higher for higher EIS but their magnitude is quite small, in the order of 0.1% quarterly.

Panel B of Table 4 reports results for the IST shock Z^i. We first consider the case of perfect competition. The loadings on the Z^i shock for the portfolio of C-firms, I-firms, and the market, are *negative*, i.e., $\beta_j^{Z^i} < 0$, $j = c, i, m$. This implies that the sign of the risk premia $\lambda_j^{Z^i}$, $j = c, i, m$, is *opposite* to that of the market price of risk γ^{Z^i} for the IST shock. The results in Panel B show that under low EIS (0.2 or 0.5) and fixed capital utilization, the risk premia $\lambda_j^{Z^i}$, $j = c, i, m$, are positive. In contrast, when EIS is high (1.2) or capital utilization is variable, the risk premia are negative.

Results are qualitatively different under monopolistic competition as illustrated in Panel B of Table 4. The loading of C-firm portfolios, $\beta_c^{Z^i}$, becomes positive when EIS is high (1.2) but only when capital utilization is flexible. Similarly, the loading of investment firms, $\beta_i^{Z^i}$, becomes positive under variable capital utilization for all levels of EIS. The loading of market portfolio, $\beta_m^{Z^i}$, is positive when EIS is high (1.2) under both fixed and variable capital utilization. Combining these loadings with the market price of risk discussed in Section 4.3.1, we observe that the only case in which loadings and risk premia are positive for *all* portfolios is when EIS is high and capital utilization is flexible (last column in Panel B). This result indicates that monopoly power in the product market can change the sign of the risk premia associated with IST shocks.

It is important to emphasize that the changes of sign documented in Panel B of Table 4 have a direct *qualitative* impact on the role of IST shocks in explaining observed levels of the market risk premium. In fact, while a positive risk premium for IST shocks under fixed capital utilization and low EIS can help explaining higher level of the equity premium, the negative risk premium of IST shocks obtained under variable capital utilization and higher EIS in perfectly competitive markets challenges the ability of the model to match observed level of the risk premium. Our analysis suggests that variable capital utilization, firms' market power, and households' preference towards early resolution of uncertainty can generate positive risk premia for IST shocks and thus improve the ability of the model in matching observed level of the risk premium.

5 Inspecting the mechanisms

The results in the previous section indicate that the sign of the market price of risk and of the risk premium associated with IST shocks depend on the degree of flexibility in capital utilization and on the degree of firms' market power. In this section, we provide an in depth analysis of these mechanisms. In the next three subsections we inspect the following three channels through which the IST shocks affect asset prices: (i) capital flexibility, measured by the degree ξ of capital utilization; (ii) market power, measured by the monopolistic markups $1/\sigma_c$ and $1/\sigma_i$; and (iii) preference towards early or late resolution of uncertainty, measured by the EIS, $1/\rho$.

5.1 The effect of flexible capital utilization

To understand the effect of flexible capital utilization on the market price of risk γ^{Z^i} for IST shocks, we need to understand its effect on the marginal utility of the representative household. Because the household derives utility from consumption and leisure we separately investigate the role of variable capital utilization on these two quantities under IST shocks.

When capital utilization is fixed, a positive IST shock increases the marginal productivity of labor in the I-sector relative to the C-sector. Because the labor market is frictionless, this shock induces a flow of workers from the C-sector to the I-sector. With fixed capital utilization, from the market clearing condition (25), a drop in labor causes a drop in consumption in response to a positive IST shock.

The effect of a positive IST shock on total working hours can be inferred from the equilibrium conditions of households and firms. Combining the households' first order conditions for consumption and labor supply (respectively, equations (A.1.2) and (A.1.3) in Appendix A.1) with the C-firm's first order condition for labor demand (equation (A.1.6)) and the market clearing condition for the consumption good (equation (A.1.4)), we obtain that

$$\frac{\theta\psi L_t^{\theta-1}}{1-\psi L_t^{\theta}} = \frac{\alpha}{L_t^c}\left(1-\frac{1}{\sigma_c}\right), \qquad \alpha, \psi > 0,\, \theta > 1. \tag{41}$$

The left hand side of (41) increases in total working hours ($L_t = L_t^c + L_t^i$) and the right hand side decreases with working hours in the C-sector, L_t^c. This implies that, under the KPR preferences specification of our model, in response to a IST shock, the total number of working hours L_t moves always in the opposite direction as that of the working hours L_t^c of the C-sector.[13] From the above discussion, under fixed capital utilization, a positive IST shock induces a drop in consumption and working hours L_t^c and, by (41) an increase in the total supply of working hours L_t (see Table 4, Panel A). The drop in consumption, and the increase in total working hours, *increase* the marginal utility after a positive IST shock. When EIS $\leq 1/\gamma$ this generates a *negative* price of risk for IST shocks under fixed capital utilization. This mechanism is emphasized by Papanikolaou (2011) who also analyzes the role of EIS in determining the sign of the market price of risk for IST shocks.

As the results in Table 4 illustrate, under variable capital utilization, the above mechanism can break down. The reason is that variable capital utilization has a direct effect on consumption. To see this, consider again the market clearing condition (25). From Panel A of Table 4 we observe that, in the case of fixed capital utilization, consumption drops upon a positive IST shock. In contrast, when capital utilization is allowed to respond to the IST shocks, consumption increases with the IST shocks because of higher level of utilization u_t^c. The increase in consumption counterbalances the effect of a drop in leisure (i.e., an increase in working hours). Under reasonable parameterization of the cost $\delta(u)$ in (11), the increase in consumption outweighs the drop in leisure and leads to *lower* marginal utility of consumption after a positive IST shock. A drop in marginal utility upon a positive IST shock implies a *positive* market price of risk for these shocks, as documented in Panel B of Table 4.

Figure 1 confirms the above intuition. The figure shows that the consumption response to a positive IST shock changes from negative, when capital is relatively inflexible (i.e., large values of the capital utilization cost parameter ξ) to positive, when capital is relatively flexible (i.e., small

[13]It is well known that the KPR preferences fail to replicate the aggregate and sectoral comovement of major macroeconomic aggregates such as output, consumption, investment and hours worked. The reason, as documented by Cochrane (1994) and Beaudry and Portier (2007), is that, under KPR preferences, the short-run wealth effect of positive news about future productivity is very strong and induces agents to *reduce* labor supply and hence output. This generates the counterfactual prediction that good news about the future cause recession in the present. Jaimovich and Rebelo (2009) propose a new class of preferences that allows to parameterize the intensity of the wealth effect and are consistent with balance growth. They show that these preferences can generate both aggregate and sectoral comovement. In an extension of our model that accommodates the preferences considered in Jaimovich and Rebelo (2009) we find qualitatively similar results with regards to the market price of risk and risk premia associated to IST shocks.

values of ξ). This effect on consumption also translates into a similar pattern for the market price of risk γ^{Z^i} for IST shocks, as shown in Figure 2. In particular, as capital becomes more flexible (i.e., as ξ becomes small), the market price of risk changes from negative to positive. These results hold both for the case of perfectly competitive firms (Panel A in Figures 1 and 2) and for the case of monopolistically competitive firms (Panel B in Figures 1 and 2).

The effect of flexible capital on the market risk premium $\lambda_m^{Z^i}$ is illustrated in Figure 3. Panel A shows that, for EIS < 1 and perfectly competitive firms, the risk premium for IST shocks can change from positive to negative as capital becomes more flexible (it is always negative for EIS > 1). This finding is a consequence of the fact that (i) $\beta^{Z^i} < 0$ in perfectly competitive markets, as shown in Panel B of Table 4, and (ii) for EIS < 1 the market price of risk for IST shocks, γ^{Z^i}, goes from negative to positive as capital becomes more flexible, as shown in Figure 2 (for EIS > 1, $\gamma^{Z^i} > 0$ always). Panel B of Figure 3 shows that the effect of flexible capital on the risk premium can be quite different for monopolistically competitive firms, depending on both firms' market power and households' EIS, as we discuss in the next two subsections.

5.2 The effect of firms' market power

As reported in Section 4.3.2, the degree of firms' market power affects qualitatively the risk premium associated with IST shocks because it directly affects firms' loadings, β^{Z^i}, on IST shocks. In perfectly competitive markets, a positive shock to IST reduces the price P^i of the investment good and induce competing firms to increase investment and production. As a result of this process, investment and labor costs incurred by firms are higher than the benefit received from the increased output. This leads to a drop in firm value upon a positive IST shock and a negative loading on the IST shock, $\beta^{Z^i} < 0$. In perfectly competitive markets, the sign of the risk premium associated to IST shocks, $\lambda_m^{Z^i} = \beta^{Z^i}\sigma^{Z^i}\gamma^{Z^i}$, is therefore *opposite* to that of the price of risk γ^{Z^i}.[14]

The above argument does not hold if firms retain some degree of market power. If firms have strong market power, i.e., high markups $1/\sigma_c$ and $1/\sigma_i$, then a positive IST shock can have

[14] An alternative interpretation for why $\beta^{Z^i} < 0$ in perfectly competitive markets can be obtained from the neoclassical q-theory of investment. In competitive markets, under constant returns in production and investment, average q equals marginal q (see Hayashi (1982)). Since the IST shock reduces the price of capital, it reduces both marginal and average q. A positive IST shock therefore reduces the value of firms because it reduces the marginal value of installed capital. This leads to negative loadings β^{Z^i} of firm value on IST shocks.

a positive impact on firm's value because, absent competitive forces, firms can internalize the reduction in investment cost following a positive IST shock and benefit from higher profits. For sufficiently high level of market power, firm's loadings on the IST shocks are positive, $\beta^{Z^i} > 0$, and therefore the sign of the risk premium associated to IST shocks, $\lambda_m^{Z^i} = \beta^{Z^i}\sigma^{Z^i}\gamma^{Z^i}$, is *the same* as that of the price of risk γ^{Z^i}.

Figure 4 confirms the above intuition. Panel A shows the market risk premium of IST shocks, $\lambda_m^{Z^i}$, as a function of market power ($\sigma_c = \sigma_i$) under fixed capital utilization ($\xi \to \infty$). The figure shows that when firms have weak market power (high σ_c and σ_i), the market risk premia $\lambda_m^{Z^i}$ indeed have the opposite sign as the market price of risk γ^{Z^i} reported in Panel A of Figure 2. However, when firms have strong market power (low σ_c and σ_i), the risk premium can have the same sign as the price of risk. For example, for EIS = 1.2, the market risk premium of IST shocks is positive when firms have strong market power. Panel B shows that the effect of market power on the market risk premium $\lambda_m^{Z^i}$ associated to IST shocks is qualitatively similar if we allow for flexible capital utilization. The main difference between panels A and B in Figure 4 concerns the market risk premia for low values of EIS (0.2. and 0.5). The risk premia are positive under fixed capital utilization (Panel A) and negative under flexible capital utilization (Panel B). As discussed in the previous section, this is a consequence of the fact that flexible capital utilization changes the sign of the market price of risk γ^{Z^i} from negative (in Panel A) to positive (in Panel B). Note also that for low value of EIS, β^{Z^i} is still negative under moderate degree of market power. Only under sufficiently high level of market power (i.e., sufficiently lower value of σ_c and σ_i), β^{Z^i} can be positive. The difference between low and high value of EIS highlights the importance of the interaction among preference towards early vs. late resolution of uncertainty, market power, and capital utilization to which we now turn.

5.3 The effect of the elasticity of intertemporal substitution

As discussed in Section 4.3, EIS plays an important role in determining the sign of both the market price of risk γ^{Z^i} and the risk premium $\lambda_m^{Z^i}$ associated with IST shocks. The effect of EIS on the market price of risk γ^{Z^i} is relatively intuitive. As pointed out by Papanikolaou (2011), a high EIS implies that the household is more willing to accept the uneven consumption profile induced by a technology shock and hence attributes relatively less values to an asset that perfectly hedges against these shocks. To understand this argument, it is convenient to refer to the expression (3) of the SDF for Epstein-Zin preferences with consumption and leisure. The EIS mechanism operates through preferences and affects the SDF primarily through the future utility channel, V_{t+1}. A positive IST shock increases the household's future utility. From the last term in equation (3), this implies a lower SDF when EIS is high (i.e., when $\rho - \gamma$ is negative). This explains the positive market price of risk under higher value of EIS. The opposite is true for low EIS.

The above argument, although intuitive, is not complete if one allows for flexible capital utilization. As shown in Figure 2, when capital is inflexible (high ξ), the market price of risk for IST shock is negative for low EIS (0.2 and 0.5) and positive for high EIS (1.2), confirming the above argument. However, when capital is flexible (low ξ), the market price of risk becomes positive for both low and high values of EIS. This indicates that, the effect of EIS on the price of risk depends on the degree of capital utilization which can, in part, "undo" some of the effects of EIS.

The effect of EIS on the risk premium $\lambda_m^{Z^i}$ depends on firms' competitive environment. If firms are perfectly competitive, then, as we discussed in the previous subsection, the beta loadings β^{Z^i} are negative. Therefore, the sign of the risk premium $\lambda_m^{Z^i}$ is opposite to that of the market price of risk γ^{Z^i}. Panel A of Figure 5 shows that for perfectly competitive firms the risk premium is monotonically decreasing in EIS. This happens because, as shown in Panel B of Table 4, the market price of risk γ^{Z^i} increases significantly as EIS increases and $\beta^{Z^i} < 0$.

If firms have market power the effect of EIS on the risk premium $\lambda_m^{Z^i}$ is significantly different from the case of perfect competition. As Panel B of Figure 5 shows, the risk premium is *U-shaped* in EIS if firms have monopoly power. For lower EIS, the $\lambda_m^{Z^i} > 0$ for fixed capital ($\gamma^{Z^i} < 0$ and $\beta^{Z^i} < 0$), while $\lambda_m^{Z^i} < 0$ for flexible capital ($\gamma^{Z^i} > 0$ and $\beta^{Z^i} < 0$). In contrast, for higher EIS, $\lambda_m^{Z^i} > 0$ for *both* flexible and inflexible capital ($\gamma^{Z^i} > 0$ and $\beta^{Z^i} > 0$).

To understand the above results, it helps to first discuss how market power and EIS affect firm values. Market power allows firms to charge a markup for their products and therefore it increases firms' cash flows upon a positive IST shock ("cash flow effect"). On the other hand, EIS affects firm values through the household's marginal utility. A positive IST shock increases future consumption and therefore decreases future marginal utility. The level of EIS affects the magnitude of the drop in future marginal utility following an IST shock and thus the magnitude of the discount factor used in evaluating future cash flows ("discount rate effect"). Households with low EIS dislike the steep consumption growth profile resulting from a positive IST shock. Therefore, they discount future cash flows more heavily relative to high EIS households.[15] Putting these two effects together, for high EIS, the cash flow effect dominates the relatively weaker discount rate effect, implying that firm values respond *positively* to a positive IST shock ($\beta^{Z^i} > 0$). This effect, combined with a positive market price of risk $\gamma^{Z^i} > 0$ generates a positive market risk premium $\lambda_m^{Z^i} > 0$ when EIS is high. For low EIS, the strong (negative) discount rate effect dominates the positive cash flow effect upon a positive IST shock, implying that firm values respond *negatively* to a positive IST shock ($\beta^{Z^i} < 0$). This effect explains why, when EIS is low, the market risk premium $\lambda_m^{Z^i}$ has a sign opposite to that of the market price of risk γ^{Z^i}, as shown in Panel B of Figure 5.

Note that, in the figure, market power can change the sign of the market risk premium only under high EIS. When EIS is high, according to the impulse response, the value of aggregate output (labor income plus dividends) increases under a positive IST shock. High market power increases the capital share of output and allows firms to cover the increased cost in investment. As a consequence, firm value benefits from a positive IST shock ($\beta^{Z^i} > 0$). In contrast, when EIS is low, the value of aggregate output drops following a positive IST shock. In this case, high market power is not sufficient to cover the increased cost in investment ($\beta^{Z^i} < 0$).[16]

The above argument can also help us understand the patterns reported in Panel B of Figure 3. The figure shows that when capital is flexible, the market risk premium for monopolistic firms depends crucially on the level of EIS. Following the above argument, for high EIS, the cash flow effect dominates the discount rate effect, leading to positive IST betas, $\beta^{Z^i} > 0$. Given a positive price of risk $\gamma^{Z^i} > 0$, this leads to a positive risk premium $\lambda_m^{Z^i} > 0$. Similarly, for low value of EIS, a negative beta, $\beta^{Z^i} < 0$, and a positive price of risk $\gamma^{Z^i} > 0$ lead to negative risk premia $\lambda_m^{Z^i} < 0$, as shown in Panel B of Figure 3 for flexible capital (low ξ). Finally, the above

[15] To see this, let us consider a special case in which consumption growth is deterministic after a positive IST shock at time t and labor is fixed. In this case, the SDF expression in (3) simplifies to $\mathbb{M}_{t,t+1} = \beta(C_{t+1}/C_t)^{-\rho}$. The corresponding multi-period discount factor is $\mathbb{M}_{t,s} = \beta^{s-t}(C_s/C_t)^{-\rho}$, where $s \geq t+1$ and $C_s/C_t > 1$. Therefore, low EIS (i.e., high ρ) households discount future consumption more heavily than high EIS households after a positive IST shock.

[16] To see this, consider the extreme case where the capital share of output is one (labor is free) and hence the firm value is the value of total output. Even in this case, the discount rate effect induced by low EIS causes the firm value to drop upon a positive IST shock.

argument also explains why we need both high EIS and market power to generate positive risk premia when capital is flexible, as illustrated in Panel B of Figure 4.

6 Conclusion

We provide a new perspective to understand the implications of IST shocks for asset pricing. We argue that capital utilization and firms' market power have a qualitatively important effect on the market price of risk and risk premia of IST shocks. Under fixed capital utilization, the current consumption drops upon a positive IST shock as workers in the consumption sector switch to the investment sector. Variable capital utilization allows agents to expand current consumption by more intensely utilizing the existing capital. Market power shields firms from competition and therefore allows positive IST shock to positively impact firm's value.

We identify three main mechanisms that drive the connection between IST shocks and asset prices. First, variable capital utilization mainly affects the sign of the market price of risk for IST shock by affecting current consumption. Second, market power affects the sign of risk premium associated with IST shock by reducing the negative impact of competitive pressures on firms's profits. Finally, the elasticity of intertemporal substitution affects both the market price of risk and risk premium of IST shocks through the stochastic discount factor channel. While the sign of the market price of risk depends on capital flexibility and EIS, the sign of the risk premium is determined jointly by market power, capital flexibility, and EIS. The new perspective we provide in this paper could potentially benefit further explorations of time series and cross sectional properties of asset returns.

A Equilibrium conditions

A.1 Original problem

Household's problem is given by (2), which we reproduce here:

$$V_t = \max_{\{C_s, L_s\}_{s=t}^{\infty}} U_t, \qquad \text{s.t. } P_s^c C_s = W_s L_s + D_s^c + D_s^i, \quad s \geq t,$$

and the corresponding Lagrangian is:

$$\mathcal{L}_t^{HH} = U_t + \lambda_t (W_t L_t + D_t^c + D_t^i - P_t^c C_t). \tag{A.1.1}$$

The first order conditions with respect to consumption and labor supply are given by,

$$\text{FOC\_1\_C:} \quad 0 = \lambda_t P_t^c - (1-\beta) C_t^{-\rho} (1 - \psi L_t^{\theta})^{1-\rho} U_t^{\rho}. \tag{A.1.2}$$

$$\text{FOC\_2\_L:} \quad 0 = \lambda_t W_t - (1-\beta) C_t^{1-\rho} (1 - \psi L_t^{\theta})^{-\rho} U_t^{\rho} \theta \psi L_t^{\theta - 1}. \tag{A.1.3}$$

$$\text{FOC\_3\_}\lambda\text{:} \quad 0 = C_t - A_t ((N^c)^{\frac{1}{\sigma_c - 1}} Z_t^c)(u_t^c K_t^c)^{1-\alpha} (L_t^c)^{\alpha}. \tag{A.1.4}$$

Consumption firm's problem is given by (13), which we reproduce here:

$$V_{f,t}^c = \max_{\{l^c, i^c, u^c\}} \mathbb{E}_t \sum_{s=t}^{\infty} \mathrm{M}_{t,s} d_{f,s}^c, \qquad \text{s.t. } d_{f,s}^c = p_{f,s}^c y_{f,s}^c - W_s l_{f,s}^c - P_s^i \varphi(i_{f,s}^c) k_{f,s}^c,$$

and the corresponding Lagrangian is:

$$\mathcal{L}_{f,t}^C = \mathbb{E}_t \sum_{s=t}^{\infty} \mathrm{M}_{t,s} \left(p_{f,s}^c y_{f,s}^c - W_s l_{f,s}^c - P_s^i \varphi(i_{f,s}^c) k_{f,s}^c + \eta_s^c (k_{f,s}^c (1 + i_{f,s}^c - \delta(u_{f,s}^c)) - k_{f,s+1}^c) \right). \tag{A.1.5}$$

Note that $p_{f,t}^c = (y_{f,t}^c / Y_t^c)^{-1/\sigma_c} P_t^c$ according to equation (6) and $y_{f,t}^c$ is given by equation (7).

The firm takes the aggregate prices and quantities as given and makes optimal decisions on hiring, investment, and capital utilization intensity. The corresponding first order conditions are,

$$\text{FOC\_4\_lc:} \quad 0 \;=\; \left(1-\frac{1}{\sigma_c}\right)\frac{\alpha p^c_{f,t} y^c_{f,t}}{l^c_{f,t}} - W_t. \tag{A.1.6}$$

$$\text{FOC\_5\_ic:} \quad 0 \;=\; \eta^c_t - P^i_t \varphi^{'}(i^c_{f,t}). \tag{A.1.7}$$

$$\text{FOC\_6\_uc:} \quad 0 \;=\; \left(1-\frac{1}{\sigma_c}\right)\frac{(1-\alpha) p^c_{f,t} y^c_{f,t}}{u^c_{f,t}} - \eta^c_t \delta^{'}(u^c_{f,t}) k^c_{f,t}. \tag{A.1.8}$$

$$\begin{aligned}\text{FOC\_7\_kc:} \quad 0 \;=\; & \mathbb{E}_t \mathbb{M}_{t,t+1} \left\{ \left(1-\frac{1}{\sigma_c}\right)\frac{(1-\alpha) p^c_{f,t+1} y^c_{f,t+1}}{k^c_{f,t+1}} - P^i_{t+1}\varphi(i^c_{f,t+1}) \right. \\ & \left. + \eta^c_{t+1}(1 + i^c_{f,t+1} - \delta(u^c_{f,t+1})) \right\} - \eta^c_t. \end{aligned} \tag{A.1.9}$$

$$\text{FOC\_8\_}\eta c\text{:} \quad 0 \;=\; k^c_{f,t}(1 + i^c_{f,t} - \delta(u^c_{f,t})) - k^c_{f,t+1}. \tag{A.1.10}$$

Investment firm's problem is given by (20), which we also reproduce here:

$$V^i_{f,t} = \max_{\{l^i, i^i, u^i\}} \mathbb{E}_t \sum_{s=t}^{\infty} \mathbb{M}_{t,s} d^i_{f,s}, \qquad \text{s.t.} \;\; d^i_{f,s} = p^i_{f,s} y^i_{f,s} - W_s l^i_{f,s} - P^i_s \varphi(i^i_{f,s}) k^i_{f,s},$$

and the corresponding Lagrangian is:

$$\mathcal{L}^I_{f,t} = \mathbb{E}_t \sum_{s=t}^{\infty} \mathbb{M}_{t,s} \left(p^i_{f,s} y^i_{f,s} - W_s l^i_{f,s} - P^i_s \varphi(i^i_{f,s}) k^i_{f,s} + \eta^i_s (k^i_{f,s}(1 + i^i_{f,s} - \delta(u^i_{f,s})) - k^i_{f,s+1}) \right). \tag{A.1.11}$$

Note that $p^i_{f,t} = (y^i_{f,t}/Y^i_t)^{-1/\sigma_i} P^i_t$ according to equation (16), and $y^i_{f,t}$ is given by equation (17).

The I-firm also takes the aggregate prices and quantities as given and makes optimal decisions on hiring, investment, and capital utilization intensity. The corresponding first order conditions are,

$$\text{FOC\_9\_li:} \quad 0 = \left(1 - \frac{1}{\sigma_i}\right) \frac{\alpha p^i_{f,t} y^i_{f,t}}{l^i_{f,t}} - W_t. \tag{A.1.12}$$

$$\text{FOC\_10\_ii:} \quad 0 = \eta^i_t - P^i_t \varphi^{'}(i^i_{f,t}). \tag{A.1.13}$$

$$\text{FOC\_11\_ui:} \quad 0 = \left(1 - \frac{1}{\sigma_i}\right) \frac{(1-\alpha) p^i_{f,t} y^i_{f,t}}{u^i_{f,t}} - \eta^i_t \delta^{'}(u^i_{f,t}) k^i_{f,t}. \tag{A.1.14}$$

$$\begin{aligned} \text{FOC\_12\_ki:} \quad 0 = {} & \mathbb{E}_t \mathbb{M}_{t,t+1} \Bigg\{ \left(1 - \frac{1}{\sigma_i}\right) \frac{(1-\alpha) p^i_{f,t+1} y^i_{f,t+1}}{k^i_{f,t+1}} - P^i_{t+1} \varphi(i^i_{f,t+1}) \\ & + \eta^i_{t+1}(1 + i^i_{f,t+1} - \delta(u^i_{f,t+1})) \Bigg\} - \eta^i_t. \end{aligned} \tag{A.1.15}$$

$$\text{FOC\_13\_}\eta i\text{:} \quad 0 = k^i_{f,t}(1 + i^i_{f,t} - \delta(u^i_{f,t})) - k^i_{f,t+1}. \tag{A.1.16}$$

There are three market clearing conditions. For the final consumption good, it is given by (A.1.4). The market clearing conditions for labor and the final capital good are:

$$\text{MCC\_14\_L:} \quad 0 = L_t - \sum_{f=1}^{N^c} l^c_{f,t} + \sum_{f=1}^{N^i} l^i_{f,t}. \tag{A.1.17}$$

$$\text{MCC\_15\_I:} \quad 0 = \sum_{f=1}^{N^c} \varphi(i^c_t) k^c_{f,t} + \sum_{f=1}^{N^c} \varphi(i^i_t) k^i_{f,t} - A_t((N^i)^{\frac{1}{\sigma_i - 1}} Z^i_t)(u^i_t K^i_t)^{1-\alpha}(L^i_t)^{\alpha}. \tag{A.1.18}$$

The above equations can be rewritten in terms of aggregate quantities by using the symmetry among firms in each sector (see equations (23) to (26)). In turn, we have total 17 equations (the above 15 plus the equation for SDF in (3) and the definition of recursive utility in (1)) to solve 17 endogenous variables (10 decision variables: $C, L, L^{c,i}, i^{c,i}, u^{c,i}, K^{c,i}$; 3 prices: $\mathbb{M}, W, P^i$ (note that we choose the final consumption good as the numeraire, so $P^c = 1$); 3 Lagrangian multipliers: $\lambda, \eta^{c,i}$; and the utility U.). All other quantities can be derived from these variables. For example, the market values for C- and I-firms are determined by (14) and (21), respectively.

A.2 Detrended problem

The original problem is non-stationary due to technology growth over time. To find the steady state of the economy, we first need to detrend the problem.

Assuming there is no growth in the total labor supply. From the market clearing condition for the final capital good in (A.1.18), the balanced growth rate of capital in the two sectors is the same, which is given by

$$g_{K^c} = g_{K^i} = (g_A g_{Z^i})^{\frac{1}{\alpha}}, \quad \text{where} \;\; g_A = e^{\mu^A}, \;\; g_{Z^i} = e^{\mu^{Z^i}}.$$

Similarly, the market clearing condition for the final consumption good in (A.1.4) gives the growth rate of consumption:

$$g_C = g_A g_{Z^c} (g_{K^c})^{1-\alpha}, \;\; \text{where} \;\; g_{Z^c} = e^{\mu^{Z^c}}.$$

Since consumption equals the sum of wage and dividends from the two firms, the growth rates of wage and investment cost have to be the same as that of consumption for the balanced growth to exist. In addition, the utility function is written as the certainty equivalent in consumption, so it has the same growth rate as consumption. Therefore, we have,

$$g_W = g_C; \qquad g_{P^i} = g_C / g_{K^c}, \qquad \text{and} \;\; g_U = g_C.$$

The original problem then can be written in terms of these detrended variables (e.g., the detrended consumption $\hat{C}_t = C_t / g_C^t$). The deterministic steady state of the detrended problem can be easily solved.

A.3 Rescaled problem

Even though the detrended problem in the previous section is mean stationary, it is not covariance stationary. This is due to the fact that the technological shocks are modeled as geometric random walks and therefore their effect is permanent. To solve the model, we need rescale our original problem such that the rescaled problem is stationary in both mean and covariance.

To achieve stationarity, we make the following choices of rescaling factors for different variables:

- $A_t((N^c)^{\frac{1}{\sigma_c - 1}} Z_t^c)(K_t^c)^{1-\alpha}$: divide C_t, U_t, W_t by this factor;

- $A_t((N^c)^{\frac{1}{\sigma_c-1}} Z_t^c)(K_t^c)^{-\alpha}$: divide P_t^i by this factor;
- K_t^c: divide K_t^i by this factor.

After rescaling, the original problem (in particular the equilibrium conditions as specified in Section A.1) can be rewritten in stationary variables which have finite mean and covariance. The equilibrium for the original problem is easy to recover from the rescaled equilibrium.

Table 1: Calibrated parameter values

This table reports the parameter values used in the numerical solution of the model. We consider different values of EIS (L for low, M for medium, and H for high) relative to the inverse of the coefficient of risk aversion. Note that the medium EIS equals the inverse of risk aversion, which corresponds to CRRA utility. This in turn requires different values for two parameters in order to preserve the deterministic steady state. For the fixed capital utilization case, the capital utilization is fixed at one for firms in both sectors. The market power of firms is measured by the CES σ_c and σ_i, with smaller value implying more market power. All other parameters are the same across different specifications of the model.

Group	Description	Symbol	Value
Preference	Time discount rate	β	0.995
	Relative risk aversion	γ	2
	EIS	$1/\rho$	0.2(L); 0.5(M); 1.2(H)
	Degree of labor disutility	θ	1.4
	Sensitivity of labor disutility	ψ	3.25(L); 3.52(M); 3.87(H)
Production	Labor share of output	α	0.64
	Degree of capital adjustment cost	ϕ	1.2
	Depreciation rate constant	δ_0	0.0125
	Depreciation rate slope	δ_1	0.099(L); 0.052(M); 0.035(H)
	Elasticity of marginal depreciation	ξ	0.5
	Constant elasticity of substitution for C-sector	σ_c	4 (monopolistic); 10^{12} (competitive)
	Constant elasticity of substitution for I-sector	σ_i	4 (monopolistic); 10^{12} (competitive)
Shocks	Growth rate of A-shock	μ^A	0.0025
	Standard deviation of A-shock	σ^A	0.01
	Growth rate of Z^c-shock	μ^{Z^c}	0.005
	Standard deviation of Z^c-shock	σ^{Z^c}	0.02
	Growth rate of Z^i-shock	μ^{Z^i}	0.01
	Standard deviation of Z^i-shock	σ^{Z^i}	0.05

Table 2: Macroeconomic quantities and asset prices: TFP shocks (A_t)

This table reports the responses of macro quantities and capital good price (relative deviations from the steady states, i.e., deviations divided by the steady state values) under positive one standard deviation shock to the TFP (i.e., a $\sigma^A = 1\%$ increase in $\ln(A)$). The asset pricing moments are calculated based on the responses of SDF and firms' market values under the same shock. For example, the price of risk γ^A for the A-shock is the negative of the relative deviation of SDF (see equation (32) when $\Delta\varepsilon^A = \sigma^A$). The betas are the relative deviations of market values divided by the standard deviation σ^A (similar to equation (34) when $\Delta\varepsilon^A = \sigma^A$). The risk premium is the product of price of risk, beta, and standard deviation of the shock (similar to equation (35)). The cases of perfect competition correspond to models under $\sigma_c = \sigma_i = \infty$ (use 10^{12} in numerical solutions), and the monopolistic competition cases correspond to models under $\sigma_c = \sigma_i = 4$. For variable capital utilization, $\xi = 0.5$. All the reported numbers except betas are in percentage.

Competition:		Perfect Competition						Monopolistic Competition					
EIS:		EIS=0.2		EIS=0.5		EIS=1.2		EIS=0.2		EIS=0.5		EIS=1.2	
Capital Utilization:		Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable
Panel A: Macroeconomic quantities and capital good price													
Consumption	C	0.993	1.219	0.960	1.196	0.890	1.098	0.998	1.259	0.978	1.246	0.938	1.191
Labor	L^c	-0.018	-0.105	-0.068	-0.129	-0.174	-0.224	-0.011	-0.067	-0.042	-0.084	-0.102	-0.139
	L^i	0.273	1.648	0.490	0.961	0.708	0.904	0.253	1.618	0.467	0.974	0.671	0.910
	L	0.016	0.097	0.057	0.110	0.131	0.170	0.012	0.075	0.044	0.090	0.100	0.138
Capital utilization	u^c	——	0.938	——	0.948	——	0.872	——	0.975	——	0.993	——	0.956
	u^i	——	2.026	——	1.846	——	1.833	——	2.002	——	1.839	——	1.823
Investment rate	i^c	1.182	1.804	0.114	0.720	-2.362	-0.800	1.337	2.480	0.593	1.432	-1.092	0.294
	i^i	6.149	21.533	7.978	13.089	9.737	11.132	6.167	22.911	8.333	14.084	10.400	12.296
Capital good price	P^i	0.397	0.340	0.426	0.382	0.461	0.384	0.391	0.342	0.414	0.374	0.435	0.374
Panel B: Asset pricing quantities													
Price of risk	γ^A	1.447	1.980	1.839	2.201	2.723	2.988	1.461	2.100	1.896	2.328	2.773	3.079
Beta	β_c^A	0.454	0.375	0.453	0.399	0.467	0.390	0.463	0.636	0.583	0.800	1.000	1.192
	β_i^A	0.408	0.259	0.410	0.336	0.438	0.357	0.488	1.408	0.692	1.187	1.064	1.310
	β_m^A	0.448	0.362	0.443	0.385	0.457	0.378	0.466	0.699	0.601	0.861	1.016	1.221
Risk premium	λ_c^A	0.007	0.007	0.008	0.009	0.013	0.012	0.007	0.013	0.011	0.019	0.028	0.037
	λ_i^A	0.006	0.005	0.008	0.007	0.012	0.011	0.007	0.030	0.013	0.028	0.030	0.040
	λ_m^A	0.006	0.007	0.008	0.008	0.012	0.011	0.007	0.015	0.011	0.020	0.028	0.038

Table 3: Macroeconomic quantities and asset prices: C-sector specific shock (Z_t^c)

This table reports the responses of macro quantities and capital good price (relative deviations from the steady states, i.e., deviations divided by the steady state values) under positive one standard deviation shock to the C-sector specific shocks (i.e., a $\sigma^{Z^c} = 2\%$ increase in $\ln(Z^c)$). The asset pricing moments are calculated based on the responses of SDF and firms' market values under the same shock. For example, the price of risk γ^{Z^c} for the Z^c-shock is the negative of the relative deviation of SDF (see equation (32) when $\Delta\varepsilon^{Z^c} = \sigma^{Z^c}$). The betas are the relative deviations of market values divided by the standard deviation σ^{Z^c} (similar to equation (34) when $\Delta\varepsilon^{Z^c} = \sigma^{Z^c}$). The risk premium is the product of price of risk, beta, and standard deviation of the shock (similar to equation (35)). The cases of perfect competition correspond to models under $\sigma_c = \sigma_i = \infty$ (use 10^{12} in numerical solutions), and the monopolistic competition cases correspond to models under $\sigma_c = \sigma_i = 4$. All the reported numbers except betas are in percentage.

Competition:		Perfect Competition						Monopolistic Competition					
EIS:		EIS=0.2		EIS=0.5		EIS=1.2		EIS=0.2		EIS=0.5		EIS=1.2	
Capital Utilization:		Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable
Panel A: Macroeconomic quantities and capital good price													
Consumption	C	2.024	2.093	2.023	2.066	2.007	2.030	2.023	2.091	2.022	2.067	2.013	2.045
Labor	L^c	0.006	0.006	0.005	0.015	-0.015	0.000	0.004	0.000	0.003	0.006	-0.010	-0.004
	L^i	-0.086	-0.068	-0.027	-0.089	0.073	0.025	-0.084	0.019	-0.022	-0.049	0.075	0.048
	L	-0.005	-0.002	-0.003	-0.008	0.015	0.009	-0.004	0.002	-0.002	-0.003	0.012	0.010
Capital utilization	u^c	——	0.346	——	0.286	——	0.239	——	0.343	——	0.295	——	0.264
	u^i	——	0.299	——	0.424	——	0.486	——	0.343	——	0.434	——	0.488
Investment rate	i^c	0.663	1.935	0.612	1.141	0.140	0.552	0.648	1.974	0.639	1.234	0.308	0.738
	i^i	-0.463	-3.338	0.242	1.451	0.801	2.225	-0.563	-3.050	0.214	1.604	0.963	2.515
Capital good price	P^i	2.282	2.095	2.236	2.243	2.197	2.251	2.288	2.120	2.244	2.244	2.209	2.253
Panel B: Asset pricing quantities													
Price of risk	γ^{Z^c}	3.910	3.885	3.911	3.949	4.306	4.454	3.908	3.886	3.910	3.941	4.311	4.460
Beta	$\beta_c^{Z^c}$	1.130	1.052	1.114	1.123	1.099	1.128	1.104	0.997	1.054	1.039	1.018	1.042
	$\beta_i^{Z^c}$	1.070	0.888	1.052	1.046	1.034	1.078	1.007	0.742	0.986	0.940	1.003	1.025
	$\beta_m^{Z^c}$	1.123	1.034	1.100	1.107	1.077	1.111	1.095	0.976	1.042	1.024	1.014	1.038
Risk premium	$\lambda_c^{Z^c}$	0.088	0.082	0.087	0.089	0.095	0.101	0.086	0.077	0.082	0.082	0.088	0.093
	$\lambda_i^{Z^c}$	0.084	0.069	0.082	0.083	0.089	0.096	0.079	0.058	0.077	0.074	0.087	0.091
	$\lambda_m^{Z^c}$	0.088	0.080	0.086	0.087	0.093	0.099	0.086	0.076	0.082	0.081	0.087	0.093

Table 4: Macroeconomic quantities and asset prices: I-sector specific shock (Z_t^i)

This table reports the responses of macro quantities and capital good price (relative deviations from the steady states, i.e., deviations divided by the steady state values) under positive one standard deviation shock to the I-sector specific shocks (i.e., a $\sigma^{Z^i} = 5\%$ increase in $\ln(Z^i)$). The asset pricing moments are calculated based on the responses of SDF and firms' market values under the same shock. For example, the price of risk γ^{Z^i} for the Z^i-shock is the negative of the relative deviation of SDF (see equation (31) when $\Delta\varepsilon^{Z^i} = \sigma^{Z^i}$). The betas are the relative deviations of market values divided by the standard deviation σ^{Z^i} (see equation (34) when $\Delta\varepsilon^{Z^i} = \sigma^{Z^i}$). The risk premium is the product of price of risk, beta, and standard deviation of the shock (see equation (35)). The cases of perfect competition correspond to models under $\sigma_c = \sigma_i = \infty$ (use 10^{12} in numerical solutions), and the monopolistic competition cases correspond to models under $\sigma_c = \sigma_i = 4$. All the reported numbers except betas are in percentage.

Competition:		Perfect Competition						Monopolistic Competition					
EIS:		EIS=0.2		EIS=0.5		EIS=1.2		EIS=0.2		EIS=0.5		EIS=1.2	
Capital Utilization:		Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable
		Panel A: Macroeconomic quantities and capital good price											
Consumption	C	-0.073	0.786	-0.229	0.775	-0.523	0.426	-0.045	0.996	-0.140	1.016	-0.302	0.832
Labor	L^c	-0.113	-0.548	-0.357	-0.701	-0.811	-1.116	-0.071	-0.336	-0.219	-0.443	-0.470	-0.679
	L^i	1.690	8.469	2.547	5.131	3.257	4.415	1.579	7.986	2.414	5.041	3.061	4.354
	L	0.101	0.492	0.293	0.580	0.595	0.816	0.076	0.366	0.225	0.458	0.452	0.652
Capital utilization	u^c	——	3.378	——	3.657	——	3.453	——	3.576	——	3.852	——	3.782
	u^i	——	9.048	——	7.652	——	7.343	——	8.759	——	7.577	——	7.286
Investment rate	i^c	3.401	1.680	-1.760	-0.727	-12.365	-6.110	4.232	4.896	0.529	2.480	-6.657	-1.332
	i^i	32.614	121.625	39.180	60.343	45.937	47.488	33.078	127.476	41.067	64.762	48.642	52.224
Capital good price	P^i	-3.979	-3.570	-3.667	-3.904	-3.347	-3.928	-4.028	-3.650	-3.755	-3.947	-3.519	-3.980
		Panel B: Asset pricing quantities											
Price of risk	γ^{Z^i}	-2.735	0.123	-0.702	1.004	2.765	3.706	-2.648	0.724	-0.408	1.675	3.002	4.144
Beta	$\beta_c^{Z^i}$	-0.723	-0.687	-0.701	-0.767	-0.665	-0.784	-0.674	-0.346	-0.482	-0.245	-0.016	0.139
	$\beta_i^{Z^i}$	-0.677	-0.546	-0.647	-0.710	-0.593	-0.738	-0.506	0.799	-0.274	0.286	0.069	0.279
	$\beta_m^{Z^i}$	-0.717	-0.671	-0.689	-0.755	-0.640	-0.768	-0.659	-0.252	-0.448	-0.162	0.005	0.173
Risk premium	$\lambda_c^{Z^i}$	0.099	-0.004	0.025	-0.039	-0.092	-0.145	0.089	-0.013	0.010	-0.021	-0.002	0.029
	$\lambda_i^{Z^i}$	0.093	-0.003	0.023	-0.036	-0.082	-0.137	0.067	0.029	0.006	0.024	0.010	0.058
	$\lambda_m^{Z^i}$	0.098	-0.004	0.024	-0.038	-0.088	-0.142	0.087	-0.009	0.009	-0.014	0.001	0.036

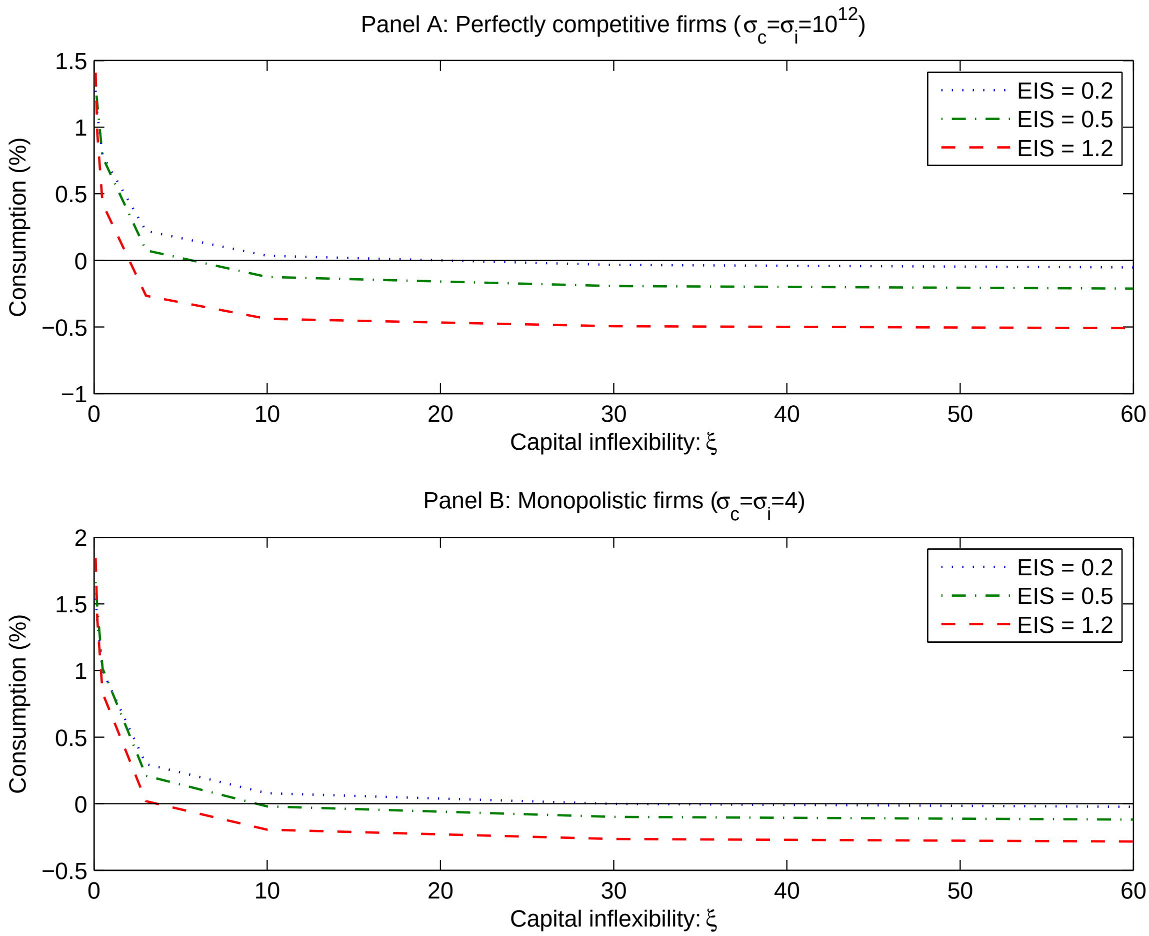

Figure 1: Capital flexibility and consumption responses to IST shocks
The figure plots the consumption responses to one standard deviation shock to the investment-specific technology under different degree of capital inflexibility (ξ). Higher value of ξ implies less flexibility to adjust the firm's capital utilization intensity. The values are obtained using the same method as in Table 4.

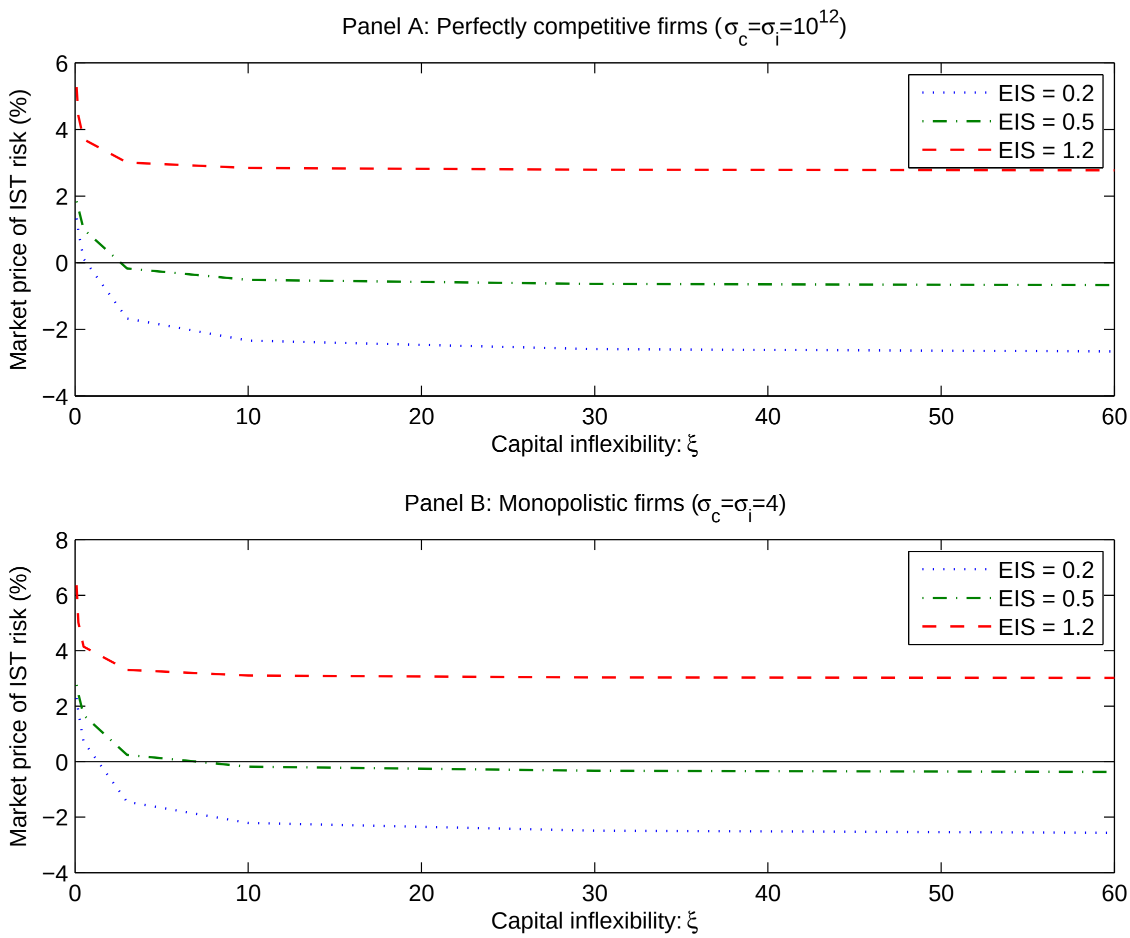

Figure 2: Capital flexibility and market price of risk for IST shocks
The figure plots the market price of risk (γ^{Z^i}) for IST shocks under different degree of capital inflexibility (ξ). Higher value of ξ implies less flexibility to adjust the firm's capital utilization intensity. The values are obtained using the same method as in Table 4.

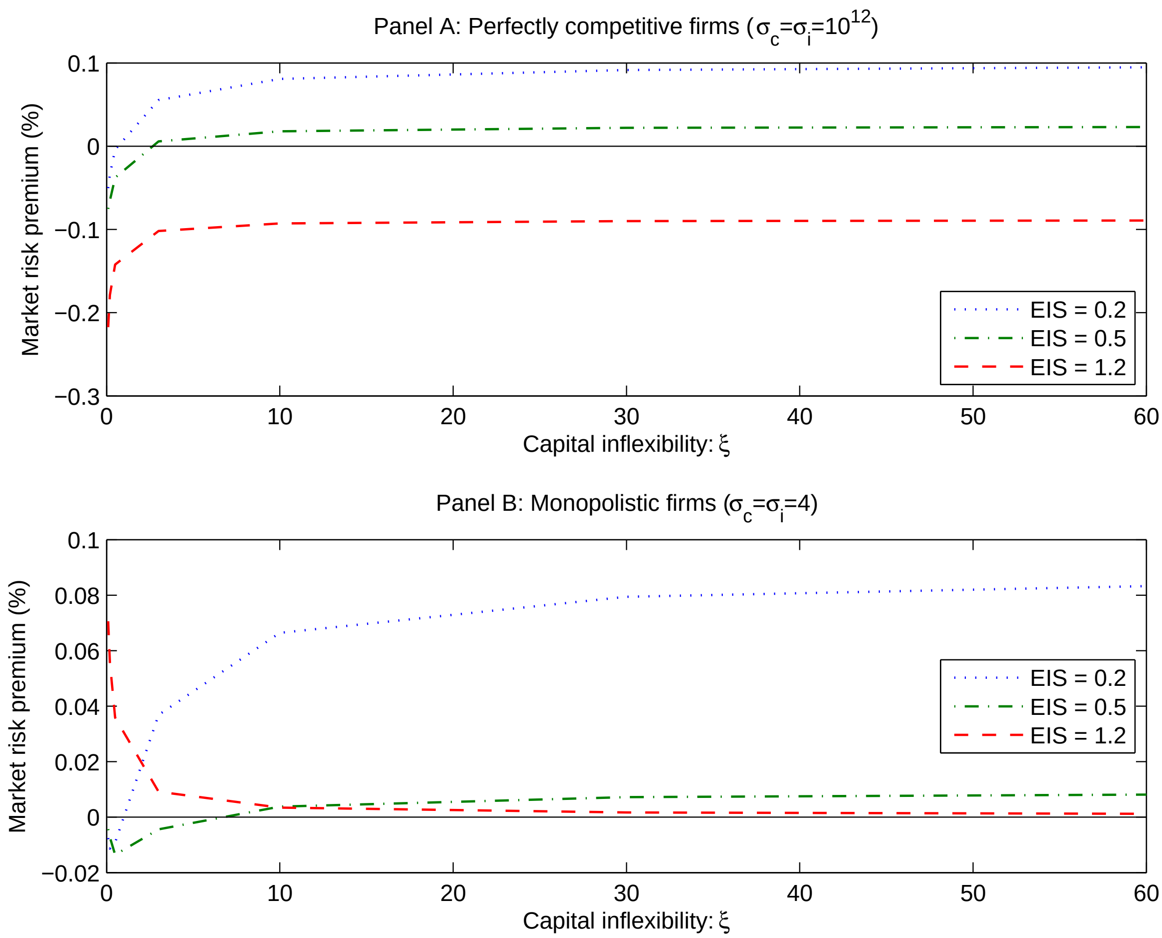

Figure 3: Capital flexibility and market risk premium of IST shocks
The figure plots the market risk premium ($\lambda_m^{Z^i}$) of IST shocks under different degree of capital inflexibility (ξ). Higher value of ξ implies less flexibility to adjust the firm's capital utilization intensity. The values are obtained using the same method as in Table 4.

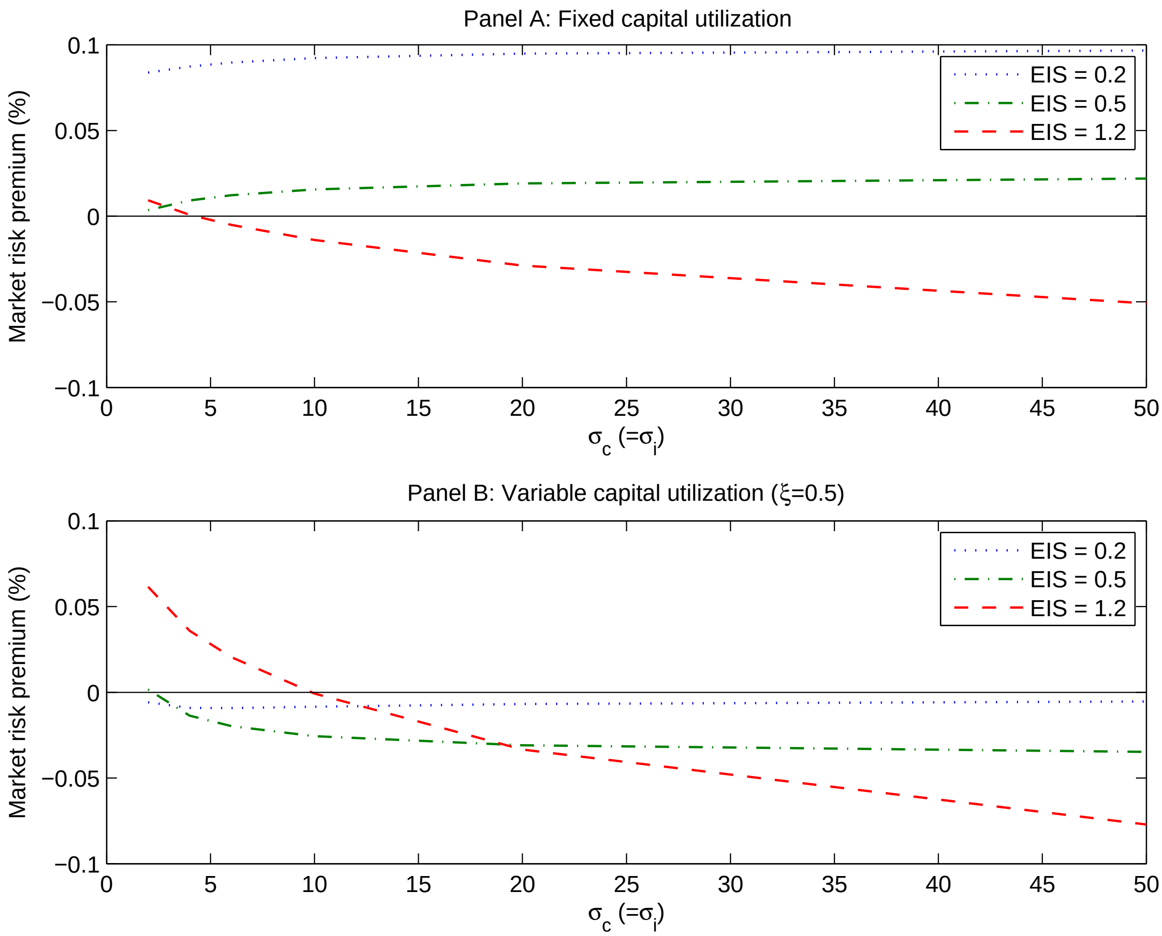

Figure 4: Market power and market risk premium of IST shocks
The figure plots the market risk premium ($\lambda_m^{Z^i}$) of IST shocks under different degree of monopolistic power (σ_c and σ_i). Lower value of $\sigma_c(\sigma_i)$ implies stronger monopolistic power in the product market. The values are obtained using the same method as in Table 4.

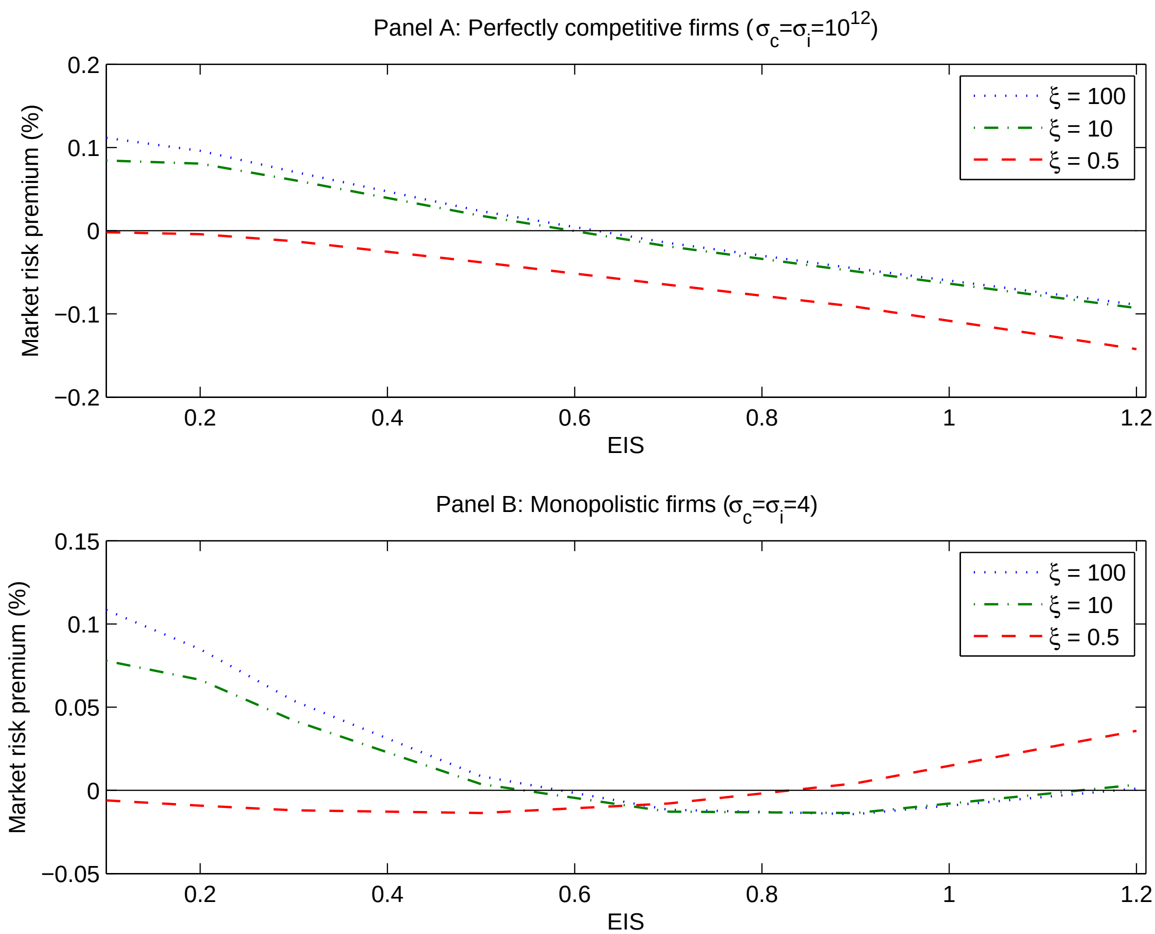

Figure 5: EIS and market risk premium of IST shocks
The figure plots the market risk premium ($\lambda_m^{Z^i}$) of IST shocks under different values of elasticity of intertemporal substitution. The values are obtained using the same method as in Table 4.

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