Information Technologies and Safe Assets*

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Abstract

We show that, although safe assets – in the form of diversified pools of risky assets – are by construction insensitive to information, their quantity is not. Information technologies discourage the sale of the assets underlying the pool by making agents more able to face their own risk and, ex-ante, more exposed to sale price uncertainty. In general equilibrium, sellers do not internalize their social benefit on the supply of safe assets, resulting in an inefficient shortage. Information technologies exacerbate the shortage, but improve welfare unless agents heavily rely on risk-selling and data leak to markets.

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1 Introduction

Safe assets are assets that maintain a stable value over time. Some are fundamentally safe, such as gold or some government debt. Others are market-made, combining risky assets in a “risk-free” pool that is insensitive to information about value shifts in the underlying assets. Examples include individuals trading to hold a diversified portfolio and financial intermediaries pooling assets to issue *asset-backed securities*. Recently, there has been an unprecedented increase in the demand of safe assets driven by fast growing economies, rapidly profiting corporations, and individuals with longer post-retirement lifespans.[1] This demand has not been met with a corresponding increase in supply, giving rise to what is commonly referred to as “safe asset shortage,” a contributing factor to the global decline in interest rates. While much literature focuses on the inability of developed countries to supply safe assets in the form of government debt, what limits financial markets to bridge the gap by supplying more in the form of diversified pools? And, given these limits, is the supply of private safe assets inefficient?

In this paper, we highlight an overlooked source of private safe asset shortages: the recent unprecedented boom in information technologies (IT). We emphasize that the risky assets underlying a diversified pool, which constitute the backbone of private safe assets, do not simply appear out of thin air. For instance, the mortgages behind mortgage-backed securities or the stocks behind indices like the S&P500 or Dow Jones must first be sold by their originators or their owners. We show that, as these agents do not internalize the pivotal role of their sales on the generation of private safe assets, they fail to coordinate on larger sales, which lead to an inefficient shortage of safe assets. In this context, we find that information technologies further discourage sales and reduces the equilibrium quantity of safe assets. However, IT adoption improves welfare unless agents heavily rely on selling assets to mitigate risk,

[1] Caballero, Farhi, and Gourinchas (2017) highlight the “global savings glut” (initially coined by a Ben Bernanke’s speech in 2005) driven by the unprecedented growth rate of underdeveloped economies like China. Loeys and Mackie (2005) among others have highlighted the ”corporate savings glut” driven by the corporate sector turning from net borrower to net lender in developed economies. Ordoñez and Piguillem (2023) highlight a ”retirement saving glut” driven by the unprecedented worldwide increase in life expectancy conditional on retirement.

and data privacy is weak in that information leaks to markets.

We build on this idea that, despite the pool being designed to be information insensitive, agents' incentives to sell the underlying assets are not. As argued by Veldkamp and Chung (2019), among others, the advent of hardware and software innovations has revolutionized the economic and financial landscapes by sharpening forecasts. On the one hand, information technologies improve the ability of corporations and individuals to react to changes in asset values. On the other hand, they enable financial markets to refine pricing, causing asset prices to align more closely with asset fundamentals. Although these two effects are usually perceived as beneficial for allocation purposes in partial equilibrium, they erode the incentives of originators to offload their risky assets. When discussing securitization, Federal Reserve Chairman Ben Bernanke emphasized that originators sell the mortgages about which they possess limited knowledge – whether that ignorance is by design or happenstance – while retaining the remainder.[2] Similarly, SEC Chairman Jay Clayton suggested that the disclosure requirements for public companies might deter firms from going public, partly accounting for the recent large decline in IPOs both in the U.S. and abroad.[3]

We study the interaction of these forces by developing a tractable general equilibrium setting that combines standard elements from macroeconomics (such as CRRA preferences and Cobb-Douglas production function) and finance (CARA-Normal specification for portfolio choices). This allows us to capture the impacts of information technologies on both trading and production. Our model can be interpreted in terms of standard economic models, and is amenable to welfare analysis. Indeed, one of our contributions is the characterization of such integrated setting.

The model is populated by risk-averse agents who hold assets laden with idiosyn-

[2]Federal Reserve Chairman Ben Bernanke said: "originators who sell loans may have less incentive to undertake careful underwriting than if they kept the loans." U.S. House of Representatives' Committee on Financial Services, Sept. 20, 2007. Excerpt from `https://www.federalreserve.gov/newsevents/testimony/bernanke20070920a.htm`.

[3]Securities and Exchange Commission (SEC) Chairman Jay Clayton, Economic Club of New York, July 12, 2017. Excerpt from `https://www.sec.gov/news/speech/remarks-economic-club-new-york`. Additional evidence of the link between information disclosure and IPO decisions is provided by Casella, Lee, and Villalvazo (2023).

cratic risk. These agents can *manage the risk* by adjusting their labor. They can also *trade the risk*, acting both in the roles of buyers and sellers of assets. As sellers, they try to balance offloading and managing idiosyncratic risk. Offloading assets carries trading costs, while adjusting labor is costly in terms of labor disutility. As buyers, agents aim to craft a diversified portfolio by acquiring a pool of risky assets supplied by other agents in competitive financial markets. Such diversified portfolios are the only *safe assets* in the economy, as they are the only source of uncontingent consumption for agents. We are able to decouple the roles of an agent as both a seller of risky assets and a buyer of safe assets so to cleanly characterize welfare.

So far we have described information technologies as exogenous. In the model, however, we allow agents to decide the degree of data-intensity of their technologies. By using more data-intensive information technologies, agents know that they generate more information about their idiosyncratic risk, some of which inevitably leaks publicly. Thus, agents understand that, while better information enhances risk management, its leakage also introduces price volatility and impairs risk selling.

We show that the choices of adopting more data-intensive technologies and keeping risk are mutually reinforcing. When agents opt to sell less, they seek more information to better manage their own risks. But depending on the degree of leaking, selling becomes even less appealing due to increased sale price volatility. As a result, the endogenous adoption of IT magnifies safe asset shortages.

To make the point as clear and stark as possible, we show that, even if information technologies are freely available and can perfectly predict idiosyncratic shocks, agents might still find it optimal not to adopt them, or when they adopt they do it *excessively.* No adoption occurs when agents place a high value on offloading idiosyncratic risk rather than managing it and prefer to shield their assets from the price volatility that more information availability might bring. Excessive adoption occurs when agents rely relatively more on risk-selling and data leak to markets. The reason is that a planner would be more inclined than individuals to sell assets, hence finding information less valuable for self-management purposes and its leaks more harmful to safe asset creation.

We align with the seminal work of Hirshleifer (1971) on the premise that information induces price volatility. However, the nature of the externality that leads to inefficient information acquisition diverges significantly. Hirshleifer (1971) highlights an *informational externality*: when agents acquire information about their own asset, they fail to internalize that this choice also conveys information about other agents' assets, and subsequently, their price volatility. We deliberately shut down this externality. We assume instead that shocks are purely idiosyncratic, agents cannot acquire information about others, and individual information is not informative about other agents' assets. Hence, agents in our setting fully internalize how their information acquisition choices amplify the price volatility of their own asset. We have instead a *trading externality*: when an agent acquires information about their asset they opt to sell a smaller portion of it, overlooking the ensuing scarcity of safe assets that could become accessible to others.

To elucidate this distinction further, let's consider a scenario where originators only acquire *fully private* information. In such a case, the price volatility of all assets remains unaffected, regardless of the presence or absence of information; essentially a leakage-free environment. In this context, not only the informational externality stressed by Hirshleifer is muted, but the effect of information on the price volatility of the own asset is also neutralized. Yet, our proposed trading externality persists. Given that agents can exploit their private information to better face idiosyncratic shocks, they become less inclined to sell their risk-laden assets. Consequently, the scarcity of safe assets amplifies with the adoption of information technologies. Importantly, however, in this leakage-free case, the supply of safe assets is inefficient but the adoption of information technologies is not: without leakages, both individuals and the planner find more information beneficial and both agree on full adoption. This may not be the case in the more general case of leakage.

Despite the presence of a single externality in our framework, both the supply of safe assets and the adoption of information may be inefficient. The wedge between individual and social valuations of asset sales is inherent to the externality, but the wedge between individual and social valuations of information is indirect and stems from the scarcity of safe assets. This means that rectifying the inefficient scarcity of safe assets also curbs the over-adoption of information technologies. Solutions can be public, such as governmental subsidies on bank asset sales, like mortgages or loans, or private, such as competing ABS issuers paying a premium to originators to sell their assets. Unfortunately, recent regulations restricting GSEs, and securitization more generally, appear to go in an opposite direction. Our findings also underscore the relevance of recent initiatives to strengthen data privacy laws. Such laws could deter information leakage and contribute to a more efficient provision of safe assets.

Related Literature. We contribute to the literature on safe asset shortages by introducing safe asset creation on a general equilibrium model with a (ex-ante) representative-agent. This model captures an overlooked externality: individuals fail to consider the societal benefits of selling their risky assets, which are used as inputs for the creation of safe assets, be it through diversified portfolios or securities. To our knowledge, this is the first exploration into the implications of this particular externality. We additionally examine the interplay between this externality and the rapid advancements in information technologies and risk management practices, all in the context of competitive yet incomplete markets.

The role of information on the supply of safe assets has been studied in the literature that defines safety as information insensitivity, as outlined in Gorton and Ordoñez (2023). This insight was first introduced by Gorton and Pennacchi (1990). They argued that generating safe assets involves combining assets of uncertain quality, which are intensive in information production (therefore risky), into a diversified pool of certain quality and insensitive to information (thus deemed safe). Here, we go a step further and show that even when the pool is fully diversified, rendering information about its content irrelevant, information still poses challenges by reducing the equilibrium supply of information-sensitive assets available for pooling.

Related papers, such as Dang et al. (2017) and Gorton and Ordoñez (2022), have noticed that when full diversification in unattainable, obfuscating information allows to trade the pool at an expected value, turning it a safe asset by exploiting "informational pooling."[4] Vanasco (2017) illustrates how information acquisition during asset

[4]Recent work has studied the sustainability of informational pooling in relation to stock markets, (see Chousakos, Gorton, and Ordoñez (2022)) and government interventions (see Nosal and Ordoñez (2016) and Gorton and Ordoñez (2020)).

origination could potentially lead to a trading freeze due to exacerbated information asymmetry.[5] In our setting we emphasize another general equilibrium negative effect of information: agents can always construct a fully diversified portfolio of assured quality. Yet, even though information does not influence the "quality" of the safe asset, it affects its "quantity" in equilibrium.

Although prior studies such as Gaballo (2016) and Farboodi and Veldkamp (2020) explore the relationship between information and price uncertainty, their focus is on the buyer's portfolio choice. In contrast, our work shifts focus to sellers who aim to offload their risk exposure in a market where buyers can, instead, perfectly diversify their portfolios. This shift helps us to stress two insights. First, asymmetric hedging possibilities break the traditional zero-sum general equilibrium. Second, agents have to individually weigh the "positive face" of information derived from production efficiency against the "negative face" in the form of price uncertainty.

As in Hellwig and Veldkamp (2009), Colombo, Femminis, and Pavan (2014) and Llosa and Venkateswaran (2022) agents may inefficiently acquire information as externalities in payoffs make them underestimate or overestimate the value of information. The difference is that the externality we highlight relates to the degree of risk exposure chosen by individuals, rather than to the use of information. Indeed in our model, adoption of information technologies may be inefficient, but never the use of information upon adoption.

Our research complements and distinguishes itself from the work of Edmans, Goldstein, and Jiang (2015) and Dow, Goldstein, and Guembel (2017). They focus on how firms learn from market price information that is useful for investment. In contrast, we focus on how information generated by firms gets reflected in market prices, and while information improves risk management, it undermines risk selling. Our treatment of information also differs from that of Gottardi and Rahi (2014). They show that the Hirshleifer effect is confronted with a Blackwell effect: information introduces incompleteness but helps portfolio optimization. In our model, market incompleteness is exogenous, and the Blackwell effect is absent because buy-

[5] Emphasizing moral hazard instead, Caramp (2017) shows the opposite direction in which asset liquidity affects the incentives to originate high-quality assets.

ers can perfectly diversify their portfolio independently of information availability. In our work, the positive side of information comes instead from managing risk better.

While macroeconomics often celebrates the positive impact of information on production efficiency, some literature points to a potential negative effect stemming from strategic interactions and incomplete or costly information acquisition. Angeletos, Iovino, and La'O (2016), for instance, show that information about non-distortionary forces, like technological shocks, is never welfare-detrimental, whereas information on distortionary forces, like markup shocks, can be socially inferior.[6] Our analysis offers a new perspective, arguing that even complete, costless, and public information about non-distortionary forces, i.e. productivity, can be inefficient in economies with consumption risk and incomplete markets.

Our work emphasizes the relevance of the contracting environment on assessing the social value of information technologies. Golosov and Iovino (2021) make a related point. They show that complete disclosure of private information about job opportunities is desirable only when governments can commit to social insurance, and without public commitment, it is generally suboptimal. In our setting, information about idiosyncratic shocks is always socially desirable when private markets are complete (contingent contracts exist) or when it is truly private (no leakages). However, this may not be the case in the empirically relevant scenario where contracts are noncontingent, markets are competitive and informationally efficient, and data leak to markets.

The next section presents the model. Section 3 characterizes the market equilibrium. Section 4 computes the social planner's solution: both constrained by market compensations, as well as unconstrained to redistribute at will, and compare them with the market equilibrium. Section 5 concludes.

[6] These insights come from seminar work by Morris and Shin (2002) and Angeletos and Pavan (2007), and expanded to fully micro-founded macro models without consumption risk (Hellwig (2005), Walsh (2007), Baeriswyl and Cornand (2010), Lorenzoni (2010). Other papers have found that dispersed information may have perverse welfare effects because of complementarities in learning from prices (Amador and Weill (2010), Gaballo (2018)) or costly information acquisition (Colombo, Femminis, and Pavan (2014), Llosa and Venkateswaran (2022)).

2 Model

In this section, we present a general equilibrium model of production with idiosyncratic risks. Markets are incomplete in that contingent contracts are not enforceable, preventing agents from sharing these production risks directly, hence exposing them to consumption risks. Agents can manage their risks through two channels. On the one hand, they can *trade* risk by selling their own risky assets and acquiring *safe assets* – i.e. perfectly diversified portfolio of other agents' risky assets – in perfectly competitive centralized markets (we call it *market-management of risk*). On the other hand, they can *reduce* the implications of risk by individually adjusting production to anticipated shocks (we call it *self-management of risk*). We will use the model to examine how the choice to adopt information technologies impact this risk management trade-off, and ultimately the provision of safe assets and welfare.

Preferences. There is a single period with a continuum of agents of mass one indexed by $i \in (0,1)$. Agent i has a standard constant relative risk aversion (CRRA) utility function

$$\mathbb{U}(C_i, L_i) \equiv \frac{C_i^{1-\sigma}}{1-\sigma} - \frac{1}{\gamma} L_i^{\gamma}, \tag{1}$$

where C_i and L_i are consumption and labor specific to agent i, $\sigma > 0$ is a constant relative risk-aversion parameter and $\gamma > 1$ controls the convexity of labor disutility.

Production of consumption goods. Each agent produces a quantity Y_i of consumption goods combining labor L_i and capital $\hat{K}_i$ according to a Cobb-Douglas production function:

$$Y_i = L_i^{\alpha} \hat{K}_i^{1-\alpha}, \tag{2}$$

where $\alpha \in (0,1)$ is the labor share in production. In what follows we describe the production of capital that determines $\hat{K}_i$.

Production of capital. The capital $\hat{K}_i$ available to agent i is given by

$$\hat{K}_i = e^{k_i} \tag{3}$$

where k_i denotes a quantity of homogeneous *intermediate capital* that is obtained by transforming *raw capital*, as we will describe next. The assumption of an exponential transformation of intermediate capital into final capital will make agents to display constant absolute risk aversion (CARA) with respect to intermediate capital in spite of constant relative risk aversion (CRRA) with respect to consumption goods. As it will become clear, this feature is extremely convenient for analytical tractability and still conservative in that it favors the individual and social desirability of information technologies (this discussion is contained in Section 4.3).[7]

Each agent is endowed with one unit of *raw capital*. The idiosyncratic productivity of the unit held by agent i is $\overline{\theta}+\theta_i \sim N\left(\overline{\theta},1\right)$, which is independently distributed across agents, with $\overline{\theta}$ assumed large enough to guarantee productivity is positive almost surely[8]. Here productivity is related to the *quality* of the agent's raw capital, not its quantity, which is normalized to one. This is the only source of risk and heterogeneity in the economy. Agent i can transform her own or others' raw capital into a quantity of intermediate capital, k, according to a linear technology:

$$k(\beta_i(j)) = (\overline{\theta}+\theta_j)\beta_i(j) - \frac{\varphi_{ij}}{2}\beta_i^2(j), \tag{4}$$

where $\beta_i(j) \in [0,1]$ is the mass of raw capital from agent $j \in (0,1)$ used by agent i. We define φ_{ij} to be the adjustment cost (an "iceberg cost") in terms of intermediate capital production that agent i incurs for using raw capital from agent j. We assume adjustment costs are symmetric and only apply when using others' raw capital,

$$\varphi_{ij} = \begin{cases} \varphi > 0 & \text{if } j \neq i, \\ 0 & \text{if } j = i. \end{cases}$$

[7]The exponential technological transformation can also be interpreted simply as a change in variables, such that decisions are made in terms of $k_i \equiv \log \hat{K}_i$.

[8]More precisely, such that $\Pr\left(\bar{\theta}+\theta_i < 0\right) \approx 0$.

Every agent i chooses the fraction $\beta_i(i)$ of her own raw capital (β_i henceforth) to use in the production of intermediate capital, sells the rest to other agents and chooses how much raw capital to buy from other agents, this is $\beta_i(j)$ from all $j \neq i$.

Competitive market for capital. Agents can exchange raw capital using non-contingent claims on intermediate capital in a centralized Walrasian market according the following protocol: each agent $j \in J(i) \equiv (0,1)/\{i\}$ can sign a contract with agent i to buy raw capital at a unit price R_i, where the price R_i represents an enforceable claim on agent j's future production of intermediate capital.

An interpretation of this contract is that agent j produces with raw capital from agent i at an adjustment cost φ in exchange of a repayment promise backed by agent j's subsequent production of intermediate capital. Here, R_i is the price of raw capital – an asset price. An alternative is that agent j produces with own raw capital and trade claims on the production of intermediate capital at a *trading cost* of φ. In this case R_i would be the price of an intermediate capital firm's share – a stock price.

We will assume throughout that intermediate capital is the only pledgeable asset in the economy, and then these transactions cannot be written in terms of consumption goods. The implication of this assumption is that each agent consumes what she produces, $C_i = Y_i$. This is useful to introduce consumption risk in a tractable way, but it is not critical for the results as it does not entail, *per se*, any departure from complete markets. Indeed, we show later that a social planner could implement the unconstrained first-best allocation with contingent transfers on intermediate capital alone, and agents still consuming their own production.

Information technologies. Each agent decides the technology that determines how much data will be available about the productivity of her unit of endowed raw capital. Formally, the process for productivity follows:

$$\theta_i = \sqrt{f(a_i)}\,\hat{\theta}_{\mathtt{c},i} + \sqrt{a_i - f(a_i)}\,\hat{\theta}_{\mathtt{p},i} + \sqrt{1-a_i}\,\hat{\theta}_{\mathtt{u},i} \tag{5}$$

where $\hat{\theta}_{\texttt{c},i}$ is the stochastic component of the productivity for agent i that is commonly known by all agents, $\hat{\theta}_{\texttt{p},i}$ is the productivity component that is privately known by agent i, and $\hat{\theta}_{\texttt{u},i}$ is the component that is unknown to everybody. We assume $\hat{\theta}_{\cdot,i} \sim N(0,1)$ are i.i.d. between them and across agents.

Agent i, at no cost, chooses $a_i \in (0,1)$, which is a direct measure of the fraction of unconditional volatility of θ_i that she will be able to anticipate (accounting for $\hat{\theta}_{\texttt{p},i}$). The choice of a_i also determines an exogenous information leakage function, $f(a_i)$, which captures the fraction of unconditional volatility of θ_i that other agents (other than i) will be also able to anticipate (accounting for $\hat{\theta}_{\texttt{c},i}$). We assume the following intuitive properties of leakages: $f(a_i) \leq a_i$, $f(0) = 0$ and $f'(a_i) > 0$.

This specification spans the whole space between two extreme benchmarks. In the *full-information benchmark* all information about raw capital productivity is infinitely precise and public, this is *available to all* agents in the economy (i.e., $a_i = f(a_i) = 1$ for all i). In the *no-information* benchmark no one has such information, nor the owner or other agents, until consumption occurs (i.e., $a_i = 0$ for all i).

Four implications of this formalization are worth highlighting. First, regardless of the technological choice a_i, productivity θ_i is distributed according to $N(\bar{\theta}, 1)$. This assumption, which can be easily relaxed, allows us to focus on the informational content of technological choices, without affecting the fundamental stochastic properties of productivity. Second, the adoption of any information technology is *costless* in terms of firm's resources. This assumption, which could also be easily relaxed, helps to emphasize the costs of information technologies that are borne out by the use of information itself. Third, in contrast to Edmans, Goldstein, and Jiang (2015) and Dow, Goldstein, and Guembel (2017), agents can generate information about their own endowment, whereas markets cannot. We could also relax this dimension by introducing an additional source of randomness learnable by markets but not by owners. Since competitive markets would aggregate such information in prices, our analysis can then be interpreted as a normalization in which all information conveyed by markets already belong to the public information set. Finally, and perhaps most significantly, allowing agents to have complete control over information regarding their own raw capital underscores our abstraction from any informational externality, such as that highlighted by (Hirshleifer 1971).

Our formalization of information technologies departs from the standard approach of investing in the precision of signals. Our choice has the tractable advantage of bypassing signals and avoiding asymmetric and dispersed information issues, while still capturing the main property that information reduces the conditional variance of productivity, which is our key statistics about the gains from information. It is possible, however, to write a representation with signals that delivers an isomorphic reduction in conditional variances, hence without changing our insights.

Our assumption of exogenous leakages as a function of data intensity is also a useful modelling choice. It provides a flexible way to capture the role of data privacy on production and trading, without the needs to delve into its sources. Leakages can be technological, as some data is inherently more susceptible to hacking, reproduction, or transmission. Regulations and disclosure mandates, like those imposed on public firms and banks, can also cause leakages. However, and perhaps more fitting, information belonging to an agent can be disclosed to others through market inferences drawn from the agent's actions, such as production or trading choices. The more "informationally efficient" a market is, and the more others can deduce from an agent's actions, the closer the scenario aligns with the case $f(a) = a$.

Market incompleteness. Our economy features incomplete markets due to restrictions on agents' ability to write contingent contracts, i.e. enforceable agreements to transfer resources based on the occurrence of verifiable uncertain events. First, we assume enforceability only applies to contracts that are written after agents are endowed with raw capital. This means that contracts cannot be written based on assets for which the agents do not yet hold property rights. Second, we assume that verifiability is only possible with public information, which means that contracts cannot condition on realizations of $\hat{\theta}_{\mathtt{p},i}$ or $\hat{\theta}_{\mathtt{u},i}$ for which there is no common knowledge. Our specification of market incompleteness allows a tractable model in which consumption risk cannot be insured away with contingent contracts, but can be managed with labor choices and trading choices.

Timing and Equilibrium. The timing is a sequence of two stages:

1. in the ex-ante stage: agents choose information technology $\{a_i\}_{i\in(0,1)}$ and the fraction of own raw capital to sell $\{1-\beta_i\}_{i\in(0,1)}$;
2. in the ex-post stage: productivity shocks realize $\Theta \equiv \{\hat{\theta}_{\mathtt{c},i}, \hat{\theta}_{\mathtt{p},i}, \hat{\theta}_{\mathtt{u},i}\}_{i\in(0,1)}$, agents set their demand for raw capital $\{\{\beta_i(j)\}_{(j\neq i)}\}_{i\in(0,1)}$ and choose labor supply $\{L_i\}_{i\in(0,1)}$;

After these two stages, raw capital is exchanged, production of intermediate capital takes place, intermediate capital payments are made, production of the consumption good takes places, and agents consume their output. This timing allows to also capture cases implied by different timing assumptions. If the demand of raw capital happened ex-ante, for instance, agents would necessarily be uninformed, entailing the case $f(a_i) = 0$ for all i. On the contrary, if the supply of raw capital happened ex-post, trading volumes would covey information about productivity realizations, entailing the case of full leakage $f(a_i) = a_i$ for all i. These different timing assumptions can then be interpreted as special cases of our analysis.

Given this sequence of events, a market equilibrium is defined as follows:

Definition 1 (Market Equilibrium)**.** *For given productivity realizations Θ, a market equilibrium is the cross-sectional allocation $\{\hat{K}_i(\Theta), C_i(\Theta)\}_{i\in(0,1)}$ and raw capital prices $\{R_i\}_{i\in(0,1)}$ such that:*

- $\{a_i\}_{i\in(0,1)}$ *and* $\{\beta_i\}_{i\in(0,1)}$ *maximize* $E[\mathbb{U}(C_i, L_i)], \forall\, i$;
- $\{L_i\}_{i\in(0,1)}$ *and* $\{\{\beta_i(j)\}_{(j\neq i)}\}_{i\in(0,1)}$ *maximize* $E_i[\mathbb{U}(C_i, L_i)], \forall\, i$.
- *Markets clear,* $\int_{j\neq i} \beta_j(i)dj = 1 - \beta_i$, $\forall\, i$.

where $E_i[\cdot] \equiv E[\cdot|\hat{\theta}_{\mathtt{p},i}, \{\hat{\theta}_{\mathtt{c},j}\}_{j\in(0,1)}]$ *is the expectation operator conditional to the information set of agent i.*

Notice this is a representative-agent economy in that each agent is at the same time a buyer, a seller, a producer and a consumer. Agents only differ in the realized productivity of endowed raw capital - they are otherwise ex-ante identical.

This unique aspect of our model enables us to discuss welfare without imposing arbitrary weight assignments to structurally heterogeneous agents. Simultaneously, it maintains the ability to disentangle and delve deeper into agents incentives in their distinct roles.

3 Market Equilibrium

In this section, we characterize the equilibrium working backward. First, we solve for an agent's ex-post optimal individual labor supply and raw capital demand, for a given informational technology and raw capital supply. Then, we solve for the optimal ex-ante individual informational technology and raw capital supply choices.

3.1 Ex-post stage

Labor supply choices. The next Lemma shows the amount of labor that agent i chooses given her expected (conditional on available information) distribution of intermediate capital,

Lemma 1 (Labor Supply). *Agent i's optimal labor supply is given by*

$$L_i = E_i[K_i]^{\frac{\phi}{\gamma}}. \tag{6}$$

with $K_i \equiv \alpha e^{(1-\alpha)(1-\sigma)k_i}$ *and the sensitivity of labor to capital given by*

$$\phi \equiv \frac{1}{1 - \frac{\alpha}{\gamma}(1-\sigma)}. \tag{7}$$

Proof. It follows from maximizing expected (1) subject to (2)-(3) and $C_i = Y_i$. □

Note that labor is increasing in intermediate capital k_i when $\sigma < 1$, and decreasing when $\sigma > 1$. These comparative statics come from standard trade-offs between income and substitution effects. When $\sigma < 1$ a substitution effect dominates: as capital becomes abundant, labor is more productive and agents work more - the additional variance of consumption is not punished as heavily because risk aversion is relatively low. In contrast, when $\sigma > 1$ the income effect dominates: as capital becomes abundant agents work less because they are comparatively more sensitive to variance. When $\sigma = 1$, these two forces exactly offset each other and labor supply does not depend on the expected amount of intermediate capital.

The role of data availability on optimal labor choices is captured through the expectation operator. Without data agents can only choose labor based on expected capital, not on each possible realization, as could be done with full-information. Thus, information allows for labor choices to better react to idiosyncratic productivity shocks that affect the amount of available capital.

Raw capital demand choices. Given (4), agent i's profits $\Pi_i(j)$ from buying a quantity $\beta_i(j)$ of agent j's raw capital, are given by:

$$\Pi_i(j) = \left(\bar{\theta} + \theta_j\right) \beta_i(j) - \frac{\varphi}{2}\beta_i^2(j) - R_j\beta_i(j), \tag{8}$$

for any $j \in J(i) \equiv (0,1)/i$, where R_j is the equilibrium per unit price of agent j's raw capital. After selling a fraction β_i of own raw capital at a price R_i, buying $\beta_i(j)$ raw capital from agents $j \in J(i)$ at prices R_j and covering adjustment costs $\frac{\varphi}{2}\beta_i^2(j)$, the amount of intermediate capital available to agent i to produce consumption goods is

$$k_i = \left(\bar{\theta} + \theta_i\right) \beta_i + (1-\beta_i)R_i + \int_{J(i)} \Pi_i(j)dj, \tag{9}$$

that is, agent i will operate with intermediate capital that comes from three sources: i) transforming a fraction β_i of own raw capital into intermediate capital with productivity θ_i, ii) selling a fraction $1-\beta_i$ of own raw capital to other agents in exchange for $(1-\beta_i)R_i$ units of intermediate capital, and iii) buying raw capital $\beta_i(j)$ from other agents and obtaining a profit $\Pi_i(j)$ from each, in terms of intermediate capital, after repayment.

The next lemma characterizes agent i's utility-maximizing demand for agent j's raw capital, and equilibrium prices R_j.

Lemma 2 (Demand of raw capital and equilibrium prices)**.** *Agent i's utility-maximizing demand of agent j's raw capital also maximizes the expectation of profits (8) and is given by*

$$\beta_i^*(j) = \frac{\bar{\theta} + E_i[\theta_j] - R_j}{\varphi}, \tag{10}$$

Market clearing implies that the per unit price of agent j's raw capital satisfies

$$R_j = \bar{\theta} + E_i[\theta_j] - \varphi(1 - \beta_j), \tag{11}$$

Proof. Postponed to Appendix A.1. □

Equilibrium prices are simply determined competitively from market clearing by equalizing the total demand from agents $i \in I(j) \equiv (0,1)/j$ with the supply from agent j that was chosen in the ex-ante stage: $\int_{I(j)} \beta_i^*(j)di = 1 - \beta_j$. Since these prices depend on what other agents know about the raw capital, the more they know the more uncertain the price is from an ex-ante perspective. This entail an *endogenous cost* of generating data: information feeds ex-ante uncertainty about the price at which agents can sell their raw capital.

Importantly, this lemma shows that the optimal individual demand for raw capital equates expected marginal return, $\bar{\theta} + E_i[\theta_j]$, and marginal cost, $R_j + \varphi\beta_i(j)$, of operating with others' capital. It boils down to a linear schedule, decreasing in price and marginal adjustment costs and increasing in expected productivity. It is instructive to notice that demand only depends on the expected productivity of raw capital - not on its conditional variance. The reason is that traders *simultaneously* demand a continuum of capital goods, each with an i.i.d. productivity shock, so that the conditional variance of the asset enters as a function of the simultaneous position on other assets. In equilibrium buyers always obtain *safe assets* in the form of a *perfectly diversified portfolio*, so that each asset contributes in mean without adding portfolio variance.

Safe Assets: Perfectly diversified portfolios. Because of market forces, perfect diversification is indeed the only possible equilibrium outcome when there is trade of raw capital (even if $\sigma < 1$ and agents like volatility of intermediate capital). Four features combine in our setting to obtain this convenient result, which separates the roles of an agent as a buyer and a seller: i) perfect competition among traders, ii) *capital-specific*, rather than *portfolio-specific*, adjustment costs φ, iii) CRRA utility in consumption (from (2)), but constant absolute risk aversion (CARA) in portfolio returns (from (2) and (3) jointly), and iv) quadratic adjustment costs which allow asset investments to be "self-financed." The last two features ensure that i's demand of j's raw capital is independent from the productivity of i's raw capital, i.e. from the only potential source of individual heterogeneity[9]; combined with capital-specific adjustment costs, this implies that agents have common asset valuations irrespective of their differences as buyers. Perfect competition requires that the marginal benefit be equalized across all buyers for each type of raw capital, so that, in equilibrium, each buyer must absorb an equal (infinitesimal) amount of raw capital supply. Finally, since per unit adjustment costs are homogeneous across all raw capital types, the distribution of optimal individual demand across types within a portfolio must also be symmetric.

Combining these elements we characterize next the amount of safe assets that each agent buys in a symmetric equilibrium in which all agents supply the same amount of raw capital. We show later our timing assumption that raw capital supply happens in the ex-ante stage implies this is indeed the unique equilibrium.

Corollary 1. *Suppose supply of raw capital is uniform across agents other than i, i.e. $\beta_j = \beta \in (0, 1)$ for any $j \in J(i)$. Agent i's portfolio profits are deterministic,*

$$\int_{J(i)} \Pi_j(j)dj = \frac{\varphi}{2}(1-\beta)^2. \tag{12}$$

[9]In particular, CARA with self-financing ensure respectively that the marginal utility of portfolio returns and the spending in others' capital does depend on one's own wealth, which in our model is determined by the price at which the agent can sell her own raw capital in the market and, ultimately, on the expected productivity of said capital.

and agent i's quantity of intermediate capital available for production, from (9), is

$$k_i = \bar{\theta} + \beta_i\theta_i + (1-\beta_i)\, E_j[\theta_i] - \varphi(1-\beta_i)^2 + \frac{\varphi}{2}(1-\beta)^2, \tag{13}$$

Proof. Postponed to Appendix A.1. □

This corollary contains three important insights.

First, buyers obtain deterministic profits from creating a perfectly diversified portfolio, *a safe asset*, which is given by equation (12). The profits derived by such diversified portfolios are the only source of non-contingent streams of consumption; this is why their equilibrium quantity is so important for welfare. The profits are positive because in average agents buy a unit of raw capital of productivity $\bar{\theta}$ at a discount $\varphi(1-\beta)$ (from compensating sellers for the marginal adjustment cost), but only face a reduction in production for $\frac{\varphi}{2}(1-\beta)$ (from the average adjustment cost).

Second, the quantity of safe assets an agent buys *is only determined by what others choose to sell*, $(1-\beta)$. In particular, it *does not depend on the information choices of the sellers* of the underlying risky assets: by the law of large numbers, the sum of profits obtained from buying a basket of raw capital from other agents is deterministic, so its ex-ante and ex-post evaluations coincide.[10] It *does not depend either on the information choices of the buyer, nor her characteristics*: buying others' capital is self-financed by the deterministic production of that purchase, and not constrained by own proceedings from selling.

Finally, the intermediate capital of an agent (equation (13)) depends on other agents only through how much they choose to sell $(1-\beta)$. We isolate this source of *trading externality* by purposefully making other agents' beliefs about agent i's productivity ($E_j[\theta_i]$) solely determined by agent i's information choices. If these beliefs would depend on agent j's information choices, then we would additionally introduce (Hirshleifer 1971)'s informational externality.

[10]We depart from the insight that information may increase risks for the buyers of assets as in Farboodi and Veldkamp (2020), Gaballo (2016) and Kurlat and Veldkamp (2015). Instead agents are not exposed to risk as buyers but they are as sellers of their own idiosyncratic risk. This result is quite important for tractability, as other agents' information technology decisions do not enter into the agent's problem, hence curtailing possible issues of multiplicity and coordination.

3.2 Ex-ante stage

We have expressed labor as a function of intermediate capital and information (equation 6) and intermediate capital as a function of raw capital supply and information (equation 13). Now we derive the expression for the expected utility that individuals maximize in the ex-ante stage. Then we characterize the choices of raw capital supply and information.

Expression for the ex-ante expected utility. For a given individual information set, let $V(E_i[k_i])$ be the unconditional variance of the expected conditional mean (what is usually known as *explained variance*) and $V_i(k_i)$ the conditional variance of k_i (this is the *unexplained variance*). By the law of total variance these are the two components of the unconditional variance. By using the ex-post stage's optimal decisions we can write the ex-ante expected individual utility as follows.

Lemma 3 (Ex-ante Expected Utility)**.** *Using (1),(2) and (6), given $\{a_i, \beta_i\}_{i\in(0,1)}$ and $f(\cdot)$, ex-ante expected utility is:*

$$\begin{aligned} E[\mathbb{U}(E_i[K_i])] &\equiv E\left[\frac{K_i\, E_i[K_i]^{\frac{\phi}{\gamma}\alpha(1-\sigma)}}{\alpha(1-\sigma)} - \frac{1}{\gamma}E_i[K_i]^{\phi}\right] \\ &= \Phi\,\bar{K}\,\exp\left\{\phi(1-\alpha)^2(1-\sigma)^2\left(\frac{\phi}{2}V(E_i[k_i]) + \frac{1}{2}V_i(k_i)\right)\right\} \quad (14) \end{aligned}$$

with $\bar{K} \equiv \alpha^{\phi}\, e^{\phi(1-\alpha)(1-\sigma)E[k_i]}$ and

$$\Phi \equiv \frac{\gamma - \alpha(1-\sigma)}{\gamma\alpha(1-\sigma)},$$

which is negative for $\sigma > 1$. Using (5) and (13),

$$\begin{aligned} E[k_i] &= \bar{\theta} - \varphi(1-\beta_i)^2 + \frac{\varphi}{2}(1-\beta)^2 \quad (15) \\ V(E_i[k_i]) &= \beta_i^2\, a_i + (1-\beta_i^2) f(a_i), \quad (16) \\ V_i(k_i) &= \beta_i^2\,(1-a_i), \quad (17) \end{aligned}$$

Finally, by the law of total variance, the unconditional variance of k_i is

$$V(k_i) = V(E_i[k_i]) + V_i(k_i) = \beta_i^2(1 - f(a_i)) + f(a_i).$$

Proof. See the derivation in Appendix A.2. □

Expression (14) is quite informative about the forces at play. The ex-ante utility always increases with expected intermediate capital $E(k_i)$. Its relation with the variance of intermediate capital is, however, more intricate on two dimensions.

First, it depends on risk-aversion. Given the exponential transformation of intermediate capital into final capital, the variance of intermediate capital increases both the average and variance of consumption. When $\sigma < 1$, the first effect dominates, and the agent would rather face a higher variance of consumption in exchange of higher expected consumption. When $\sigma > 1$ instead, which is the most interesting case, the second effect dominates, and agents prefer to face intermediate capital with less variance.

Second, explained and unexplained variances affect expression (14) asymmetrically. The explained variance is multiplied by ϕ, which is the sensitivity of labor to information. Agents understand that the more they know, the more they will be able to react adjusting labor.[11] Does this imply that agents always strive for more information? This would be the case if the unconditional variance of intermediate capital $V(k_i)$ were fixed and exogenous, so information that increases $V(E_i[k_i])$ also reduces $V_i(k_i)$. In our framework, however, this logic only operates for the fraction of raw capital the agent remains exposed to, β_i, with exogenous unconditional variance (as it is clear from inspecting equations (16) and (17)). For the part $1 - \beta_i$ that the agent sells, the increase in data availability has an asymmetric effect: it just increases the explained variance proportionally to leakages $f(a_i)$. So for the part that is sold, the agent has to face a higher variance if increasing a_i.

The previous discussion highlights the main trade-offs the agent faces in this environment: the unconditional variance is not exogenous to the decision of selling

[11] This is evident when $\phi > 1$ (i.e. $\sigma \in (0, 1)$); when instead $\phi \in (0, 1)$ (i.e. $\sigma > 1$) note that $\Phi < 0$, so information generates a "less negative" expected utility.

and to information. If the agent sells everything ($\beta_i = 0$) and does not produce information ($a_i = 0$), for instance, its unconditional variance is zero. Isn't this always optimal when $\sigma > 1$? Not necessarily, as selling is costly in terms of compensating for adjustment costs, hence reducing the expected amount of intermediate capital, as can be seen in (15). But if the agent does not sell everything then it may want some information, to increase (16) and be able to react with labor. Their problem of how much to sell (in contrast to how much to buy) is then related to the amount of information they can acquire. We explore these interactions formally next.

Joint information and raw capital supply choices. We now derive the first order conditions of the agents' two joint choices, supply of raw capital, $(1 - \beta_i)$, and information technology, a_i.

In terms of the supply of raw capital, it is optimal to increase β_i (this is, reduce the supply of raw capital) as long as

$$\phi(1-\alpha)^2(1-\sigma)^2\frac{1}{2}\left(2\phi\beta_i(a_i - f(a_i)) + \beta_i(1-a_i) - \frac{\varphi}{(1-\alpha)(\sigma-1)}(1-\beta_i)\right)E[\mathbb{U}(E_i[K_i])] > 0. \tag{18}$$

When $\sigma < 1$, this expression is always positive and agents chose the corner solution of not selling anything, $\beta_i^* = 1$. When $\sigma > 1$, however, there is a non-trivial trade-off of selling raw capital, between decreasing the variance of intermediate capital (by offloading risk on the market) and decreasing average productivity (by the discount for adjustment costs that sellers have to compensate buyers). Agents never sell all their raw capital: at $\beta_i = 0$, it is always optimal to reduce supply as (18) holds (recall $E[\mathbb{U}(E_i[K_i])] < 0$ with $\sigma > 1$). How much to sell depends on the data intensity a_i.

Before switching to the information choice, it is worth noticing that when evaluating pros and cons of selling, agents take the proceedings from buying a safe asset fixed as they only depend on others' selling choices. As it will be clear in section 4, this feature will originate an externality in the supply of risky assets β_i, as each agent neglects that by providing her own raw capital, she increases the quantity of safe assets (perfectly diversified portfolios) available to other agents.

In terms of the adoption of an information technology, it is optimal to increase a_i (this is, more data intensity) as long as

$$\phi(1-\alpha)^2(1-\sigma)^2\frac{1}{2}\left(f'(a_i)\phi(1-\beta_i^2)+\beta_i^2(\phi-1)\right)E[\mathbb{U}(E_i[K_i])]>0. \tag{19}$$

Again, with $\sigma < 1$ (that is $\phi > 1$), the expression is always positive and then the solution is the corner of full information $a_i^* = 1$. When $\sigma > 1$, however, $\phi < 1$ and there is a non-trivial trade-off of information, between increasing the variance of intermediate capital and being able to face part of it by adjusting labor better. The net benefit of using information technologies depends on the supply of raw capital, hence the exposure to own risk, β_i.

Note here the role of the derivative of the leaking function $f'(a_i)$ measuring the increase in ex-ante uncertainty on market prices due to a marginal increase in data intensity. With $f'(a_i) = 0$, information would not have any shortcoming: for any β_i level, information would be unambiguously beneficial. This feature will be important when discussing in section 4 the wedge between market and social planner in the evaluation of information.

The next Lemma characterizes the joint solution of information technology and raw capital supply,

Lemma 4 (Information technology and raw capital supply)**.** *Raw capital supply $\beta_i^*(a_i)$ and the degree of technological data intensity $a_i^*(\beta_i)$ are jointly determined by*

$$\beta_i^*(a_i) = \max\left\{\min\left\{1,\frac{A}{A+1-a_i(1-\phi)-\phi f(a_i)}\right\},0\right\} \tag{20}$$

$$a_i^*(\beta_i) = \max\left\{\min\left\{1,\ f'_{-1}\left(\frac{\beta_i^2-\phi\beta_i^2}{\phi-\phi\beta_i^2}\right)\right\},0\right\} \tag{21}$$

where $A \equiv \frac{2\varphi}{(1-\alpha)(\sigma-1)}$ and $f'_{-1}(\cdot)$ being such that $f'_{-1}(f'(x)) = x$ for any $x \in \mathrm{R}$.

Proof. It just comes directly from the first order conditions above, restricting the range of both β_i and a_i to $[0, 1]$. □

Combining the ex-post and ex-ante solutions, the following proposition characterizes the equilibrium allocations.

Proposition 1 (Equilibrium Allocations)**.** *Labor supply is given by equation* (6) *in Lemma 1. Raw capital demand is given by* (10) *in Lemma 2. Raw capital supply* $\beta_i^*(a_i)$ *and the degree of technological data intensity* $a_i^*(\beta_i)$ *are jointly determined by* (20) *and* (21) *in Lemma 4.*

Illustration of market equilibrium allocations. In figure 1 we illustrate how technology and supply choices are jointly determined for three possible specifications of information leakage: *no leakage* ($f(a_i) = 0$ in the left panel), *partial leakage* ($f(a_i) = a_i^5$ in the central panel) and *full leakage* ($f(a_i) = a_i$ in the right panel).

In the first raw, the solid line shows the individual optimal locus $\beta_i^*(a_i)$ given the technology data intensity, from (20). The dotted line shows instead the individual optimal locus $a_i^*(\beta_i)$ given how much agents want to sell, represented as the inverse function of (21), namely $\tilde{\beta}_i(a_i) \equiv \left(\frac{f'(a_i)\phi}{1-\phi(1-f'(a_i))}\right)^{\frac{1}{2}}$. We have then

$$\frac{E[\partial \mathbb{U}(E_i[K_i])]}{\partial \beta_i} > 0 \quad \text{if} \quad \beta_i < \beta_i^*(a_i), \tag{22}$$

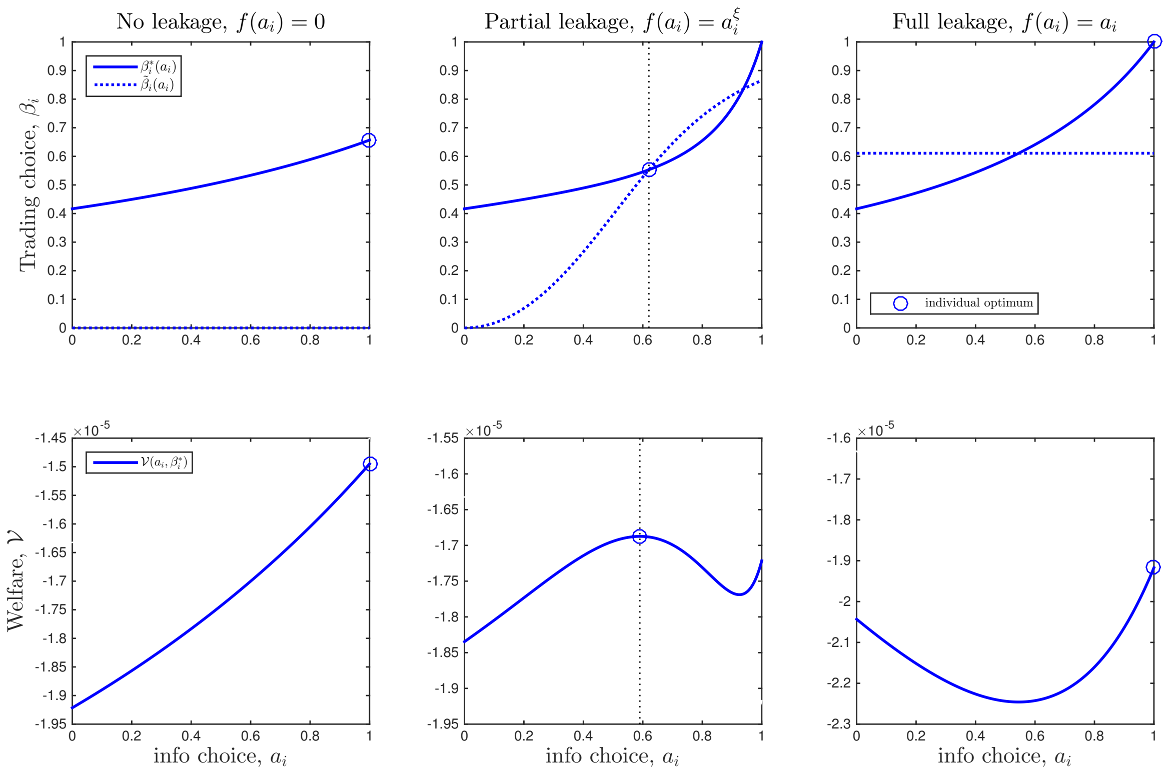
$$\frac{\partial E[\mathbb{U}(E_i[K_i])]}{\partial a_i} > 0 \quad \text{if} \quad \beta_i > \tilde{\beta}_i(a_i), \tag{23}$$

that is, when the solid line is above the dotted line, producing information is optimal. The positive slope of $\beta_i^*(a_i)$ indicates that more data intensity (an increase in a_i) induces the agent to sell less raw capital (an increase in β_i^*). This is our first main insight: *Information technologies always reduce the supply of safe assets.*

The weakly positive slope of $\tilde{\beta}_i(a_i)$ represents that the less an agent sells (an increase in β_i), the more data intensity is adopted (an increase in a_i^*). There is a candidate interior solution when these two lines intersect, and/or candidate corner solutions with $a_i^* = 1$ ($a_i^* = 0$) if the solid line is above (below) the dotted line at those corners. As more than one local maxima exist, in the second raw of figure 1 we plot the ex-ante utility (14)as a function of a_i, taking as given the supply choice of others, β, so that we can easily identify the global maximum.

In the left panel there is no leakage and data-intensive technologies reveal productivity only to the owner. In this case, the information technology does not affect the

Figure 1: Individual Information and Supply Choices



The first raw plots β_i^* (in solid) and $\tilde{\beta}_i$ (in dotted), as a function of a_i. The second raw plots the highest level of ex-ante utility, i.e. welfare, as a function of a_i, taking as given others' supply choices β at the individual optimum β_i^*. The three columns are different specifications of $f(a)$. Other parameters are: $\sigma = 8, \xi = 5$, $\alpha = 0.6, \gamma = 2.5, \varphi = 1, \bar{\theta} = 10$.

supply of raw capital. The only equilibrium is a corner with $a_i^* = 1$. This is intuitive, as information can be used to face uncertainty without inducing more of it through markets. Still, the agent does not sell all the raw capital because of the trade-off between reducing consumption risk and accepting a price discount to compensate buyers for the adjustment costs. As φ declines, however, the agent would sell more, and would sell everything when $\varphi = 0$.

In the central panel, leakages are partial and increase with data intensity at an increasing rate. In this case there are two intersections. The one at lower levels entails a local maximum, and the other a local minimum (the solid line cuts the dashed line from below). There is also a local corner maximum at $a_i^* = 1$. In the corresponding panel below we can compare the two local maxima and see that the interior solution delivers the global maximum (highlighted by a circle): intermediate levels of raw capital supply and data intensity are optimal.

In the right panel there is full leakage, and any information available to the agent is also available to traders. In this case there are two local corner maxima, one at $a_i^* = 0$ with no information technology and one at $a_i^* = 1$ with full information technology. How these extremes can both be local maximum? On the one hand, when $a_i^* = 0$ agents choose to sell a lot in the market and then it is optimal not to use information technologies, to prevent buyers from learning too much. On the other hand, when $a_i^* = 1$ agents choose not to sell anything in the market, it is indeed optimal to fully adopt an information technology to make better labor choices. These two alternatives highlight that adopting information technologies and unloading risk in markets are substitute strategies for risk management. In this case, the global maximum is achieved by the corner with full information and no trading.

Notice that the best responses of information and trading from equations (20) and (21) do not contain the choice of other agents, β. However, the trading choices of other agents do enter into the evaluation of ex-ante individual utility because they increase the expectation of intermediate capital. The more others sell their capital, the more an agent can diversify, and this availability of safe assets vertically shifts the ex ante utility depicted in the second row of the figure. This is the nature of a pure externality from others' choice into the agent's utility. Given this externality individual and social evaluations generally differ. We study this difference in what follows by restricting attention to the nontrivial case in which $\sigma > 1$.

4 Welfare and Social Planning

In this section, we first solve a *constrained planner's problem*, in which the planner is constrained by the same trading restrictions that agents face, i.e. compensation implied by market prices. In other words, this planner can mandate the use of information technologies and the supply of raw capital in the ex-ante stage and let agents trade at equilibrium prices in the ex-post stage. We show that the planner would like agents to supply more raw capital than in equilibrium, highlighting the nature of an externality in the use of markets to manage risk.

Second, we solve an *unconstrained planner's problem*, who can also mandate transfers of intermediate capital instead of through a market. This planner can replicate the allocation with *complete markets* turning information technologies socially desirable always. While competitive markets use information to allocate intermediate capital "regressively", i.e. more intermediate capital to agents with raw capital of higher productivity, a planner would use information to allocate it "progressively" and equalize intermediate capital across agents.

4.1 Constrained Social Optimum

The constrained planner's problem is identical to the one individuals face in terms of choosing labor, information and the demand of raw capital. The difference comes from the supply of raw capital, as the planner does not take supply of other agents β as given, and instead solve for the $\beta_i = \beta$ for all agents.[12] Imposing this restriction in the expression of $E[k_i]$ in Lemma 3,

$$E[k_i] = \bar{\theta} - \frac{\varphi}{2}(1-\beta)^2.$$

This relatively small change, in which the constrained planner internalizes the effect of supply on the profits of other agents, makes the problem identical to that in Lemma 4, with the difference that equation (20) becomes

$$\beta^*(a) = \max\left\{\min\left\{1, \frac{A_P}{A_P + 1 - a(1-\phi) - \phi f(a)}\right\}, 0\right\} \tag{24}$$

[12] Our welfare criterion is based on each identical individual agent from an ex-ante perspective, not the representative agent which is normatively unrepresentative, as explained by Schlee (2001).

where a is the information technology that the planner chooses for all agents and

$$A_P = \frac{\varphi}{(1-\alpha)(\sigma-1)} < A \tag{25}$$

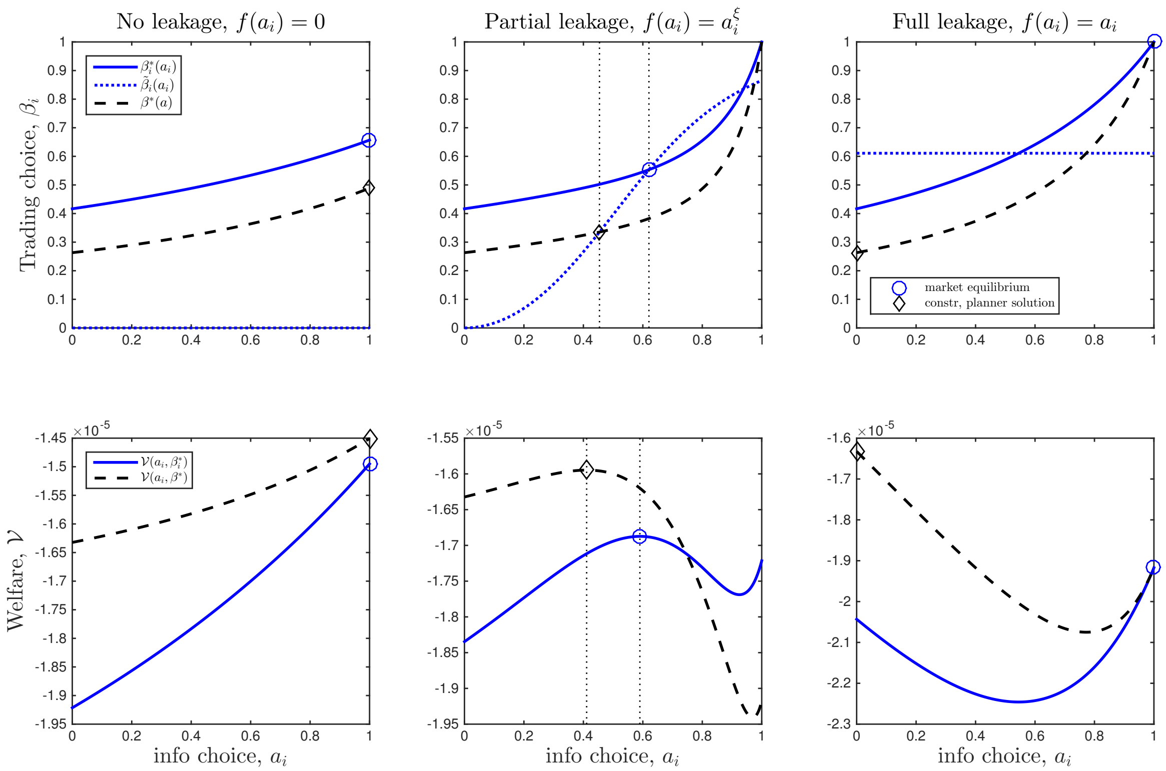
Compared to the decentralized equilibrium, $\beta^* \leq \beta_i^*$. This is, the planner weakly prefers to use the market more intensively than individuals. In other words, the planner internalizes that marginally increasing the supply of raw capital of an agent increases the possibilities of diversification, increasing the supply of safe assets and welfare. The market, instead, does not compensate sellers for these "pooling gains". This is our second main insight: *Safe asset shortages are inefficient.*

The first raw of Figure 2 replicates that in Figure 1, adding in dashed black the planner's best response to data intensity a_i, this is $\beta^*(a_i)$. This line is always under the solid line, $\beta_i^*(a_i)$, (the intensity chosen by individuals). So, the planner values trading more than individuals. In contrast, the planner's optimality conditions for the choice of a_i, *for a given* β_i, is the same as individuals' ones. In fact, *for a given* β_i, the market and the planner have the same evaluation of information. Nevertheless, as the market and the planner would choose different β_i *for a given* a_i, the externality in the trading choice spills over the choice of data intensity.

The second raw of Figure 2 plots the corresponding level of ex-ante welfare obtained by these constrained planner's allocations. The case of full leakage – in the right bottom panel – shows a case where the planner would opt for no data and heavy trade whereas the market would choose the opposite: full information and no trade. This divergence in the evaluation of information depends on how the incentives for acquiring information and selling assets reinforce each other as entailed by equations (18) and (19). By focusing at the other extreme, with no leakage ($f'(a_i) = 0$) – in the left bottom panel – one realises that planner and individuals would agree on more info acquisition, despite an inefficient supply of safe assets. This is our third main insight: *The adoption of information technologies can be excessive only when data leak to markets.*[13]

[13]Notice that the endogenous costs of information in terms of own sale price volatility, captured by $f'(a_i) > 0$ additional data intensity inefficient despite the absence of a direct externality in

Figure 2: Information and Supply Choices: Market vs. Constrained Planner



Plot of β_i^* (in solid) and $\tilde{\beta}_i$ (in dotted) and β^* (in dashed) as a function of a_i for different specification of $f(a)$. Other parameters are: $\sigma = 8, \xi = 5$, $\alpha = 0.6, \gamma = 2.5, \varphi = 1, \bar{\theta} = 10$. The circle denotes the individual best reply, the diamond the constrained planner solution.

4.2 Welfare Comparisons with Full Leakage

Here we compare analytically the two corner allocations when there is full leakage, $f(a) = a$ (third column in figures 1 and 2). One in which agents operate a fully opaque technology (no-information benchmark, $a_i^* = f(a_i^*) = 0$) and a fully data-intensive technology in the other (full-information benchmark, $a_i^* = f(a_i^*) = 1$). These extremes are useful to isolate *two faces of information: risk self-management*

information acquisition, as that present in (Hirshleifer 1971).

vs. risk market-management. Since the wedge between individual and social evaluations of welfare arise from trading, there is no difference across evaluations for the first face, but there is for the second.

Proposition 2 (The two faces of information with full leakage)**.** *Assume $\sigma > 1$ and $f(a) = a$. The individual and planning evaluation of ex-ante utilities, $m \in \{I, P\}$ respectively are:*

$$E[\mathbb{U}(E_i[K_i])] = \Phi \bar{K} E[e^{(1-\alpha)(1-\sigma)\theta_i}]^{\phi\omega(a)} \tag{26}$$

where $\bar{K} = \alpha^{\phi} e^{\phi(1-\alpha)(1-\sigma)\bar{\theta}}$. In the full-information benchmark, $\omega(a = 1) = \phi$. In the no-information benchmark, $\omega(a = 0) = \beta^m$, where

$$\beta^m = \frac{1}{1 - \frac{1-\alpha}{\varphi}(1-\sigma)\chi^m}. \tag{27}$$

The difference between individual and planning evaluations are manifested in differences on trading in the no-information benchmark, such that

$$\chi^I = \frac{1}{2}; \qquad\qquad \chi^P \equiv 1. \tag{28}$$

Proof. Postponed to Appendix A.3. □

This proposition contrasts, just in $\omega(a)$, the two opposite faces of information. When there is full information, $\omega(1) = \phi$. Agents face the whole variance of 1, regardless of how much raw capital they sell, as prices perfectly reflect realized productivity. For this reason agents prefer not to sell anything (no *risk market-management*) and instead adjust labor (*risk self-management*) to an extent given by the sensitivity ϕ of labor to information about realized intermediate capital. This is in addition to the single ϕ in (26) from adjusting labor in response to expected intermediate capital. When there is no-information, $\omega(0) = \beta^m$. Agents only face the variance of productivity for the unsold raw capital, β^m (*risk market-management.* However, because there is no information, agents cannot react with labor to that residual variance (no *risk self-management*). With full leakage we can solve analytically the fraction of raw capital that agents or the planner decide keep, given by equation (27).

Note how β^m in (27) is the mirror image of ϕ in (7). This analogy is also instructive about the parallel impact of *risk market-management* and *risk self-management* on the ex-ante expected utility. The trade-off that sellers face of lowering variance at a trading cost, which is typically studied in the finance literature, is essentially the same as the trade-off that households face when adjusting labor to reduce variance at a disutility labor cost, which is typically studied in the macro literature.

The next proposition exploits this analogy to characterize when information technologies are undesirable, comparing the strength of market- and self-management of risk, both from an individual and a social standpoint.

Proposition 3 (Individual and social undesirable information technologies)**.** *Assume $\sigma > 1$ and $f(a) = a$. Full-information allocations are inferior to no-information allocations if and only if $\beta^m < \phi$, that is*

$$\frac{\alpha}{\gamma} < \frac{1-\alpha}{\varphi}\chi^m. \tag{29}$$

Proof. With $\sigma > 1$ we have that $\Phi < 0$ (from Lemma 3) and $0 < \phi < 1$ (from equation 7). The proposition is a direct implication of comparing ω in (26). □

This proposition can also be explained intuitively from comparing the two channels through which individuals can reduce the variance of consumption.

One channel is *risk self-management*. When agents know productivity realizations perfectly, the market stops providing insurance. Still individuals can self-insure by allocating labor optimally. This reduction of variance is proportional to ϕ, which increases in α/γ. In words, risk self-management is powerful when labor is important in the production function (high α) and when the Frisch elasticity (the elasticity of labor disutility to labor supply) is low, so it is not costly for agents to adjust labor to capital shocks (low γ).

The other channel is *risk market-management*. When individuals do not know productivity realizations, they cannot self-insure for the own unsold raw capital, but the market can provide insurance for the rest, at an adjustment cost φ. In the absence of information, agents get more market-insurance when $(1-\alpha)/\varphi$ is high. In words, risk market-management is powerful when capital is important in the production function and when adjustment costs are small.

The benefit of market-management of risk relative to self-management is adjusted by χ^m, which captures the difference in valuation between individuals and the social planner. As we mentioned, agents do not internalize that by selling raw capital they effectively increase diversification possibilities and the availability of safe assets. As such the planner values more managing risk in the market. This is our fourth main insight: *The adoption of information technologies are excessive when data leak to markets only when agents rely heavily on markets to manage risks.*

4.3 Discussion

Implementation of the constrained social optimal with taxes. As we noted, agents fail to internalize the positive effect of supplying raw capital for other agents' diversification. A government could subsidize the sale of raw capital by an amount $s(\beta_i)$ in terms of intermediate capital; financing the subsidies with lump-sum taxes T. Given this subsidy scheme, the expected amount of intermediate capital becomes $E[k_i] = \bar{\theta} - \varphi(1-\beta_i)^2 + \frac{\varphi}{2}(1-\beta)^2 + s(\beta_i) - T$ and the socially optimal supply of raw capital can be implemented by setting $s(\beta_i) = \frac{\varphi}{2}(1-\beta_i)^2$. Note this scheme does not require information on productivity, just on actual supply. Take the case of asset backed securities. Policymakers should not only tax information, as proposed by Gorton and Ordoñez (2022), to encourage the trade of certain assets that are used as inputs of private safe assets (such as mortgages for MBS, or bonds for CDOs), but here we show that they may also want to subsidize the trading of those assets.

A theory of financial intermediation. Implementing the constrained efficiency does not need, however, government's intervention. A competitive (zero-profit) *mutual fund* could induce the coordination that sellers cannot achieve in a decentralized market and allow them to reach the constrained socially optimal allocations. Assume each agent "invests" in the mutual fund $1-\beta_i$ units of raw capital, the mutual fund pools all the raw capital, and produces intermediate capital subject to adjustment costs. Given perfect diversification, the mutual fund can compensate the agent $\bar{\theta}(1-\beta_i)-\frac{\varphi}{2}(1-\beta_i)^2$ units of intermediate capital. This is, the agents' return in terms of expected intermediate capital is lower in expectation, but deterministic. A mutual fund effectively sells insurance at a "fee", $\frac{\varphi}{2}(1-\beta_i)^2$, thereby turning an agent's expected amount of intermediate capital, into $E[k_i] = \bar{\theta} - \frac{\varphi}{2}(1-\beta_i)^2$, which makes the agent's objective function mathematically identical to that of the constrained social planner; thus, agents optimally contribute to the mutual fund the socially optimal amount. Being that all agents contribute the same amount $1-\beta$, the mutual fund produces in total $\bar{\theta}(1-\beta) - \frac{\varphi}{2}(1-\beta)^2$ units of intermediate capital, which is what we conjectured compensates investors, making zero profits.

This potential implementation suggests the importance of financial intermediation in increasing the supply of "safe assets" in the economy, for instance, by securitization which indeed consists on an originator pooling assets with idiosyncratic quality and, at a cost, generating a "new asset" of lower variance. In contrast to Dang et al. (2017), in which intermediaries are superior than markets in "informationally pooling assets," by concealing information about their quality, in our model intermediaries are the same as markets in generating a diversified portfolio of known quality. In our setting, intermediaries are superior, however, in inducing agents to supply more assets to pool within an asset backed security.

To see this distinction more clearly, Dang et al. (2017) highlights that a bank would like to obscure information about the mortgages in their balance sheet, as if such information is revealed their value becomes volatile. In this paper, information about mortgages discourage banks from selling them, both because the obtained price is volatile and because they are better equipped to deal with their idiosyncratic risk (for instance writing better derivative contracts). This underprovision, however, can be fixed by a mutual fund that makes banks to internalize the value of their mortgages as inputs of diversification through the creation and trading of asset backed securities.

Different interpretations of data processing improvements. In this paper we have focused on how information technologies affect what agents know, both about own and others' raw capital. Data-intensive technologies, however, may also help completing markets (improving insurance in the economy) or affect the mapping between information and other fundamental parameters. Those additional effects would change the conditions under which information is socially undesirable, but not the fundamental forces. Here we highlight three commonly alluded to alternatives:

i) Information technologies improve productivity (a_i raises $\bar{\theta}$): Data-intensive technologies have been modeled in the literature as increasing productivity through a better allocation of resources. We are already capturing this effect. Data-intensive technologies may also allow information to raise the amount of intermediate capital directly. This extra benefit of information would increase $E(k_i)$ and make information mechanically more desirable as data processing improves.

ii) Information technologies facilitate trading (a_i reduces φ): Data can also make trading easier. In this case, information technologies would induce to use the market more intensively, given a level of data intensity, but also reduces the incentives to be data-intensive. The final result would depend on how much information makes trading cheaper relative to increasing ex-ante price uncertainty.

iii) Information technologies facilitate learning about others (a_i raises $f(\cdot)$): Data-intensive technologies may improve the ability of an agent to infer the information available to other agents. More leaks induce agents to trade less, discouraging the adoption of information technologies. This possibility points towards the importance of data privacy policies, which in our setting can be interpreted as policies that shift $f(\cdot)$ down and induce both trading and the adoption of information technologies to enhance production choices.

The role of our functional-form assumptions. Even though the previous results are mostly based on a set of standard functional-form assumptions in macroeconomics and finance, we have also resorted to specifications that enhanced tractability and expositional clarity. First, the production function of capital is special: exponential on intermediate capital, which implies that when $\sigma < 1$ individuals are risk lovers on intermediate capital (even though being risk averse on consumption goods). Second, the production function of intermediate goods is also special: linear in the productivity of raw capital.

A potentially unattractive implication of combining these two assumptions is that the unconditional distribution of capital is not mean invariant (expected capital production is not the same as the capital produced with expected intermediate capital), that is

$$E[K_i(\theta_i)] = e^{E[k_i]+\frac{1}{2}V(k_i)} \neq K_i(E[\theta_i]) = e^{E[k_i]} .$$

This means that the expected capital available to produce consumption goods increases with the variance of intermediate capital and always exceeds the capital obtained by using the average amount of intermediate capital.

One may wonder to which extent our result about the social undesirability of free and perfect public information could be an artifact of these assumptions. In fact, it is the opposite. The exponential shape of capital production implies that *average production increases with variance*, and as information induces more variance by discouraging market-insurance, information is more, not less, desirable compared to, a perhaps more realistic, linear or concave production function of capital. Intuitively, when agents use information technologies intensively prices are volatile. On the one hand, this volatility generates utility losses from consumption uncertainty: the negative face of information. On the other hand, this volatility implies a higher expected consumption, and utility gains: our positive face of information. Thus, our functional forms overestimate the social benefits of information technologies.

4.4 Unconstrained Social Optimum

Now, we study a planner that seeks to maximize the ex-ante utility of a representative agent, and can freely redistribute intermediate capital (it is not restricted by decentralized markets compensations). Individuals could implement this allocation if they were able to write ex-ante contracts which specify transfers of intermediate capital contingent on productivity realizations.

We have already established that the unconstrained optimal is achieved with a data-intensive technology that does not leak information to the public, this is $f(a) = 0$ for all a. In this case it is optimal to use information technologies fully, and both self- and market-managing risks. For this reason we focus on the other extreme, in which the data-intensive technology fully leaks information to the public, this is $f(a) = a$ for all a. Even in this extreme, we show that the unconstrained planner still prefers to always use fully information technologies.

We assume the planner can choose both the proportion of in-house production of intermediate capital β_i and the exchange of intermediate capital after production τ_i. Given that, in this benchmark, the planner's hands are not tied by market compensations, her problem becomes,

$$\max_{\{\beta_i(j),\tau_i\}_{(i,j)\in(0,1)^2}} E[\mathbb{U}(K_i)]$$

subject to

$$\begin{aligned} k_i &= (\bar{\theta}+\theta_i)\beta_i + \tau_i + \int_{J(i)} \left[(\bar{\theta}+\theta_j)\beta_i(j) - \frac{\varphi}{2}\beta_i^2(j)\right] dj\,, \\ \int \tau_i\, di &= 0\,, \\ 1-\beta_i &= \int_{J(i)} \beta_j(i)\, dj \end{aligned}$$

In other words, the planner maximizes ex-ante utility by controlling the production of intermediate capital, through β_i, and its distribution, through τ_i.

Proposition 4 (Unconstrained planner's solution)**.** *The unconstrained planner allocation is characterized by no-trade in raw capital (that is $\beta_i = 1$ for all i) and redistribution of intermediate capital as follows,*

$$\tau_i = \begin{cases} 0 & \text{if } \sigma < 1 \\ -\theta_i & \text{if } \sigma \geq 1 \end{cases}$$

Proof. Postponed to Appendix A.4. □

Intuitively, an unconstrained planner wants to employ raw capital where it is most productive - in the hands of original owners who don't face adjustment costs

- and, having maximized aggregate intermediate capital, go on to achieve perfect risk sharing when it is desired (this is, when $\sigma > 1$), by equalizing intermediate capital via redistribution. This implies all agents would also choose same labor and enjoy same consumption. In stark contrast to the market, which allocates more intermediate capital to the agents with higher productivity (*regressive redistribution*), the unconstrained planner allocates more intermediate capital to agents with lower raw capital productivity (*progressive redistribution*).

For the unconstrained planner, it is always optimal to operate information technologies, as this allows her to make transfers contingent on productivity (more transfers to less productive agents when $\sigma > 1$). In other words, when the planner is not constrained on how to redistribute, information is unequivocally beneficial as the planner will use it to both increase production and equalize labor and consumption. This is not the case in equilibrium because the market uses information in a way that increases production but prevents risk sharing. All in all, a planner may prefer to avoid information technologies only when it is constrained on how to redistribute.

Implementation of the unconstrained social optimal with taxes. With incomplete markets, a government could implement the planner's desired allocation by imposing taxes and subsidies that achieved zero-trade along with redistribution as per $\tau_i(\theta_i)$. Naturally, the feasibility of such transfers would critically depend on observability, pledgeability, and verifiability of raw capital productivity by the government. This result stresses once more an important assumption of the standard view that information is important for insurance to work properly by facilitating the fulfillment of contingent contracts.[14]

[14]Notice that the optimal set of taxes and subsidies eliminates the need of private contracts, an extreme version of a rich literature that claims that public insurance may crowd out private insurance (such as Golosov and Tsyvinski (2007), Krueger and Perri (2011) and Park (2014)).

5 Final remarks

Information technologies (IT) are well known for improving decisions and price discovery. We show that the combination of these positive partial equilibrium effects induce a negative general equilibrium result: *scarcity of safe assets* in equilibrium. In our setting a safe asset is a diversified portfolio of known quality, constructed by buying pieces of assets that others sell. IT discourage the supply of assets because their prices better reflect fundamentals, and agents prefer to keep the assets that selling them at a cost. But when agents keep their assets, they rather use IT more intensively to make better decisions, hence discouraging supply even further.

When agents make IT and trading decisions, however, do not internalize the role of their asset supply on the diversification possibilities of other agents. They do not take into account their role on providing inputs for the production of safe assets in general equilibrium. For this reason there is a scarcity of safe assets and excessive use of IT relative to what a planner would implement. Allocations can be realigned by the government with taxes on the use of IT or subsidies on selling assets, but also by financial intermediaries, such as mutual funds, that structure asset backed securities.

In spite of our main general equilibrium result, the trade-off that IT induces between self-management and market-management of risk also provides partial equilibrium insights to inform recent regulatory reforms. Take the case of banking stress tests, for instance. When regulators reveal to a bank results about stress scenarios, they reveal pieces of information (mostly about sources of systemic risk) that are useful for the bank to rebalance its own portfolio (the positive face of improving self-insurance). Those pieces of information, however, also become available to other banks, who may revise their own beliefs about the bank's individual portfolio and its market valuation, introducing additional volatility and inhibiting the functioning of interbank markets (the negative face of weakening market-insurance). This trade-off is critical in designing information disclosure of stress tests once regulators weight the relevance of portfolio rebalancing vs. interbank market operations.

We have been deliberately agnostic about the type of information technologies and idiosyncratic risks we consider, hence providing a laboratory to study their interplay that displays two properties. First, it parsimoniously combines macro and finance standard tools, making it amenable to use in studying the join effect of other technologies or policies that involve the combination of real and financial activities. Second, it is flexible enough to accommodate different technological parameters, preferences, market protocols and information characteristics, which may guide empirical efforts to uncover the heterogeneity in the adoption and use of information across countries, industries and firms that are observed in the economy.

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A Proofs

A.1 Proof of Lemma 2 and Corollary 1

Proof. **Derivation of ex-ante utility.** We first note that

$$\frac{\phi}{\gamma}\alpha(1-\sigma) = \phi - 1.$$

Using (1),(2) and (6), and denoting $\hat{k}_i = (1-\alpha)(1-\sigma)k_i$ we can write the unconditional expected utility as

$$\begin{aligned}
E[\mathbb{U}(E_i[K_i])] &\equiv E\left[\frac{K_i\, E_i[K_i]^{\frac{\phi}{\gamma}\alpha(1-\sigma)}}{\alpha(1-\sigma)} - \frac{1}{\gamma}E_i[K_i]^{\phi}\right] \\
&= \alpha^{\phi} E\left[\frac{e^{\hat{k}_i}\, E_i[e^{\hat{k}_i}]^{\phi-1}}{\alpha(1-\sigma)} - \frac{1}{\gamma}E_i[e^{\hat{k}_i}]^{\phi}\right] \\
&= \alpha^{\phi} E\left[\frac{e^{\hat{k}_i - E_i[\hat{k}_i] + \phi E_i[\hat{k}_i] + \frac{\phi-1}{2}V_i(\hat{k}_i)}}{\alpha(1-\sigma)} - \frac{1}{\gamma}e^{\phi E_i[\hat{k}_i] + \frac{\phi}{2}V_i(k_i)}\right] \\
&= \alpha^{\phi}\left(\frac{e^{\frac{1}{2}V_i(\hat{k}_i) + \phi E[\hat{k}_i] + \frac{\phi^2}{2}V(E_i[\hat{k}_i]) + \frac{\phi-1}{2}V_i(\hat{k}_i)}}{\alpha(1-\sigma)} - \frac{1}{\gamma}e^{\phi E[\hat{k}_i] + \frac{\phi^2}{2}V(E_i[\hat{k}_i]) + \frac{\phi}{2}V_i(\hat{k}_i)}\right) \\
&= \alpha^{\phi}\left(\frac{1}{\alpha(1-\sigma)} - \frac{1}{\gamma}\right) e^{\phi E[\hat{k}_i] + \frac{\phi^2}{2}V(E_i[\hat{k}_i]) + \frac{\phi}{2}V_i(\hat{k}_i)} \\
&= \Phi\, \alpha^{\phi}\, e^{\phi E[\hat{k}_i] + \frac{\phi^2}{2}V(E_i[\hat{k}_i]) + \frac{\phi}{2}V_i(\hat{k}_i)}
\end{aligned}$$

where

$$\Phi \equiv \frac{\gamma - \alpha(1-\sigma)}{\gamma\alpha(1-\sigma)},$$

which is positive for $\sigma < 1$ and negative for $\sigma > 1$.

Utility-maximizing asset demand. Agent i maximizes $E[\mathbb{U}(E_i[K_i])]$ choosing $\beta_i(j)$ such that, for all j, where

$$k_i = \left(\bar{\theta} + \theta_i\right)\beta_i + (1-\beta_i)R_i + \int_{J(i)} \Pi_i(j)dj.$$

The first order condition for $\beta_i(j)$ reads as:

$$\begin{aligned}\phi(1-\alpha)(1-\sigma)\frac{\partial E\left[\int_{J(i)}\Pi_i(j)dj\right]}{\partial\beta_i(j)}E[\mathbb{U}(E_i[K_i])] &+ \\ \frac{\phi^2}{2}(1-\alpha)^2(1-\sigma)^2\frac{\partial V\left(\int_{J(i)}\Pi_i(j)dj\right)}{\partial\beta_i(j)}E[\mathbb{U}(E_i[K_i])] &+ \\ \frac{\phi}{2}(1-\alpha)^2(1-\sigma)^2\frac{\partial V_i\left(\int_{J(i)}\Pi_i(j)dj\right)}{\partial\beta_i(j)}E[\mathbb{U}(E_i[K_i])] &= 0\end{aligned}$$

Since portfolio returns enter exponentially in the utility function, constant absolute risk aversion obtains, and the optimal individual asset demand is invariant in the expected value of the rest of the portfolio (total amount of intermediate capital) - as in standard CARA asset pricing models.

In what follows we solve for the profit-maximizing demand of raw capital and then show that it is also the utility-maximizing demand of raw capital satisfying the first order condition above. The profit maximizing demand of agent i, denoted by $\beta_i^*(j) \in (0,1)$ must satisfy:

$$\begin{aligned}\frac{\partial E_i[\Pi_i(j)]}{\partial\beta_i(j)} &= \frac{\partial E_i\left[\left(\bar{\theta}+\theta_j\right)\beta_i(j)-\frac{\varphi}{2}\beta_i^2(j)-R_j\beta_i(j)\right]}{\partial\beta_i(j)} = 0 \\ \implies \quad \beta_i^*(j) &= \frac{\bar{\theta}+E_i[\theta_j]-R_j}{\varphi}\end{aligned} \tag{30}$$

If the supply of agent j's raw capital is $1-\beta_j$, market clearing implies,

$$\int_{I(j)}\beta_i^*(j)di = 1-\beta_j,$$

and the equilibrium price in the market of agent j's raw capital would be

$$R_j = \bar{\theta}+E_i[\theta_j]-\varphi(1-\beta_j). \tag{31}$$

Equations (30) and (31) correspond to those in Lemma 2. Since all agents other than j have identical information about agent's j raw capital, $E_i[\theta_j]$ is the same for all $i \in I(j)$. The profit of agent i as a buyer of agent j's raw capital can then be written as

$$\Pi_i(j) = (\theta_j - E_i[\theta_j])(1-\beta_j)+\frac{\varphi}{2}(1-\beta_j)^2.$$

By a law of large numbers with a continuum of iid random variables $\int_{(0,1)} E_i[\theta_j]dj = \int_{(0,1)} \theta_j dj = 0$ almost surely.[15] As stated in Corollary 1, aggregate portfolio profits,

$$\int_{J(i)} \Pi_i(j)dj = \frac{\varphi}{2} \int_{J(i)} (1-\beta_j)^2 dj$$

are deterministic, agents attain perfect diversification, and (since this quantity is strictly positive) agent's total demand for raw capital can be "self-financed".

Now, we prove the conjecture that profit-maximizing demand is the same as utility-maximizing demand. Since portfolio profits are deterministic, $V_i\left(\int_{J(i)} \Pi_i(j)dj\right) = V\left(\int_{J(i)} \Pi_i(j)dj\right) = 0$ and,

$$\frac{\partial V(\int \Pi_i(j)dj)}{\partial \beta_i(j)} = 2E\left[\frac{\partial \Pi_i(j)}{\partial \beta_i(j)}\left(\int \Pi_i(j)dj - E\left[\int \Pi_i(j)dj\right]\right)\right] = 0$$

which shows, jointly with (30), that profit-maximizing demand $\beta_i^*(j)$ also satisfies utility-maximizing first-order conditions.

Finally, the expression for the quantity of intermediate capital available to agents at the end of the period, as stated in equation (13) in Corollary 1, comes from substituting the price received from selling raw capital (equation (31) for agent i) and the profits from buying raw capital (equation (12)) into equation (9). □

A.2 Proof of Lemma 3

Using results form the previous proposition about the derivation of ex-ante utility, we can write the unconditional expected utility as

$$E[\mathbb{U}(E_i[K_i])] = \Phi \bar{K} e^{\phi(1-\alpha)^2(1-\sigma)^2\left(\frac{\phi}{2}V(E_i[k_i]) + \frac{1}{2}V_i(k_i)\right)}$$

where

$$\bar{K} = \alpha^\phi e^{\phi E[\hat{k}_i]} = \alpha^\phi\, e^{\phi(1-\alpha)(1-\sigma)\left(\bar{\theta} - \varphi(1-\beta_i)^2 + \frac{\varphi}{2}(1-\beta)^2\right)}$$

gathers all deterministic factors, and $V(E_i[k_i])$ and $V_i(k_i)$ are the volatility of the conditional mean and the conditional volatility, of k_i respectively. Using (5), these

[15] Sun, Yeneng and Yongchao Zhang (2009), "Individual risk and Lebesgue extension without aggregate uncertainty", *Journal of Economic Theory* 144, 432-443.

last two terms obtain as:

$$
\begin{aligned}
V(E_i[k_i]) &= V\left(\beta_i(\sqrt{f(a_i)}\,\hat{\theta}_{\mathtt{c},i} + \sqrt{a_i - f(a_i)}\,\hat{\theta}_{\mathtt{p},i}) + (1-\beta_i)\sqrt{f(a_i)}\hat{\theta}_{c,i}\right) \\
&= \left(\beta_i^2 a_i + (1-\beta_i)^2 f(a_i) + 2\beta_i(1-\beta_i) f(a_i)\right) \\
&= \left(\beta_i^2\,(a_i - f(a_i)) + f(a_i)\right),
\end{aligned}
$$

and

$$
\begin{aligned}
V_i(k_i) &= V\left(k_i - E_i[k_i]\right) \\
&= V\left(\beta_i\theta_i + (1-\beta_i)\sqrt{f(a_i)}\hat{\theta}_{c,i} - E_i[k_i]\right) \\
&= V\left(\beta_i\sqrt{1-a_i}\,\hat{\theta}_{\mathtt{p},u}\right) \\
&= \beta_i^2(1-a_i).
\end{aligned}
$$

where, in the latter, we used the fact that the conditional volatility $V_i(x)$ of a random variable x is equal to the volatility of the forecast error conditioning on the information set i, this is $V(x - E_i[x])$, the unexplained volatility of x according to information set held by i.

A.3 Proof of Proposition 2

To solve the two benchmarks from an individual perspective, let us fix others supply choices to $\{\beta_j\}_{j\neq i}$ and define

$$
\hat{\Phi} = \Phi\,\alpha^{\phi}\,e^{(1-\alpha)(1-\sigma)\phi\frac{1}{2}\int(1-\beta_j)^2 dj}
$$

With full-information, there is never trade $\beta_i^*(a_i = 1) = 1$ from equation (21). Further, given that $V_i(k_i) = 1$, according to Lemma (3) we have,

$$
\begin{aligned}
\hat{\Phi}E[K_i(\theta_i)^{\phi}] &= \hat{\Phi}e^{(1-\alpha)(1-\sigma)\phi\bar{\theta}+\frac{1}{2}((1-\alpha)(1-\sigma))^2\phi^2} = \\
&= \hat{\Phi}e^{(1-\alpha)(1-\sigma)\phi\bar{\theta}}E[e^{(1-\alpha)(1-\sigma)\theta_i}]^{\phi^2}
\end{aligned}
$$

With no information, trade is possible, as characterized by $\beta_i^*(a_i = 0)$ from equation (21). In this case, $V_i(k_i) = \beta_i^{*,2}$, according to Lemma (3) we have,

$$
\begin{aligned}
\hat{\Phi}E[K_i(\theta_i)]^{\phi} &= \hat{\Phi}e^{(1-\alpha)(1-\sigma)\phi\left(\bar{\theta}-\varphi(1-\beta_i^*)^2\right)+\frac{1}{2}((1-\alpha)(1-\sigma))^2\phi\beta_i^{*,2}} = \\
&= \hat{\Phi}e^{(1-\alpha)(1-\sigma)\phi\bar{\theta}}e^{\frac{1}{2}(1-\alpha)^2(1-\sigma)^2\phi\left(\beta_i^{*,2}-\frac{2\varphi}{(1-\alpha)(1-\sigma)}(1-\beta_i^*)^2\right)} \\
&= \hat{\Phi}e^{(1-\alpha)(1-\sigma)\phi\bar{\theta}}E[e^{(1-\alpha)(1-\sigma)\theta_i}]^{\phi\left(\beta_i^{*,2}-\frac{2\varphi}{(1-\alpha)(1-\sigma)}(1-\beta_i^*)^2\right)}
\end{aligned}
$$

where we define

$$\beta^I \equiv \beta_i^{*,2} - \frac{2\,\varphi}{(1-\alpha)(1-\sigma)}(1-\beta_i^*)^2 = \beta_i^{*,2} + A(1-\beta_i^*)^2$$

where $A = \frac{2\,\varphi}{(1-\alpha)(\sigma-1)}$ and $\beta_i^*(a_i = 0) = \frac{A}{1+A}$, from Lemma 4. Then,

$$\beta^I = \frac{1}{1 - \frac{1-\alpha}{\varphi}(1-\sigma)\chi^I}; \qquad \texttt{with} \quad \chi^I = \frac{1}{2}.$$

Finally, from the planner's perspective it also takes into account this is a symmetric situation, so the computation is identical to the social perspective analysis, but replacing β_i^* by β^*. Then we define

$$\beta^P \equiv \beta^{*,2} - \frac{\varphi}{(1-\alpha)(1-\sigma)}(1-\beta^*)^2 = \beta^{*,2} + A_P(1-\beta^*)^2$$

where $\beta^*(a = 0) = \frac{A_P}{1+A_P}$ from equation (24) and $A_P = \frac{\varphi}{(1-\alpha)(\sigma-1)}$ from equation (25). Then,

$$\beta^P = \frac{1}{1 - \frac{1-\alpha}{\varphi}(1-\sigma)\chi^S}; \qquad \texttt{with} \quad \chi^S = 1.$$

A.4 Proof of Proposition 4

Proof. The problem of the unconstrained planner is

$$\max_{\{\hat{\beta}_i(j),\tau_i\}_{(i,j)\in(0,1)^2}} E[\mathbb{U}(K_i)] = \Phi\alpha^{\phi} e^{(1-\alpha)(1-\sigma)\phi E[k_i] + \frac{1}{2}((1-\alpha)(1-\sigma)\phi)^2 V(k_i)} \tag{32}$$

where

$$k_i = \bar{\theta} + \beta_i\theta_i - \tau_i + \int_{J(i)} \beta_i(j)\theta_j\, dj - \int_{J(i)} \frac{\varphi}{2}\beta_i^2(j)\, dj\,,$$

subject to the resource and balance-budget constraints,

$$1 - \beta_i = \int_{J(i)} \beta_j(i) dj$$
$$0 = \int \tau_i di$$

The first observation is that necessarily in any equilibrium $1-\beta_i = \beta_j(i) = \beta_h(i)$ for any $j, h \in J(i)$. If this condition were violated, let us say $\beta_h(i) < \beta_j(i)$, the planner could save on quadratic costs without loosing on expected production by moving raw capital type i from agent j to agent h. By the law of large numbers, and using the relevant constraints,

$$\begin{aligned} E[k_i] &= \bar{\theta} + \int \beta_i \theta_i \, di - \int \tau_i di - \int \int_{J(i)} (1-\beta_j)\theta_j \, dj \, di - \frac{\varphi}{2} \int \int_{J(i)} (1-\beta_j)^2 \, dj \, di \\ &= \bar{\theta} - \frac{\varphi}{2} \int (1-\beta_i)^2 \, di \, , \\ V(k_i) &= \int \left(\beta_i \theta_i - \tau_i - \int \beta_i \theta_i \, di \right)^2 di. \end{aligned}$$

where we used $E[\theta_i] = \int \theta_i di = 0$ and,

$$\int_{J(i)} (1-\beta_j)\theta_j \, dj = \int (1-\beta_j)\theta_j \, dj \quad \text{and} \quad \int_{J(i)} (1-\beta_j)^2 \, dj = \int (1-\beta_j)^2 \, dj$$

As such,

$$\begin{aligned} \frac{\partial E[k_i]}{\partial \beta_i} &= \varphi(1-\beta_i) \\ \frac{\partial V(k_i)}{\partial \beta_i} &= 2\theta_i \left(\beta_i \theta_i - \tau_i - \int \beta_i \theta_i \, di \right) \\ \frac{\partial V(k_i)}{\partial \tau_i} &= 2 \left(\beta_i \theta_i - \tau_i - \int \beta_i \theta_i \, di \right) \end{aligned}$$

all of which are equal to zero at $\beta_i = 1, \tau_i = -\theta_i$ and therefore imply that all the necessary first order conditions of problem (32) (factoring in the constraints) for optimality are also satisfied. □