

# Theoretical framework

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March 14, 2024

## Abstract

This thesis formulates a Ramsey-Cass-Koopmans theoretical model, addressing the complex scenario wherein firms, intent on dividend maximization, grapple with financial frictions encompassing both monitoring costs and fixed leverage constraints. A pivotal achievement of this work is the derivation of a closed-form solution to the firms' infinite intertemporal maximization problem, encapsulated within the participation constraints of financial lenders, underpinned by monitoring expenditures and financing constraints. Employing a Lagrangian framework, I extract the Euler equation for dividends, thereby uncovering the fundamental principles guiding optimal dividend policies in the face of financial constraints.

Building on the analytical groundwork, the thesis employs Monte Carlo simulations to investigate the behavior of heterogeneous firms—varied in terms of leverage and productivity—under the influence of business cycles. It uncovers that the 'cleansing effect,' which fosters a reallocation of resources during economic downturns, leads to a 20% augmentation in the overall output of the economy in scenarios devoid of monitoring costs. However, this effect is attenuated to a 7% increase when firms are subject to a 15% monitoring cost. This empirical evidence, aligning with insights from Osotimehin and Pappadà [2017], confirms the theoretical propositions regarding the modulating role of financial frictions on the cleansing effect.

In conclusion, this thesis contributes significantly to the literature by providing a comprehensive analysis of how financial frictions impact firm behavior and the overall economic landscape. By developing a model that captures the effects of such frictions on firm dynamics and leveraging empirical evidence to validate theoretical insights. This endeavor sets the stage for subsequent investigative efforts in the field.

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# Chapter 1

## Introduction

In macroeconomic theory, the dynamic interplay between business cycles and long-term economic growth poses a complex challenge, drawing a parallel to the reconciliation efforts between quantum mechanics and Einstein's theory of relativity in physics. This traditional academic compartmentalization tends to overlook a crucial question: how do business cycles affect long-term economic growth? Investigating this query is essential, as it sheds light on the implications of short-term economic policies for the broader economic trajectory.

This thesis focuses on the dynamics of firm optimization amidst financial frictions, bridging theoretical constructs with practical economic phenomena. A significant portion of this research is devoted to understanding how financial market frictions might influence the 'cleansing effect' of reallocation. This effect, akin to natural selection, is scrutinized for its potential long-term impacts on economic stability and growth.

Inspired by biological cycles and their long-term trends, described in Lotka-Volterra equations, this work draws an analogy to economic cycles, suggesting that short-term fluctuations may conceal underlying growth patterns. Similar to biological interventions that might initially seem beneficial, economic policies aimed at stabilizing cycles could inadvertently hinder the natural selection process, leading to unforeseen long-term consequences.

Employing a biological analogy, this thesis hypothesizes that recessions can act as a natural selection mechanism within economies, purging less efficient firms and promoting more productive ones. Through theoretical models and Monte Carlo simulations, this research endeavors to elucidate the relationship between short-term economic fluctuations and long-term growth. The thesis particularly emphasizes solving firms' intertemporal maximization problems under financial constraints through a closed-form solution, spotlighting the significant influence of financial frictions.

Recessions are characterized by increased instances of bankruptcies and business shutdowns. Notably, during the Great Recession, the annual establishment exit rate in the US escalated from 11.8% to 13.5% from March 2008 to March 2009. This surge in firm exit rates during economic contractions has propelled the notion that recessions serve a 'cleansing' role in the economy: inefficient firms, becoming unprofitable, are phased out, thereby facilitating the redistribution of resources to more productive entities.

This traditional perspective, highlighted in the work of Caballero and Hammour [1994], presupposes that markets inherently favor the survival of the most productive firms. Nonetheless, this premise has been contested by numerous studies indicating that a firm's likelihood of exiting is influenced not just by its productivity but also by its ability to secure credit. These insights imply that, amidst credit frictions, even highly productive firms that are financially strained might be compelled to leave the market. Consequently, credit frictions could potentially undermine the productivity-boosting impact of recessions as found in Osotimehin and Pappadà [2017].

This thesis marks a significant departure from prior studies that predominantly rely on numerical methods by offering a closed-form solution for determining the optimal trajectories of capital and dividends. Such a breakthrough provides a nuanced understanding of the intertemporal maximization challenges faced by firms. This research delves into the repercussions of credit frictions on the cleansing effect observed during recessions within a framework encompassing firm dynamics, credit restrictions, and mechanisms for firm exit. It is found that, even in the presence of credit frictions,

recessions exert a cleansing effect by enabling the redistribution of resources to more efficient entities.

Credit constraints within the model are endogenously driven by asymmetric information and the costs associated with verifying states. Incorporating a one-period financial contract, mirroring the methodology proposed by Bernanke and Gertler [1986], into the model of firm dynamics, allows for the delineation of borrowing capabilities and the determination of interest rates by financial intermediaries, which are contingent upon each firm’s productivity and leverage. Additionally, the model imposes a borrowing constraint on firms, stipulating that leverage is exogenous and remains constant over time.

Following the theoretical developments, this thesis employs Monte Carlo simulations to rigorously analyze the behavior of firms differentiated by their productivity and leverage ratios in the face of business cycle fluctuations. These fluctuations are modeled as continuous sinusoidal shocks to the productivity component, simulating the dynamic pressures of economic cycles. A key feature of the model is the exit mechanism, which compels firms to exit the market if their return on capital falls below the risk-free rate, directly engaging with the discourse on the cleansing effect of recessions.

The heterogeneity in firm characteristics, notably in terms of productivity and leverage, allows for a detailed examination of how diverse firms respond to economic cycles and credit constraints. Firms with higher leverage may face greater financial stress during downturns, influencing their survival and contributing to the market’s cleansing process. Similarly, variations in productivity affect firms’ ability to withstand economic shocks, further delineating the selection process during recessions.

The simulations reveal that recessions facilitate a significant enhancement in the economy’s overall output by enabling the reallocation of resources towards more efficient firms, particularly in scenarios devoid of monitoring costs. However, the introduction of such costs tempers this efficiency gain, underscoring the nuanced role that financial frictions play in influencing the economy’s adaptive capacity during downturns. This observed cleansing effect, albeit modulated by the presence of financial

frictions, substantiates the theoretical assertions posited earlier in the thesis.

Moreover, this empirical evidence, resonating with the findings from Osotimehin and Pappadà [2017], affirms the contention that, despite the dampening influence of credit constraints, recessions retain an inherent capacity to purge the economy of less efficient firms. This mechanism, facilitated by a well-defined exit criterion based on returns relative to the risk-free rate and nuanced by firm-specific attributes of productivity and leverage exemplifies the complex interplay between financial frictions, firm dynamics, and economic resilience under cyclical pressures.

The initial segment of this thesis introduces the theoretical frameworks of Caballero and Hammour [1994] and Osotimehin and Pappadà [2017], aiming to highlight how the incorporation of financial frictions alters previously established results in the literature. Following this introduction, the thesis delves into the formulation of theoretical models that explore the dynamics of capital flow and debt in financial contracts. An examination of the firm's problem in the absence of debt, mirroring the Ramsey-Cass-Koopmans model where consumption is represented by dividends and leverage, employs a Lagrangian approach to derive the Euler equation for dividends. This equation serves as the cornerstone for determining the optimal policies for dividends and investment. Utilizing the derived solution, a phase diagram for capital and dividends is constructed to identify a potential saddle path toward a stationary state for both variables.

Subsequently, the theoretical model is expanded to accommodate the firm's ability to finance investment through debt, subjecting it to financial frictions manifested as monitoring costs and borrowing constraints. By applying the Lagrangian method, steady-state conditions for dividends are extracted from the Euler equation, along with consolidation constraints to ascertain the steady-state condition for capital. These findings enable the plotting of a phase diagram for capital and dividends, illustrating their interrelation.

Reformulating the problem through a Bellman equation and employing a guess-and-verify approach yields the optimal path for capital, policy function for dividends, and the steady state for capital.



In the concluding part, these results underpin simulations that assess the impact of monitoring costs on capital, demonstrating significant reductions in capital levels due to such costs. Monte Carlo simulations further explore economies with heterogeneous firms, characterized by variations in leverage and productivity. Firms in this model are compelled to exit if their return on capital falls below the risk-free rate, enabling an examination of the cleansing effect of recessions in the context of financial frictions. This multifaceted analysis offers insightful conclusions about the influence of financial frictions on firm behavior, the allocation of resources, and the overall efficiency of the economy during downturns, thereby contributing to the broader understanding of economic dynamics in the presence of financial constraints.

# Chapter 2

## Literature review

### 2.1 Business cycle history

#### 2.1.1 From Business Cycles to Long-Term Growth

In the domain of economic theory, the relationship between business cycles (BC) and long-term growth is dissected into two principal schools of thought. The conventional viewpoint suggests that long-term growth is chiefly propelled by technological progress. Within this framework, technological advancements are often viewed as exogenous—arising outside the economic model’s explanatory scope, as highlighted in the seminal contributions of Solow [1956] and Swan [1956]. This perspective treats technological progress as an independent variable that exerts influence on economic growth without being influenced by the economy’s internal dynamics.

Contrastingly, an alternative strand of theoretical work aims to endogenize technological progress, weaving it into the fabric of the economic process. These models embed factors such as incentives for innovation, the value of education, and the accumulation of knowledge through economic activities, epitomizing the ‘learning by doing’ paradigm. A prominent example of this approach is found in Stadler [1990], which posits technological progress as an emergent property of economic behavior and incentives, rather than a mysterious external force.

A critical aspect of the 'learning by doing' model is its premise that technological frontiers are contingent upon the existing knowledge base, which expands primarily through practical experience. Consequently, periods of economic expansion witness a sharp increase in the knowledge stock, driven by higher employment levels, whereas recessions tend to stabilize or even diminish this stock due to reduced employment rates. This dynamic suggests that economies devoid of cyclical fluctuations might attain superior steady-state growth, as employment remains consistently high, fostering continuous technological advancement. From this perspective, the concept of a 'cleansing effect'—whereby economic downturns eliminate low-productivity jobs and ostensibly strengthen the economy—is challenged. The elimination of even low-productivity roles can erode the overall knowledge base.

Such theories reframe the discourse on stabilization policies, particularly fiscal interventions, by highlighting their role in sustaining employment and, by extension, supporting the technological frontier even in downturns.

To illustrate this theory's implications more vividly, consider a nuanced example: an antiquated factory with limited land resources discovers an innovative method to utilize an old tractor more efficiently. Despite the ingenuity of this breakthrough, if the broader economy has moved beyond the technology that the tractor represents, the innovation might not significantly contribute to the overall knowledge stock or push the technological frontier forward. This scenario prompts a fundamental inquiry: does innovation at the lower end of the skill spectrum or within outdated technological contexts meaningfully advance the technological frontier? Or, would it be more beneficial for economic growth to transition such small-scale innovations into larger entities equipped with modern technologies?

One significant critique concerns the disparity in learning opportunities across different sectors and among individuals. The model's premise of uniform learning opportunities does not always align with the reality that some industries, such as the technology sector, offer rapid innovation and learning environments compared to more traditional manufacturing industries, where the pace of learning and innovation may

be inherently slower due to the nature of the work processes involved.

Furthermore, the model may not adequately address the issue of structural unemployment that can arise from technological advancements. As certain workers benefit from 'learning by doing,' leading to increased productivity, others may find their skills becoming obsolete due to automation and other technological changes. This dynamic is evident in the automation of routine manufacturing jobs, which, while fostering 'learning by doing' in fields like robotics and software engineering, simultaneously leads to structural unemployment for workers displaced by these technologies.

Another point of contention is the potential for diminishing returns to learning. The assumption that 'learning by doing' continuously fuels growth may not hold up against the reality that initial rapid gains in productivity tend to taper off as workers gain proficiency, suggesting that the benefits of learning may diminish over time.

The model also potentially overlooks the externalities and spillover effects associated with 'learning by doing.' Technological advancements in one firm or sector do not automatically translate into broader economic growth if these advancements remain isolated and do not benefit other sectors or industries. This is illustrated by a software company that develops cutting-edge algorithms, enhancing its productivity but failing to contribute to the wider economy if the knowledge remains proprietary.

This nuanced exploration challenges the simplistic notion of 'learning by doing' by questioning the value and impact of incremental innovations within the broader economic and technological ecosystem. It underscores the complexity of technological progress and its interplay with economic dynamics, inviting a deeper investigation into the mechanisms that drive long-term growth and the role of policy in nurturing an environment conducive to continuous innovation and knowledge expansion.

The contemporary perspective on technological advancement, when viewed as a product of incremental contributions from every market participant, appears overly simplistic. A more accurate depiction of technological progress recognizes it as predominantly driven by those at the forefront of research. The expansion of the technology frontier is essentially shaped by the knowledge and breakthroughs of these leading-edge

innovators. Other entities in the economy adopt these innovations at varying paces, influenced by the associated adoption costs. While firms that are not at the innovation frontier may achieve marginal efficiency gains through adoption, the impact of such improvements is often minimal. These marginal innovations are frequently a reflection of the adopting firms' constraints, particularly their inability to invest in more advanced and expensive technologies. Consequently, these incremental innovations have limited potential for widespread diffusion, as they stem from a position of necessity rather than pioneering advancement.

Another theory describes a recession as a period in which the opportunity cost of investing in productivity-enhancing projects is lower since the workforce is not fully in demand to produce goods. Doing this would lead in theory to higher productivity in the period of expansion. The key role here is that the productivity-enhancing activity is costly and thus diverts capital and labor force from production as Hayek [1933] explained. For this view to be valid two key aspects should be true at the same time: in the first place the expectations about the length of the recession should reinter in the short-term otherwise it is cheaper to destroy some production units (labor and capital) to accommodate the slow in demand. The last condition is that internal resources must be less costly than external ones, however, it would be cheaper to hire more skilled workers and fire the low-skill one. An additional remark is that this theory describes all those initiatives like worker formation that affect only marginally the productivity of a firm. It misses the main mechanics in which a firm can increase its productivity sharply: thorough technical innovation, and to do so you need a research program where the workforce is fully dedicated to it and not diverted from production.

Another theory posits that recessions offer a period in which the opportunity cost of investing in productivity-enhancing projects are lower, primarily because the workforce is not fully engaged in producing goods. Theoretically, this would lead to higher productivity during subsequent periods of expansion. A crucial element in this perspective is the acknowledgment that productivity-enhancing activities are expensive, thereby diverting capital and labor away from immediate production, a concept Hayek [1933]

elucidated.

For this viewpoint to hold, two critical conditions must be concurrently satisfied: firstly, expectations regarding the duration of the recession must be short-term. If the recession is anticipated to be prolonged, it becomes economically viable to dismantle some production units (both labor and capital) to adjust to reduced demand. Secondly, the cost of utilizing internal resources for such productivity-enhancing ventures must be lower than the cost of acquiring external resources. Otherwise, it might be more economical to hire more skilled workers and lay off less skilled ones.

An additional observation about this theory is that it accounts for initiatives like worker training, which only marginally affect a firm's productivity. This overlooks the primary mechanism through which a firm can significantly boost its productivity: through technical innovation. To achieve substantial innovation, a dedicated research program is essential, where the workforce is fully committed to innovation efforts rather than being diverted to current production tasks. This highlights a gap in the theory, suggesting that while reallocating resources during recessions may offer some productivity benefits, the most dramatic productivity improvements are likely achieved through focused innovation and research activities, not merely through the opportunistic reallocation of resources during economic downturns.

An intricate theory that elaborates on the dynamics of economic recessions and the associated lower opportunity costs is grounded in the concept of labor hoarding, as discussed in the seminal work by Clark [1973]. This theory posits that firms maintain employment levels higher than what immediate efficiency metrics might dictate. The rationale behind such a strategy is to prepare for a potential surge in demand, ensuring that the firm can quickly ramp up production without the delays associated with recruiting and training new employees. However, this strategic maneuver towards the internal possibility frontier—where firms optimize their readiness for future demand—does not manifest as observable changes in employment rates. Consequently, this leads to discrepancies or residuals in the statistical series of employment, which do not align with what might be considered the level of optimal employment, a phenomenon further

analyzed in the work of Burnside et al. [1993].

This labor hoarding theory offers a partial explanation for the strong pro-cyclically of measured productivity. During economic upturns, firms can immediately respond to increased demand using their hoarded labor, thereby appearing more productive. Conversely, during downturns, the reluctance to shed this excess labor, due to the anticipation of future demand recovery, results in lower observable productivity levels. This behavior underscores a strategic depth in firm management, navigating through the cyclical economic waves by balancing between immediate efficiency and long-term responsiveness.

Expanding on this foundation, it becomes evident that the decision to engage in productivity-enhancing activities during recessions is not merely a reaction to lower opportunity costs but also a strategic consideration influenced by expectations of the recession's duration and the comparative costs of internal versus external resources. If firms anticipate a short-lived recession, the logic of hoarding labor and investing in internal productivity initiatives becomes compelling. However, this strategy hinges on the assumption that improving the skill set of the existing workforce or reallocating resources towards innovation is less costly than the alternative—acquiring new, possibly more skilled labor post-recession.

The opportunity cost (OC) approach closely aligns with the theory of labor hoarding, which seeks to elucidate the pronounced procyclicality of measured productivity. This observation implies that during economic downturns, firms appear to retreat towards the interior of their production possibility frontier, opting for a strategic reduction in operational efficiency rather than workforce downsizing. This strategy is partly attributed to the invisible nature of one crucial input—effort—to statisticians, and the economic rationale that, given the costs associated with employee turnover, it proves more economically viable for firms to dial back effort during slumps instead of terminating employment.

An intriguing alternative to diminishing effort is the redirection of employee tasks from immediate production roles to undertakings that bolster the firm's long-term pro-

ductivity. At first glance, this strategy bears a resemblance to labor hoarding but carries the added outcome that these so-called shadow activities, embraced during recessions, eventually manifest as enhancements in total factor productivity.

The concept of adjustment costs does not singularly confine firms from adapting their production factors according to operational necessities. This opportunity cost mechanism could theoretically extend to a macroeconomic scale, influencing individual entities via price adjustments. During periods marked by diminished production value, the immediate returns from production activities (e.g., wages for workers) decline in comparison to alternative endeavors, notably human capital accumulation, whose benefits are pegged to future earnings. This economic mechanism could precipitate a resource reallocation towards these alternative activities. The empirical observation that education durations tend to extend during economic recessions lends credence to this argument. Nevertheless, except for leisure, most sectors shadow the movements of aggregate GDP. Thus, if productivity-enhancing activities (PEAs) are to occur during recessions, the resource reallocation process must predominantly unfold within the firms themselves.

One notable deviation might be labor reallocation. As demonstrated by Davis and Haltiwanger [1992], job destruction exhibits a more countercyclical pattern compared to job creation. Viewing job reallocation through the lens of both destruction and creation suggests a countercyclical trend, positing job reallocation as an investment in cultivating superior firm-worker matches, thereby sowing the seeds for heightened productivity in the future. Davis and Haltiwanger [1992] further postulate, within the framework of a model featuring a representative agent, that economic recessions present an optimal window for labor reallocation, highlighting a strategic dimension to workforce management during downturns that might ultimately contribute to long-term productivity gains.

The 'lame ducks' theory, initially proposed by Caballero and Hammour [1994], offers an intriguing perspective on recessions as mechanisms that phase out less profitable, outdated capital. This theory delineates how the destruction of older units during down-



turns is more pronounced than the construction of new ones, characterizing recessions as periods marked by the systematic elimination of obsolete capital, hence the moniker 'lame ducks' theory. Notably, this framework sheds light on observations documented by Davis and Haltiwanger [1992], positioning it as a prominent theoretical approach that will be delved into more thoroughly in subsequent discussions.

Despite its insights, this model lacks consideration of the financial dimensions of firms, an aspect addressed by the theoretical work of Osotimehin and Pappadà [2017]. Their research weaves the financial decision-making process into the broader context of intertemporal capital decisions, highlighting how financial frictions influence the lender's participation constraint. The study reveals that, despite financial frictions, the cleansing effect of recessions on productivity persists, potentially leading to a more pronounced productivity surge during expansion phases. This analysis serves as a pivotal foundation for the new theoretical framework introduced in this thesis, marking a significant departure from traditional views and emphasizing the multifaceted impact of recessions on firm productivity and economic recovery.

In the forthcoming sections, we will explore the theoretical underpinnings that form the basis of the new, streamlined theoretical framework introduced in this thesis. Our examination begins with the insights of Caballero and Hammour [1994], focusing on the interplay between the destruction and creation margins in economic cycles. Subsequently, we will delve into the work of Osotimehin and Pappadà [2017], which sheds light on the financial dimensions, particularly how capital lending frictions can precipitate misallocations. These studies collectively inform the development of our theoretical framework, setting the stage for a comprehensive analysis of economic dynamics and firm behavior during recessions.

## 2.2 Literature review of theoretical models

### 2.2.1 Introduction

This section of the literature review examines two influential theoretical models that analyze the cleansing effect of recessions on the economy. The first model, introduced by Caballero and Hammour [1994], utilizes a vintage model of creative destruction to investigate how industries adapt to cyclical demand variations. This model is pioneering in its approach, highlighting how recessions can facilitate the removal of outdated and less efficient production units, potentially leading to an overall increase in industry productivity. The model's insights are derived from a framework where production units of varying vintages coexist, and the rate of technological adoption plays a crucial role in determining industry responses to economic fluctuations.

In contrast, the second model explored in this review, by Osotimehin and Pappadà [2017], introduces financial frictions into the analysis of the cleansing effect of recessions. This addition brings a new layer of complexity to the understanding of how economic downturns affect firm dynamics, particularly by influencing the selection process through which firms enter and exit the market. The model underscores the role of credit constraints in mediating the impact of recessions, suggesting that financial frictions can dampen the potential productivity gains that might otherwise arise from the purging effects of a downturn.

Both models rely on numerical methods to solve their respective frameworks, acknowledging the intricate dynamics and non-linearities inherent in their analyses. By comparing these models, this review seeks to illuminate the diverse mechanisms through which recessions can influence economic outcomes, as well as the varying implications of introducing different types of market frictions into theoretical frameworks.

### 2.2.2 The cleansing effect by Caballero

In the first paper that rationalizes the cleansing effect of recessions, Caballero and Hammour [1994] and published in the *American Economic Review* in 1994, the primary aim was to investigate how industries respond to cyclical variations in demand. They did this by employing a vintage model of creative destruction. The underlying concept postulates that the processes of creation and destruction within an industry partially explain business cycles. Industries continuously experiencing creative destruction can adapt to demand fluctuations in two ways: by adjusting the rate at which they produce new units embodying advanced techniques or by altering the rate at which outdated units are retired. The model they used incorporated heterogeneous firms, where production units embodied the most advanced technology at the time of their creation. The costs associated with creating new units slowed down technology adoption, resulting in the coexistence of production units with varying vintages.

Key to understanding how firms adapt to business cycles are the concepts of the creative margin and the destruction margin. For example, a demand reduction can be accommodated either by reducing the rate of technology adoption or by retiring older production units. One of the primary factors determining which margin is more responsive to business cycles is the adjustment cost. When this cost follows a linear pattern, the study shows that insulation is complete, and the industry's response relies exclusively on its creation margin. Consequently, the creation margin becomes smoother over time in comparison to the destruction margin, which exhibits greater responsiveness to the business cycle.

Crucially, Caballero and Hammour [1994]'s research Blanchard et al. [1990] offers theoretical insights supported by empirical evidence. Their findings on the cyclical nature of the destruction margin align with the studies conducted by Blanchard et al. [1990], as well as Davis and Haltiwanger [1992], in their respective works from 1990. This convergence between theoretical framework and empirical substantiation underscores the importance of comprehending the dynamic interplay between creative de-

struction and business cycles, which significantly influences how industries respond to economic fluctuations.

In their study Davis and Haltiwanger [1992], where they assess the heterogeneity of employment changes at the establishment level in the U.S. manufacturing sector from 1972 to 1986, it is revealed that job destruction exhibits procyclical tendencies, responding more robustly to downturns in the economic cycle compared to the creation rate, in line with the theoretical model proposed by Caballero and Hammour [1994] Caballero and Hammour [1994]. The authors leverage a natural experiment inherent in the data to examine whether the structure of adjustment costs can account for the behavior of these two margins. This natural experiment arises from the asymmetric nature of business cycles, with recessions being shorter but more severe than expansions. The theoretical model predicts that these differences should be attenuated in the creation process, a prediction that is substantiated by the data since creation exhibits relative symmetry around its mean, while destruction displays a high degree of asymmetry. The underlying concept driving the behavior of the destruction margin can be traced back to the theories of Schumpeter and Hayek. They suggest that recessions represent periods during which unprofitable or outdated techniques are pruned from the economy, leaving behind the most efficient firms Hayek and Caldwell [2007].

### **Theoretical model**

The model in question is a vintage model that simulates an industry experiencing exogenous technological progress. Within this model, production units are constructed using a fixed proportion of labor and capital, and they are continually being created and phased out. Notice that only the creation of new production units incurs a cost. This simplification is plausible, particularly in the context of the United States, where the expense associated with hiring is typically higher than the cost of termination, as demonstrated by Abowd and Kramarz [2003].

In this model, when a production unit is created at a specific time  $t_0$ , it embodies the most advanced technology available at that moment and consistently generates a uni-

form output represented by  $A(t_0)$  throughout its operational lifetime. The productivity of this technology denoted as  $A(t)$ , experiences continuous growth at an exogenously determined constant rate  $\delta \geq 0$ . This growth in technology can be interpreted in two ways: either as the adoption of new technology or as a product innovation. In the latter scenario, a continuum of perfectly substitutable products can yield varying levels of output.

$$[f(a, t) \quad 0 \leq a \leq \bar{a}(t)]$$

The above function represents the cross-sectional density of the production units aged  $a$  at time  $t$ , where  $\bar{a}(t)$  is the age of the oldest production unit at time  $t$ . The first assumption is that  $f(a, t)$  and  $\bar{a}(t)$  are continuous functions. The mass of production units at time  $t$  is given by:

$$N(t) = \int_{\bar{a}(t)}^0 f(a, t) da$$

$N(t)$  is a measure of either the industry's capital stock or its employment, due to a fixed share of capital and labor. Thus, the industry's output is given by:

$$Q(t) = \int_{\bar{a}(t)}^0 A(t - a) f(a, t) da$$

The deterioration of production units involves both an exogenous depreciation rate  $\delta$  and an endogenous destruction process, which impacts  $f(a, t)$  at its limits. The count of production units surviving for  $a$  years is expressed as:

$$f(a, t) = f(0, t - a)e^{-\delta a} \quad \text{where } 0 < a \leq \bar{a}(t)$$

The production flow is determined by:

$$\dot{N}(t) = f(0, t)[1 - \bar{a}(t)] + \delta N(t)$$

Here, the first term represents the production rate, while the second term encapsulates the destruction rate, encompassing the obsolescence rate  $f(\bar{a})(t)$ , the technological obsolescence change over time  $-f(\bar{a})(t)\bar{a}'(t)$ , and the depreciation rate  $\delta N(t)$ .

The assumptions made by the authors are denoted as  $\forall t \mid f(0, t) > 0 \cup \bar{a}'(t) < 0$ .

The alteration in output concerning these flows is articulated as:

$$\dot{Q}(t) = A(t)f(0, t) - A(t - \bar{a}(t))f(\bar{a}(t), t) \cdot [1 - \bar{a}'(t)] + \delta Q(t)$$

The authors define a perfectly competitive industry in partial equilibrium, where supply is dictated by free entry and perfect equilibrium. Additionally, they introduce a cost function related to creating new production units:

$$c = c(f(f(0, t))) \quad \text{where } c(\cdot) > 0, c'(\cdot) \leq 0$$

This cost function is contingent on the creation rate, implying that higher creation rates correspond to increased costs. The equilibrium condition is established by equating the cost of unit creation to the present discounted value of profits throughout its lifespan. The authors set the cost of a production unit to 1, and  $P(t)$  is the price of a unit of output. Thus, the profits generated at time  $t$  by a production unit aged  $a$  are defined as:

$$\pi(a, t) = P(t)A(t - a) - 1$$

$$\bar{a}[t + T(t)] = T(t)$$

Here,  $T(t)$  signifies the maximum lifetime of a unit created at  $t$ . At any given time  $t$ , the free entry condition is expressed as:

$$c(f(0, t)) = \int_{t+T(t)}^t \pi(s - t, t) e^{-(r+\delta)(s-t)} ds$$

In the above equation, where  $r > 0$  represents the exogenously determined instantana-

neous interest rate, the determination of the exit of a production unit is contingent upon continuous  $P(t)$  and the instance when the profits generated by a unit being destroyed reaches zero. This occurrence signifies the moment when the oldest unit operational at time  $t$ , denoted as  $\bar{a}(t)$ , must adhere to the equation:

$$P(t)A(t - \bar{a}(t)) = 1$$

The authors posit that  $P(t)$  exhibits a decreasing trend due to the model's assumption regarding endogenous destruction, specifically  $\dot{\bar{a}}(t) < 1$ . To see, differentiate

$$\dot{P}(t) = -\gamma [1 - \bar{a}P(t)]$$

Consequently, when the profits of a production unit diminish to zero for the first time, it will be subject to destruction.

On the demand side, the authors assume a unit-elastic demand function and consider the aggregate expenditure as exogenous  $\bar{D}(t) = P(t)Q(t)$ . The equilibrium is a path  $\{f(0, t), \bar{a}(t), T(t), Q(t)\}_{t \geq 0}$  that satisfy the following conditions:

1.

$$Q(t) = \int_{\bar{a}(t)}^0 A(t - a)f(a, t)da$$

2.

$$f(a, t) = f(0, t - a)e^{-\delta a}$$

3.

$$T(t) = \bar{a}(t + T(t))$$

4.

$$c(f(0, t)) = \int_t^{t+T(t)} [P(s)A(t) - 1] e^{-(r+\delta)(s-t)} ds$$

5.

$$P(t)A(t - \bar{a}(t)) = 1$$

6.

$$P(t)Q(t) = \bar{D}(t)$$

The first three equations (1, 2, 3) and the fifth one (5) suffice to delineate the trajectories of  $T(t)$ ,  $P(t)$ , and  $Q(t)$ , which are determined by  $\{f(0, t), \bar{a}(t)\}$ . To affirm the robustness of the conditions expressed in equations 6 and 5, it is possible to derive these equations as first-order conditions for the maximization of a number of perfectly competitive firms holding production units.

To comprehend the functioning of endogenous destruction, let's consider a scenario with constant demand. In this case, both the destruction and creation rates change only due to supply factors. This steady state is characterized by a constant lifetime of production units  $T(t) = \bar{a}(t) = \bar{a}^*$ , resulting in a time-invariant age distribution  $f(a, t) = f^*(a)$ . Equation 5 implies that the price  $P(t)$  must consistently decrease at a rate  $\sigma$ . Higher innovation rates lead to increased productivity, raising the supply and consequently lowering the price. Equation 2 reveals that the distribution of production units in the steady state follows a truncated exponential distribution:

$$f^*(a) = f^*(0)e^{-\delta a} \quad 0 \leq a \leq \bar{a}^*$$

Using free entry conditions (4) and the clearing condition (6), one can determine the creation and destruction ages  $f^*(0)$  and  $\bar{a}^*$ . Equations 1 and 5 yield the cost function



and productivity of a new production unit:

$$c(f^*(0)) = \frac{e^{\gamma\bar{a}^*} - e^{-(r+\delta)\bar{a}^*}}{\gamma + r + \sigma} - \frac{1 - e^{-(r+\delta)\bar{a}^*}}{r + \delta}$$

$$f(0) = \frac{(\sigma + \delta)\bar{D}^*}{e^{\sigma\bar{a}^*} - e^{\delta\bar{a}^*}}$$

The authors then normalize the creation rate:

$$N = f^*(0) \cdot (1 - e^{\delta\bar{a}^*})$$

In the steady state, this is given by:

$$(9)CC^* = \frac{\delta}{1 - e^{-\delta\bar{a}^*}}$$

Considering a special case where the creation cost is a constant  $c$ , i.e.,  $c(f^*(0)) = c$ , substituting into equation 2.2.2 allows retrieval of  $\bar{a}^*$ . The effect of technological rate  $\sigma$  on  $\bar{a}^*$  is decreasing, as a higher innovation rate increases the opportunity cost of delayed renovation, while a higher cost of creating new units lowers the renovation rate. An optimal lifetime of production units increases with higher  $r$  and  $\delta$  as it becomes harder to recover creation costs.

Now, dropping the assumption of constant demand, we examine how the industry adjusts to demand fluctuations. Two ways are identified in which the industry adapts production to meet demand: by reducing the rate of creation  $f(0, t)$  and by increasing the rate of endogenous destruction  $f(\bar{a}(t), t) \cdot [1 - \bar{a}(t)]$ , thus reducing  $\bar{a}$ , the age at which units are demolished.

These two adjustments interact, leading to a reduction in demand causing the most outdated units to be scrapped, rendering them unprofitable. However, if the recession is partially accommodated by a reduction in the creation rate, the effect on the destruction margin is diminished. The authors argue that the extent to which creation will 'insulate' existing units from variations in demand depends on the marginal cost of creating

new units  $c'f(0, t)$ . When the marginal cost of creation is zero, demand fluctuations are entirely adjusted by the creation margin. This is exemplified in the case where  $c(f(0, t)) = c$ . In such instances, the insulation effect is complete, as there is no need to retire older units. Lowering  $f(0, t)$  is sufficient, and it is cheaper than reducing the life of existing production units.

The insulation effect is not solely due to asymmetric adjustment costs on the creation and destruction margins. Complete insulation would occur even with linear adjusting costs. The creation rate in the case of constant creation cost is given by:

$$f(0, t) = \frac{\dot{D}(t) + \delta \bar{D}(t) + P(t)A(t - \bar{a}(t))f(\bar{a}(t), t)[1 - \dot{\bar{a}}(t)] - \dot{P}(t)Q(t)}{P(t)A(t)}$$

In the attained equilibrium, variations in demand are entirely offset by adjustments at the creation margin denoted as  $f(0, t)$ , with  $\bar{a}(t)$  remaining steady at the destruction margin. The creation process effectively counteracts the impact of demand fluctuations on the price  $P(t)$ , shielding existing units from demand changes. The price  $P(t)$  experiences a constant decline at a rate represented by  $\sigma$ , reflecting the pace of technical progress. This consistent decline in  $P(t)$  serves as a clear signal for production units to function optimally throughout their constant lifetime  $\bar{a}(t)^*$ .

In the aforementioned scenario, the destruction rate is not constant, but it does not respond to demand through variations in the age  $\bar{a}(t)^*$  at which units are destroyed. Instead, variations in the creation rates have an impact on the number of units that reach obsolescence. If fewer units are created, fewer units become obsolete after  $\bar{a}(t)^*$  periods. It is noteworthy that any modification leaving equations 3 to 5 independent of  $\bar{D}(t)$  and  $f(0, t)$  does not alter the full-insulation results.

Interestingly, assumptions such as perfect competition, industry-wide return to scale, and perfect foresight are not necessary for these conclusions. The latter is particularly noteworthy as it asserts that fully accommodating demand on the creation side only requires knowledge of current conditions. As long as the non-negativity constraint

on  $f(0, t)$  is never binding, implementing equilibrium behaviors does not necessitate expectations of future demand.

## Application of the model

The model undergoes calibration utilizing Job-flow data and Industry production data. The former facilitates the replication of job creation dynamics, while the latter is employed to mimic the behaviors of firm creation and destruction in the manufacturing industry. To capture these dynamics, the marginal cost of creating new production units is stipulated as positive  $c'f(0, t)$ . This allows for a partial insulation effect, and the destruction margin responds to demand fluctuations. However, introducing a dependency of  $c$  on  $f(0, t)$  compromises the analytical tractability of the system (Equations 1 - 6). Consequently, the authors resort to methods such as multiple shooting to ascertain the optimal equilibrium and subsequently employ an iterative procedure to converge to the correct expected creation rate.

For numerical solutions, the authors adopt a linear formulation:

$$c(f(0, t)) = c_0 + c_1 f(0, t)$$

To gain a deeper understanding of how creation and destruction respond to demand, the authors simulate sinusoidal demand using the equation:

$$\overline{D}(t) = 1 + 0.07 \sin(t)$$

The results are visualized in the image below, depicting the feedback of normalized creation and destruction (CC and DD) to changes in demand.

The plot clearly illustrates that the insulation effect is only partial; otherwise, DD would have remained flat, as in the case with  $c(f(0, t) = c)$ . From a mathematical perspective, destruction responds to demand as equations 3-5 are no longer independent of the path  $f(0, t)$  and demand. From an economic standpoint, increasing creation costs smoothen the creation process. In scenarios with a nearly flat innovation rate,

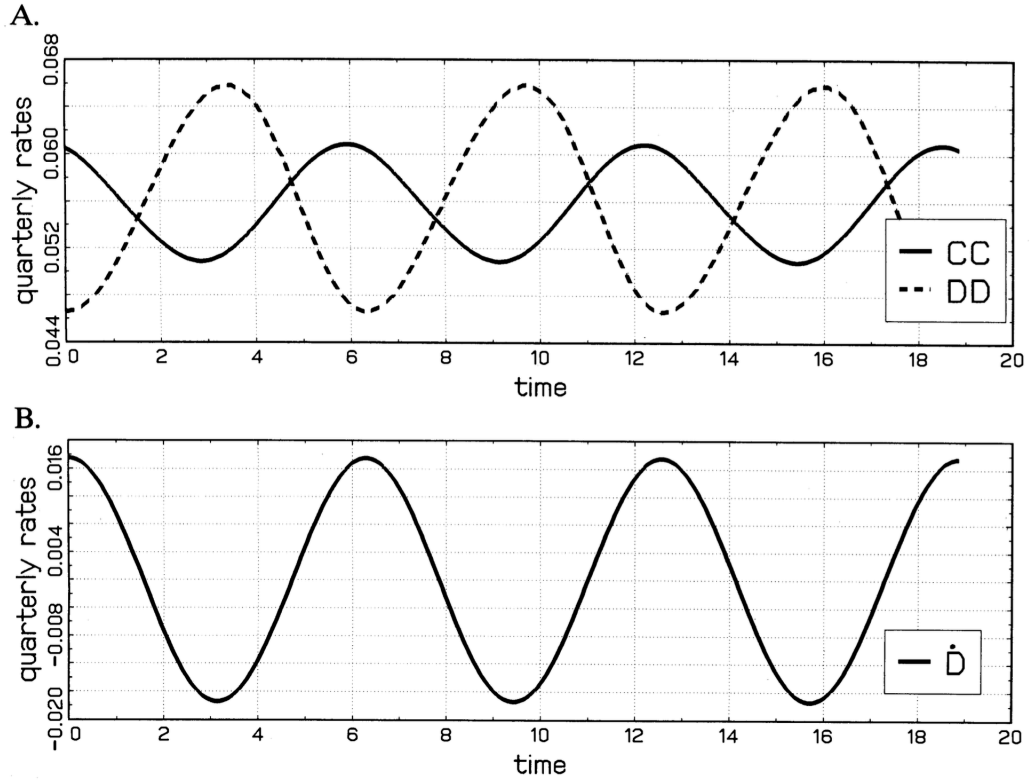


FIGURE 2. A) CREATION AND DESTRUCTION ( $c_0 = 0.3$ ,  $c_1 = 1.0$ ); B) CHANGE IN DEMAND (SYMMETRIC)

Figure 2.1: Figure 1. A Creation and destruction  $c_0 = 0.3, c_1 = 1$  B Change in demand (Symmetric)

firms during crises cannot fully accommodate lower demand, nullifying the adoption of new production units, as the marginal costs would exceed the reduction in existing production units.

In the considered model, production units integrate labor and capital in fixed proportions to generate output. Each unit can be conceptualized as contributing to job creation within the industry, and job-flow data serves as a metric for quantifying the flows of production units.

Datasets that closely align with the theoretical CC and DD series have been compiled by Davis and Haltiwanger [1990, 1992] and Blanchard et al. [1990], drawing from various sources. The primary focus lies on the dataset curated by Davis and Haltiwanger [1990, 1992], who leverage the Longitudinal Research Database to construct quarterly series for U.S. manufacturing plants spanning the period 1972:2-1986:4.

In their empirical approach, ?utilize output to empirically determine demand, employing the growth rate of the industrial production index as a proxy for output growth. Notably, in the foundational theoretical model,  $Q(r)$  is smoothed by price movement, with the elasticity of demand determining the extent of smoothing, assumed to be equal to 1. While the theoretical model maintains a constant dividend wage, the authors acknowledge that considering a procyclical dividend wage, as in the case of general equilibrium with correlated industry shocks, may dampen the effect of demand shocks. However, they assert that this adjustment would alter only the magnitude, not the direction, of the analysis.

The figure below illustrates the data that the model seeks to replicate, showcasing job creation, job destruction, and growth.

To discern the characteristics of the series, the authors perform regression analysis on sectoral rates of job creation and job destruction against leads and lags of the corresponding rates of growth. They find that job creation is less responsive to demand fluctuations, while job destruction exhibits a more countercyclical behavior. The initial finding indicates that the rate of job destruction displays greater responsiveness to changes in sectoral activity compared to the rate of job creation. Specifically, the sums

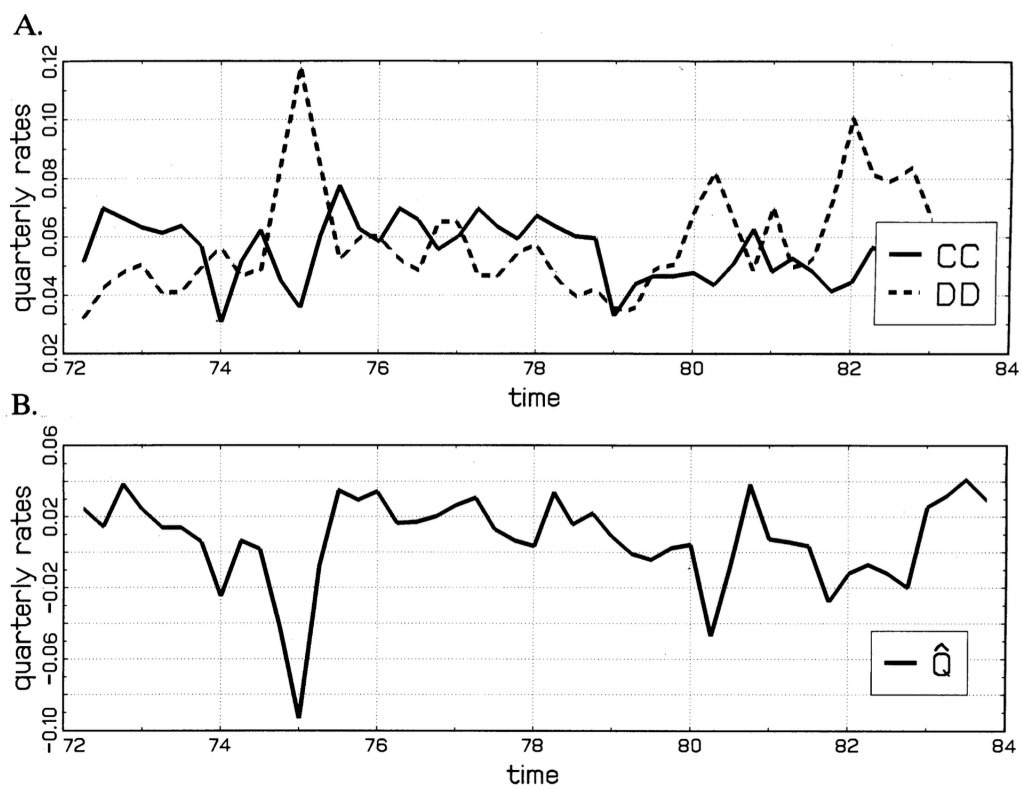


Figure 2.2: Job creation and job destruction in U.S. Manufacturing B Index of the industrial production

Regressor	Timing	Creation		Destruction	
		Coefficient	Standard deviation	Coefficient	Standard deviation
$\hat{Q}$	2 leads	0.029	0.006	0.030	0.010
	1 lead	0.065	0.007	-0.068	0.010
	contemporaneous	0.108	0.007	-0.185	0.010
	1 lag	0.013	0.007	-0.103	0.010
	2 lags	0.003	0.006	-0.058	0.010
	Sum:	0.218	0.013	-0.384	0.017
$\hat{Q}^+$	2 leads	0.052	0.012	0.012	0.016
	1 lead	0.102	0.012	0.002	0.016
	contemporaneous	0.131	0.012	-0.065	0.016
	1 lag	0.059	0.012	-0.025	0.016
	2 lags	0.055	0.012	-0.008	0.016
	Sum:	0.399	0.026	-0.066	0.023
$\hat{Q}^-$	2 leads	0.002	0.010	0.006	0.014
	1 lead	0.022	0.011	-0.149	0.014
	contemporaneous	0.093	0.012	-0.293	0.015
	1 lag	-0.012	0.012	-0.139	0.015
	2 lags	-0.021	0.012	-0.059	0.015
	Sum:	0.084	0.020	-0.634	0.024

Figure 2.3: Job Creation and Job Destruction in U.S. Manufacturing Response to Output Growth: : the table presents the reaction of job creation to the growth rate of the industrial production index. The latter is categorized into values above and below its mean ( $Q$ ). The table encompasses quarterly observations for the two-digit SIC industries during the period 1972:2-1986:4. The coefficients are uniformly constrained to be equal across all sectors, except for a constant (not shown).

of coefficients are -0.384 for job destruction and 0.218 for job creation showed in the table 2.3, the same results as in Davis and Haltiwanger [1990, 1992] and in Blanchard et al. [1990]. The authors capitalize on a natural experiment rooted in the intrinsic asymmetric characteristics of business cycles. Recessions, marked by brevity but intense contractions, provide the backdrop for the authors' model. This model endeavors to emulate the creation rate while concurrently mitigating the impact of asymmetric cyclicity inherent in business cycles. The empirical evidence supporting this model's behavior is encapsulated in Table 2.3, wherein two distinct scenarios are explored: output growth trajectories above  $Q^+$  and below  $Q^-$ , relative to their respective means. The table meticulously delineates how creation and destruction rates respond to these deviations in output growth.

The salient observation emerges regarding creation rates, elucidating that they exhibit a more rapid and robust response in instances of vigorous output growth, as opposed to scenarios where the output growth rate experiences a reduction. On a contrasting note, the destruction margin, in line with the model's projections, manifests heightened sensitivity to a decline in output. This responsiveness is particularly pronounced from one quarter before the onset of the shock to one quarter after. Notably, during expansionary phases, the mean response of the destruction margin is -0.066, a notably milder reaction compared to the recessionary case where the mean response stands at -0.634.

These empirical outcomes seamlessly align with the predictions of the model. Specifically, the creation rate exhibits heightened responsiveness during expansionary phases, given their cyclical and symmetric nature. In contrast, the asymmetric and non-cyclical nature of recessions triggers a more substantial decline in the production unit rate, in line with the model's expectations.

In order to better understand the asymmetrical behavior the authors simulate an asymmetrical demand function:

$$\bar{D}(t) = 0.05[\cos(t) + \sin(t)] - 0.016\sin(2t) - 0.003\cos(3t)$$



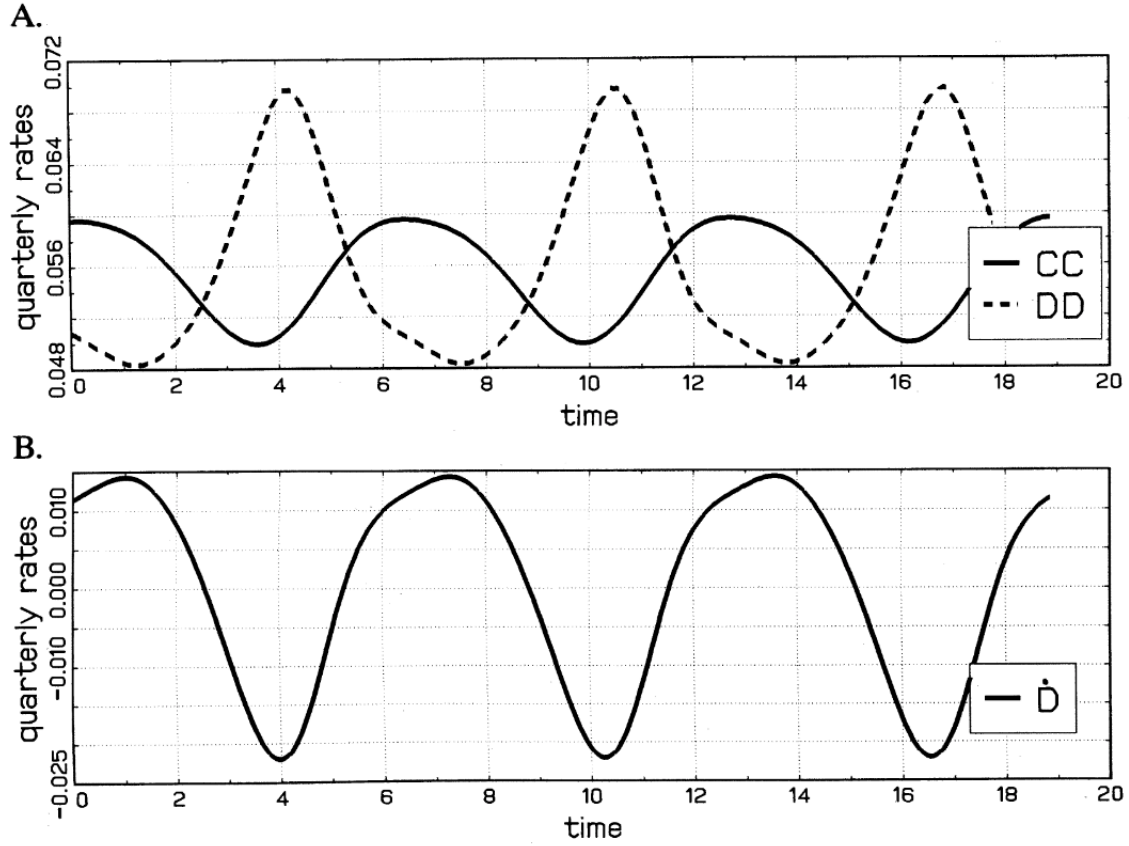


Figure 2.4: A. Creation and Destruction B. Output Growth: the figure depicts a simulation of asymmetrical supply growth.

$$\bar{D}(t) = 1 \quad r = 0.065, \delta = 0.15, \gamma = 0.028, c_0 = 0.3, c_1 = 1.0$$

The results are depicted in 2.4

From the plot 2.4, it is evident that firms use prediction in demand to smooth job creation to avoid big change, since they are too costly, by averaging the demand over the lifetime of a production unit. On the other hand, destruction depends only on current conditions, thus responding only to significant deviations from the demand prediction. It can be better understood thinking about a case in which creation rates respond only mildly to a sharp decrease in demand, and the equilibrium price falls leading to additional destruction since older units' profits go to 0. Indeed, destruction not only preserves but amplifies the asymmetry of demand.

**Frictionless economy** The authors culminate their study with a compelling calibration exercise using manufacturing series to exploit the model. This entails dissecting the observed net change in employment into destruction and creation rates, as well as applying the same approach to output production. The model is simulated for the duration of 1972:2-1983:4, with parameters as follows:

Table 2.1: Calibrated Parameters		
Variable	Symbol	Value
Interest rate	$r$	0.065
Depreciation rate	$\delta$	0.150
Rate of technical progress	$\gamma$	0.028
Adjustment cost parameters	$c_0$	0.403
Marginal cost parameters	$c_1$	0.500

The technical progress is selected to attribute all the growth in employment and manufacturing to technological advancements, setting  $\lambda$  as 2.8. The authors employ Equation 2.2.2, linking the steady state to the lifetime of jobs and job turnover ( $CC^*$ ), determining  $\bar{a}^* + 7.42$  years. Utilizing this information, they ascertain the steady state entry cost to be 0.525, equivalent to half a year's operating costs for production units. Subsequently, they employ ordinary least squares (OLS) to retrieve the value of  $c_1$ , the marginal cost of creating a new unit, which is found to be 0.5. This aligns with a small elasticity for the creation cost function, signifying the vulnerability of the insulation mechanism to breakdown. The model's simulations on employment and output, shown in Figure 2.5, reveal discrepancies with actual data, particularly in the smoother job creation trends, likely due to the model's exclusion of uncertainty. Nonetheless, it successfully captures the volatility in job creation and destruction patterns, along with job creation's greater symmetry, providing insights into employment and output fluctuations. The model's examination of the creation margin's response and its impact on the destruction margin offers a baseline for understanding the cleansing effect's role in production unit distribution.

However, the model overlooks the impact of financial frictions, which could significantly affect both creation and destruction margins. It also entertains the notion

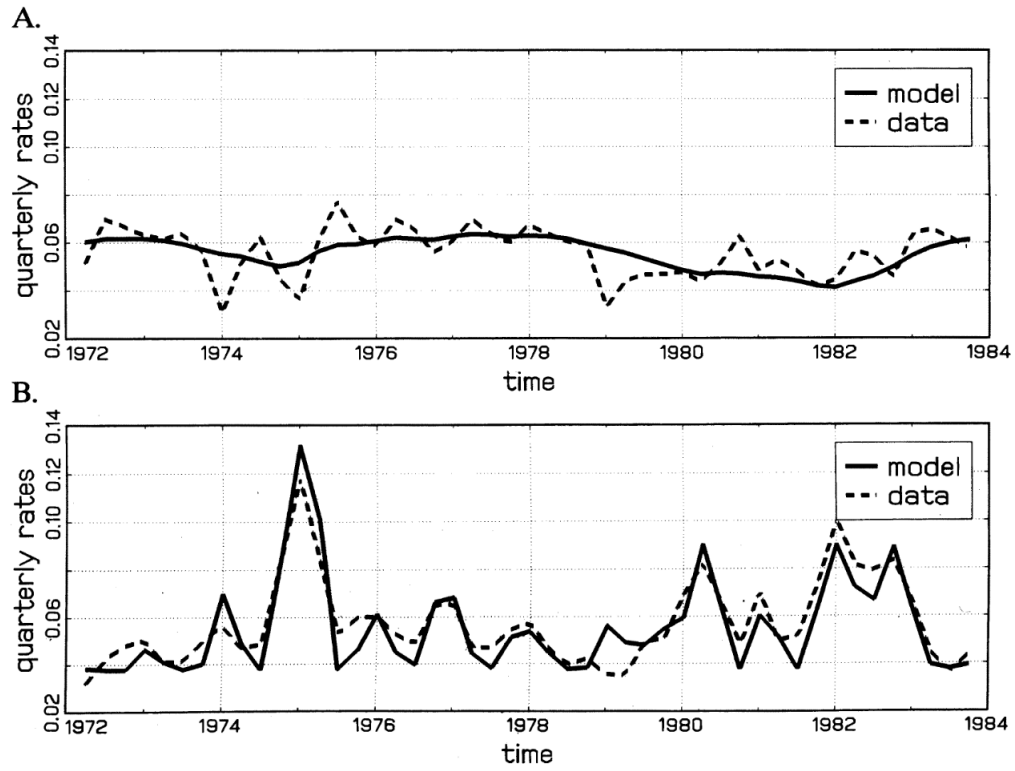


Figure 2.5: A employment driven job creation  $c_0 = 0.403, c_1 = 0.5$  B Employment job destruction  $c_0 = 0.403, c_1 = 0.5$

of recessions as 'pit-stops' for strategic investment, adding depth to recession analysis. Despite the common view of procyclical labor productivity, the model, supported by Galí and Hammour [1992], suggests that recessions can indirectly boost long-term productivity through the cleansing effect.

A notable limitation is the assumption of constant marginal creation costs, which recent studies challenge, especially for larger firms known for substantial adjustments in response to demand drops. This observed behavior in larger firms, aligning with the model's predictions on downsizing, underscores its ability to reflect real-world dynamics despite its simplifications.

### 2.2.3 Credit Frictions and The Cleansing Effect of Recessions

The economy comprises risk-neutral firms with a constant discount rate represented by  $0 < \beta < 1$ . These firms exhibit heterogeneity in productivity and net worth. They employ a production technology that relies solely on capital (or production units) as input, featuring diminishing returns to scale.

In each period, firms incur a fixed production cost denoted as  $c$  to initiate production. After production, they decide how to allocate profits for the next period. The remaining profits are invested in a risk-free asset. Firms face a choice: they can either continue operating and reinvest their profits or exit the market, investing their entire net worth, denoted as  $e$ , in the risk-free asset.

Firms opt to exit the market when expected profits no longer outweigh the fixed cost  $c$ , or when the value of production becomes inferior to the value they could gain by investing in the risk-free asset.

The value obtained from investing in the risk-free asset is given by:

$$q_t + \sum_{s=0}^{+\infty} \beta^s [\beta(1+r) - 1] e_{t+s+1}.$$

Notably, when the condition  $\beta(1+r) \leq 1$  holds, this value simplifies to  $q$ . In such

cases, firms are either indifferent regarding the timing of dividend distributions or have a preference for distributing their end-of-period net worth to shareholders or investors. In this economic model, the agents are the firms themselves, aiming to maximize their value over time by selecting an optimal level of capital denoted as  $k$ . The production function, accounting for the fixed cost  $c$ , is expressed as follows:  $Y = Z(\theta + \epsilon)k^\alpha$ .

Key variables include:

- $Z$ : Stochastic aggregate productivity common across firms.
- $\theta$ : Persistent firm-specific productivity shock (modeled as a Markov Chain).
- $\epsilon$ : Firm-specific productivity shock with  $\epsilon \sim \mathcal{N}(0, \delta)$ .
- $k^\alpha$ : Capital or production units, as in Caballero and Hammour [1994] (AER).

The timeline of events is as follows:

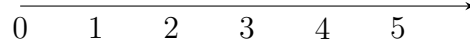


Figure 2.6: Timeline of Events

The sequence of events includes:

1. The firm possesses knowledge of  $Z, \theta, k^\alpha, e$  (where  $e$  represents its endowment, different from  $k$  since the firm can borrow money with  $d = c + k - e$ ).
2. The firm computes the optimal  $k$  to maximize the expected value of the firm, with  $k$  ranging from  $[0, +\infty]$ . If  $k = 0$ , it indicates the firm's decision to exit.
3. At the end of the period, the firm observes  $\epsilon$  and the aggregate shock.
4. The firm repays its debt and the fixed operating cost  $(c + k - e)$ , resulting in an end-of-period net worth  $q$ .
5. The firm decides on the level of dividends to distribute  $(q - e')$ , observes the productivity shock  $\theta', Z'$ , and the process restarts from step 1.

**Frictionless economy** In a frictionless economy, firms have the option to borrow an amount denoted as  $c + k - e$  at the risk-free interest rate  $r = \frac{1}{\beta} - 1$ . Therefore, at the start of the period, the firm's value is determined by the following expression:

$$V_{FL} = \max_k E \int \max[q, \max_{e'}(q - e' + \beta V_{FL}(e', \theta', Z'))] d\Phi(\epsilon)$$

where the end of period net worth is equal to:

$$q = Z(\theta + \epsilon)k^\alpha + (1 - \delta)k - (1 + r)(c + k - e)$$

Under the condition of survival, it can be demonstrated that:

$$\widehat{V}_{FL}(\theta, Z) = \max_k E \int [Z(\theta + \epsilon)k^\alpha - (1 + r)c] d\Phi(\epsilon) + \beta \max[0, \widehat{V}_{FL}(\theta', Z')]$$

In the absence of market friction, firms choose to exit when their productivity reaches a certain threshold. Specifically, they exit if  $\theta' < \underline{\theta}_{FL}(Z')$ , where  $\underline{\theta}_{FL}(Z')$  is defined as the value for which  $\widehat{V}_{FL}(\underline{\theta}_{FL}, Z') = 0$ .

**Economy with Credit Market Frictions** After production, the firm privately observes the temporary shock  $\epsilon$ , while financial intermediaries can only observe it at a cost of  $\mu k^\alpha$ . For one-period debt contracts, financial intermediaries observe  $\epsilon$  only if the firm faces financial distress, which occurs when the private shock is insufficient to repay its debt. The terms of the financial contract depend on the firm's net worth  $e$ , current productivity  $\theta$ , and aggregate productivity value  $Z$ , all observable by both the financial intermediary and the firm at no additional cost.

**HP1 (Hypothesis 1):** The risk-free interest rate is  $\beta < \frac{1}{1+r}$ , which implies a lower risk-free rate in an economy with credit frictions compared to a frictionless one. It also ensures that firms do not always reinvest their profits.

When a firm defaults, the financial intermediary incurs verification costs and seizes

all of the firm's income. The default threshold  $\bar{\epsilon}$  is determined by the equation:

$$Z(\theta + \bar{\epsilon})k^\alpha + (1 - \delta)k = (1 + \tilde{r})(c + k + e)$$

Default results in a zero net worth but does not necessarily force the firm to exit the market, depending on its persistent productivity component  $\theta$ .

The financial intermediary lends  $(c + k - e)$  to the firm only if the expected income from the loan equals the opportunity cost of the funds, as expressed by the inequality:

$$(1 + \tilde{r})(k + c + e)(1 - \Phi(\bar{\epsilon})) + \int_{-\infty}^{\bar{\epsilon}} [Z(\theta + \bar{\epsilon})k^\alpha + (1 - \delta)k - \mu k^\alpha] d\Phi(\epsilon) \geq (1 + r)(c + k + e)$$

The financial contract is characterized by  $(k, \bar{\epsilon})$ . Given  $Z, \theta, e$ , the participation constraint indicates the default threshold  $\bar{\epsilon}$  required by the financial intermediary to lend a given amount. For some firms, their net worth is too low for the participation constraint of the financial intermediary to be satisfied. In fact, given  $\theta, Z$ , there is a unique threshold  $e_b(\theta, Z)$  below which the financial intermediary refuses to lend any amount:

$$Z[\theta + G(\bar{\epsilon}_b)]k^\alpha + (1 - \delta)k - uk_b^\alpha \Phi(\bar{\epsilon}_b) = (1 + r)(k_b + c - \underline{e}_b)$$

where  $\bar{\epsilon}_b$  maximizes the expected income of the financial intermediary. When the firm has a net worth below  $\underline{e}_b$ , the firm defaults.

After production, the firm's end-of-period net worth is equal to:

$$q = \begin{cases} Z(\theta + \bar{\epsilon})k^\alpha + (1 - \delta)k - (1 + \tilde{r})(k + c - e) & \text{if } \epsilon \geq \bar{\epsilon} \\ 0 & \text{otherwise} \end{cases}$$

Using the default condition we can rewrite it as

$$q = \max[Zk^\alpha(\epsilon - \bar{\epsilon}); 0]$$

**The firm's problem** Define  $V$  as the firm's value at the start of the period, which hinges on investment outcomes and exit decisions. If the end-of-period net worth falls below a threshold ( $q < e_b(\theta', Z')$ ), the firm exits. Otherwise, it compares its continuing value to the end-of-period net worth ( $q \geq e_b(\theta', Z')$ ) and exits if the continuing value is lower.

The firm's value function is given by:

$$V(e, \theta, Z) = \max_{(k, \bar{\epsilon})} E \left\{ \int I(q)q + (1 - I(q)) \max[q, \max_{e'} q - e' + \beta V(e', \theta', \zeta')] d\Phi(\epsilon) \right\}$$

Where:

$$I(q) = \begin{cases} 0 & \text{if } q \geq e_b(\theta', Z') \\ 1 & \text{if } q < e_b(\theta', Z') \end{cases}$$

Subject to the following constraints:

1.

$$Z[\theta + G(\bar{\epsilon}_b)]k^\alpha + (1 - \delta)k - uk_b^\alpha \Phi(\bar{\epsilon}_b) \geq (1 + r)(k_b + c - \underline{e}_b)$$

2.

$$q = \max[Zk^\alpha(\epsilon - \bar{\epsilon}); 0]$$

3.

$$\bar{e}_b(\theta', Z) \leq e' \leq q$$

The firm aims to maximize expected dividends while complying with the financial intermediary's participation constraint (constraint 1). Equation (constraint 2) characterizes the firm's end-of-period net worth, and Equation (constraint 3) ensures that the net worth is sufficiently high to satisfy the participation constraint.

Furthermore, the firm is prohibited from issuing new shares and can only augment its net worth by reinvesting profits. This limitation presents a trade-off: increasing capital boosts production capacity but also raises the risk of default, as the default threshold set by the financial intermediary increases with borrowed amounts.



## Findings

This study investigates the complex interplay between credit frictions and the cleansing effect of recessions on firm dynamics. By integrating models of firm dynamics with credit frictions, the authors examine how these frictions influence the selection process for entering and exiting firms, potentially leading to the premature exit of some high-productivity entities. Despite the impact of credit frictions on firm selection, an increase in average productivity is observed following an aggregate productivity shock. Mirroring the dynamics in a frictionless economy, a negative aggregate productivity shock enhances average productivity by predominantly increasing the net exit rate of low-productivity firms.

The analysis underscores that the extent of the recession’s cleansing effect significantly depends on the steady-state distributions of productivity and net worth among firms. The amplification in average productivity can be more substantial than in a frictionless context, depending on the severity of credit frictions and the productivity distribution of firms. Through calibration, the authors demonstrate that credit frictions generally mitigate the rise in average productivity, indicating a systematic diminution in the intensity of productivity enhancement for each percentage point increase in productivity, irrespective of the level of credit frictions and the productivity distribution.

Further exploration into the nature of economic shocks reveals that the type of shock critically influences the cleansing process. Specifically, while recessions can exert a cleansing effect, the intensity of this effect is attenuated when the downturn is triggered by a financial shock. This reduction is due to the financial shock affecting high-productivity firms as well, suggesting a nuanced relationship between the type of economic shock and the intensity of the cleansing effect: non-financial shocks tend to have a more significant cleansing impact compared to financial shocks.

Contributing to the literature on the cleansing effect of recessions, this study elucidates the role of credit frictions in affecting the average productivity of firms by facilitating the selective exit of low-productivity firms, even under credit constraints. It

is imperative to note that the findings do not posit that recessions inherently enhance resource allocation efficiency. On the contrary, in the presence of credit frictions, many of the existing firms could have remained operational in the absence of these constraints. This inefficiency is particularly evident during financial shocks, where the exit of potentially viable firms highlights the intricate dynamics governing the cleansing effect of recessions, emphasizing the importance of a nuanced understanding of economic downturns and their impact on firm dynamics.

# Chapter 3

## The Firm's Problem

### 3.1 Introduction

This thesis presents a partial equilibrium model in which firms maximize dividends over an infinite period, under financial frictions, investigating how those frictions can affect the saddle path of capital and dividends. Compared to Osotimehin and Pappadà [2017] and Caballero and Hammour [1994], this model allows us to find a closed-form solution optimal path for dividends and capital. The subsequent sections delve into the formulation of the flow of funds and its dynamics. Following this, the focus shifts to scenarios where financial frictions are present, examining their implications on firm behavior and market outcomes.

### 3.2 Law of motion of capital and debt

This model is set within a partial equilibrium framework where firms are differentiated by their productivity levels. They have the option to fund their operations by obtaining loans from financial intermediaries, as outlined by Bernanke and Gertler [1995], or by retaining dividends. The capital at any time  $t$  is calculated by adjusting capital from the previous period for depreciation ( $\delta$ ), then adding gross investment ( $I$ ), thus the law

of motion of capital stock is:

$$k_{t+1} = k_t(1 - \delta) + I_t$$

We can rearrange the above equation and get gross investment at time  $t$

$$I_t = k_{t+1} - k_t(1 - \delta) \quad (3.1)$$

The 3.1 equation states gross investment at time  $t$  is equal to the net capital formation plus replacement of depreciated capital. The flow of funds constraint is:

$$I_t + Rb_t + d_t = f(k_t) + b_{t+1} \quad (3.2)$$

where  $R$  denotes the gross interest rate and  $b_t$  represents the debt from period  $t$ . The components of the flow of funds (f-of-f) at time  $t$  include:

1.  $I_t$  gross investment at time  $t$
2.  $Rb_t$  repayment of debts (principal and interest)
3.  $d_t$  dividends distributed at time  $t$

Conversely, the right-hand side details the sources of fund inflows:

1.  $f(k_t)$  output at time  $t+1$
2.  $b_t$  debt at time  $t+1$

The f-of-f constraint can be rewritten as the law of motion of debt:

$$b_{t+1} = Rb_t + I_t - S_t \quad (3.3)$$

where  $S_t = f(k_t) - d_t$  represents retained earnings. This formulation clarifies that the debt level at time  $t+1$  is the sum of the repayment for the previous period's debt (both principal and interest) and the net investment, adjusted for internal financing.

From equations 3.1, 3.3 and the definition of net worth  $n_{t+1} = k_{t+1} - b_{t+1}$ , we derive the law of motion for net worth as follows:

$$\begin{aligned} n_{t+1} &= k_{t+1} - b_{t+1} = k_t(1 - \delta) + I_t - Rb_t - I_t + S_t \\ &= k_t - \delta k_t - b_t - rb_t + S_t \\ &= n_t - \delta k_t - rb_t + [f(k_t) - d_t] \end{aligned}$$

The net worth or equity of the firm is given by the net worth of the previous period less the depreciated capital, less the interest matured from the previous period augmented by the retained earnings. Therefore a firm can increase its net worth only through increasing the retained earnings levels, thus increasing output or decreasing dividends. Using equations 3.1 and 3.2, we get the flow of funds constraint for capital:

$$k_{t+1} = k_t(1 - \delta) - Rb_t - d_t + f(k_t) + b_{t+1} \quad (3.4)$$

The above equation describes how capital evolves: capital at time  $t + 1$  is equal to capital at time  $t$  net of depreciation, less the repayment of debt (principal + interest), augmented by retained earnings.

### 3.2.1 Steady State

From 3.1, assuming  $(k_{t+1} = k_t = \hat{k})$ , we get the steady state investment:

$$\begin{aligned} \hat{k} &= \hat{k}(1 - \delta) + \hat{I} \\ \hat{I} &= \delta \hat{k} \end{aligned} \quad (3.5)$$

3.5 states that in the steady state, the firm will invest only to substitute depreciated capital( $\delta\hat{k}$ ). From 3.3, assuming  $(b_{t+1} = b_t = \hat{b})$  and  $d_t = d_{t+1} = \hat{d}$ , we get:

$$\hat{b} = R\hat{b} + \hat{I} - \hat{S} \quad (3.6)$$

or  $\hat{S} = f(\hat{k}) - \hat{d}$ , therefore:

$$f(\hat{k}) - \hat{d} - \delta\hat{k} = r\hat{b} \quad (3.7)$$

Equation 3.7 states that in the steady state, retained earnings should be used to repay interest over debt. Equation 3.7 can be rewritten as:

$$f(\hat{k}) = \delta \cdot \hat{k} + r \cdot \hat{b} + \hat{d} \quad (3.8)$$

To illustrate the equilibrium locus, one can refer to the graph in 3.1, which depicts the locus as defined by equation 3.8, employing the following production function:

$$f(k_t) = Zk_t^\alpha, \quad (3.9)$$

with  $Z$  indicating the firm's productivity level,  $0 < \alpha < 1$ .

The figure illustrates the steady state relationships among debt ( $\hat{b}$ ), capital ( $\hat{k}$ ), and dividends ( $\hat{d}$ ) in a three-dimensional plot. The graph demonstrates how various combinations of debt and capital influence the distribution of dividends. It is evident that, for any given level of  $\hat{k}$ , a higher level of debt results in lower dividends, as a larger portion of resources is allocated towards servicing interest payments. Conversely, the relationship between capital and dividends, given  $\hat{b}$  is depicted as concave, highlighting an increase in dividends with higher capital levels, under the specified model parameters:  $\delta = 0.1$ ,  $\alpha = 0.8$ , and  $Z = 0.5$ . For example, the firm starting with initial capital  $k_0 = 0.2$  and debt  $b_0 = 0.1$ , to maintain a steady state for both capital and debt, the

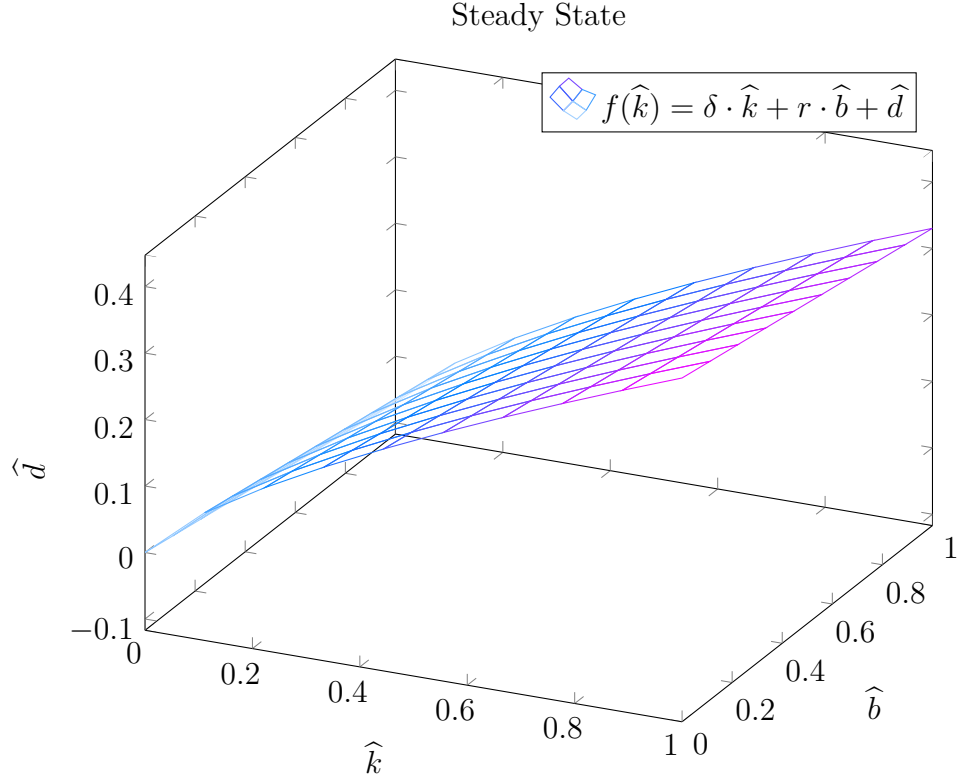


Figure 3.1: The three-dimensional plot delineates the steady state locus as defined by equation 3.8, where the production function parameter values are set as  $\delta = 0.1$ ,  $r = 0.1$ ,  $\alpha = 0.8$ , and  $Z = 0.5$ . It highlights how at any steady-state level of capital  $\hat{k}$ , an increment in debt  $\hat{b}$  necessitates a decline in dividends  $\hat{d}$ , illustrating the trade-off between debt servicing and dividend distribution.

dividends should be equal to  $\hat{d} = 0.5 \times 0.2^{0.8} - 0.1 \times 0.2 - 0.1 \times 0.1$ . This specific combination of  $k = 0.2$ ,  $b = 0.1$ ,  $d \approx 0.11$  represents a stationary point in the model.

### 3.2.2 Dynamics of capital

In the simplified scenario where a firm operates without incurring debt ( $b_t = 0$  for all  $t$ ) and imposing constant and positive dividends ( $d_t = d > 0$ ), the flow of funds constraint changes as follows:

$$I_t + d = f(k_t) \quad (3.10)$$

$$I_t = S_t \quad (3.11)$$

In the absence of debt, a firm's investment is solely financed through retained earnings, as specified in equation 3.11. From 3.11, we derive the difference equation describing the evolution of capital:

$$\Delta k_{t+1} = f(k_t) - d - \delta k_t \quad (3.12)$$

$$\Delta k_{t+1} = k_{t+1} - k_t$$

Equation 3.12 presented implies that variation in capital stock depends on the balance between retained earnings and depreciated capital. Thus, for a positive increase in capital  $\Delta k_{t+1} > 0$ , it is necessary for a company to hold back earnings over what is required to offset depreciated capital:

$$f(k_t) - d > \delta k_t$$

Similarly, the reverse scenario holds as well. To determine the steady-state level of capital, we apply the previously used production function (see equation 3.9), setting



$k_{t+1} = k_t = \hat{k}$  within the difference equation (refer to equation 3.12):

$$Z\hat{k}^\alpha - d = \delta\hat{k} \quad (3.13)$$

The slope of the phase diagram is:

$$\frac{\partial k_{t+1}}{\partial k_t} = (1 - \delta) + f'(k_t) = \quad (3.14)$$

$$= (1 - \delta) + \alpha Z k_t^{\alpha-1} \quad (3.15)$$

Analysis reveals two distinct scenarios based on the derivative of capital with respect to  $k_t$ :

1. **Exploding Path When Derivative Is Greater Than 1:** If the partial derivative with respect to  $k_t$  is greater than 1, it suggests that small deviations from the steady-state level ( $\hat{k}$ ) will lead to increasing divergence rather than convergence back to  $\hat{k}$ . This scenario can be characterized by potentially unstable dynamics. The condition is:

$$(1 - \delta) + \alpha Z k_t^{\alpha-1} > 1, \quad \alpha Z k_t^{\alpha-1} > \delta, \quad k_t > \left( \frac{\alpha Z}{\delta} \right)^{\frac{1}{1-\alpha}}$$

2. **Convergence to Steady State:** Conversely, if the derivative is less than 1, this indicates that deviations from the steady-state level will diminish over time, leading to a stable equilibrium. This scenario reflects a stable path where the system tends to return to its steady state following a perturbation. The condition is:

$$(1 - \delta) + \alpha Z k_t^{\alpha-1} < 1, \quad \alpha Z k_t^{\alpha-1} < \delta, \quad k_t < \left( \frac{\alpha Z}{\delta} \right)^{\frac{1}{1-\alpha}}$$

The following phase diagram represent the case  $\frac{\partial k_t}{\partial k_{t-1}} > 1$ , using the following parameters:  $\delta = 0.1$ ,  $\alpha = 0.8$ ,  $Z = 0.5$ , and  $d = 0.8$

The graph distinctly demonstrates that when capital at time  $t$  is below the red

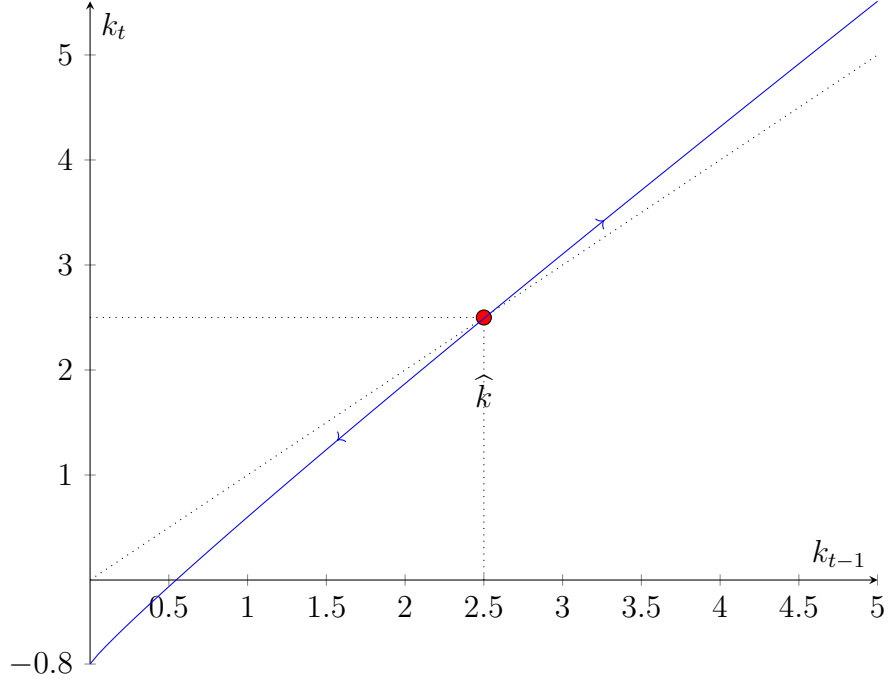


Figure 3.2: The phase diagram demonstrates the evolution of capital in a debt-free scenario, with the dynamics dictated by the specific parameters: depreciation rate ( $\delta = 0.1$ ), capital's output elasticity ( $\alpha = 0.8$ ), total factor productivity ( $Z = 0.5$ ), and fixed dividends ( $d = 0.8$ ). The blue trajectory line depicts the capital accumulation process, calculated with the formula  $k_{t+1} = 0.5 \cdot k_t^{0.8} - 0.1 \cdot k_t + k_t - 0.8$ , which captures the interplay between capital growth through production, the diminishing returns as capital increases (reflected by the concavity of the curve), and the outflow due to depreciation and dividends. The steady-state capital ( $\hat{k}$ ), marked by a red dot, indicates the level where the economy naturally gravitates over time. At this point, the firm's investment is precisely calibrated to replace depreciated capital and issue dividends, with no additional net investment. Notably, this equilibrium is a focal point of the system; below this level, capital accumulates, and above it, capital stock adjusts downward, converging back to this stable point. The diagram serves as a visual aid to comprehend capital dynamics within this economic framework and underscores the balancing act between production, depreciation, and dividend distribution in long-term capital management.

dot, it means that capital is less than the steady-state capital, leading to a diminishing trajectory in the firm's capital. Conversely, if capital is above the steady-state level, indicated by  $\widehat{k}$ , the firm is overcapitalized, and the trajectory becomes explosive, with capital increasing without bound.

If a firm's capital is less than the steady state, the outflows—such as the replacement of depreciated capital and dividends—are disproportionately high compared to its production. This dynamic will inevitably cause the firm's capital to go down to zero. It's crucial to recognize that this path is predicated on the assumption of constant dividends.

Furthermore, the steeper the slope of the blue line, the higher the productivity factor  $Z$ , signifying a reduced need for capital.

### 3.2.3 Dynamics of debts

To examine the dynamics of debt, consider a scenario where capital remains constant  $k_t = k_{t+1} = \widehat{k}$ , thus it is at the steady-state level. From equation 3.8 we get the difference equation for debt:

$$\Delta b_{t+1} = d - f(\widehat{k}) + \delta \widehat{k} + r b_t \quad (3.16)$$

To derive the steady-state debt level, we'll look for the point where debt doesn't change from one period to the next, which means  $\Delta b_{t+1} = 0$ . This occurs when:

$$d - f(\widehat{k}) + \delta \widehat{k} + r b_t = 0 \quad (3.17)$$

Solving for the steady-state debt level  $\widehat{b}$ , we set  $b_t = \widehat{b}$  and get:

$$d - f(\widehat{k}) + \delta \widehat{k} + r \widehat{b} = 0 \quad (3.18)$$

where  $f(\hat{k})$  is the output of the firm given the steady-state capital  $\hat{k}$ . Since  $f(k)$  follows a Cobb-Douglas production function 3.9, then:

$$d - Z\hat{k}^\alpha + \delta\hat{k} + r\hat{b} = 0 \quad (3.19)$$

Isolating  $\hat{b}$  to find the steady-state level of debt, we get:

$$\begin{aligned} r\hat{b} &= Z\hat{k}^\alpha - \delta\hat{k} - d, \\ \hat{b} &= \frac{Z\hat{k}^\alpha - \delta\hat{k} - d}{r} \end{aligned} \quad (3.20)$$

This equation gives us the steady-state level of debt  $\hat{b}$ , assuming that the output of the firm is enough to cover depreciation and dividends, with the remaining used to service debt. If output is insufficient, the firm would need to borrow more, and the steady-state debt would be higher. If the output exceeds the depreciation and dividends, the firm can pay down the debt, and the steady-state debt would be lower. Let's determine the condition for a stable path taking the partial derivatives with respect to  $b_{t-1}$ :

$$\frac{\partial b_t}{\partial b_{t-1}} = 1 + r \quad (3.21)$$

$$(3.22)$$

Since  $r > 0$ , the partial derivative will always be greater than one, thus the slope of the difference equation for debt will always be steeper than one. Adding a negative intercept due to positive dividends we get that under those conditions there exists a steady state of debt. Moreover, if the debt is below the steady state, the debt will shrink toward 0, while if the debt is over the steady state the dynamics of debt will explode toward  $+\infty$ . The phase diagram 3.3 illustrates the relationship between a firm's current debt ( $b_t$ ) and its capacity for future operations ( $k_{t+1}$ ), within the context of constant dividends. The steady state is indicated by the red dot, signifying the juncture at which

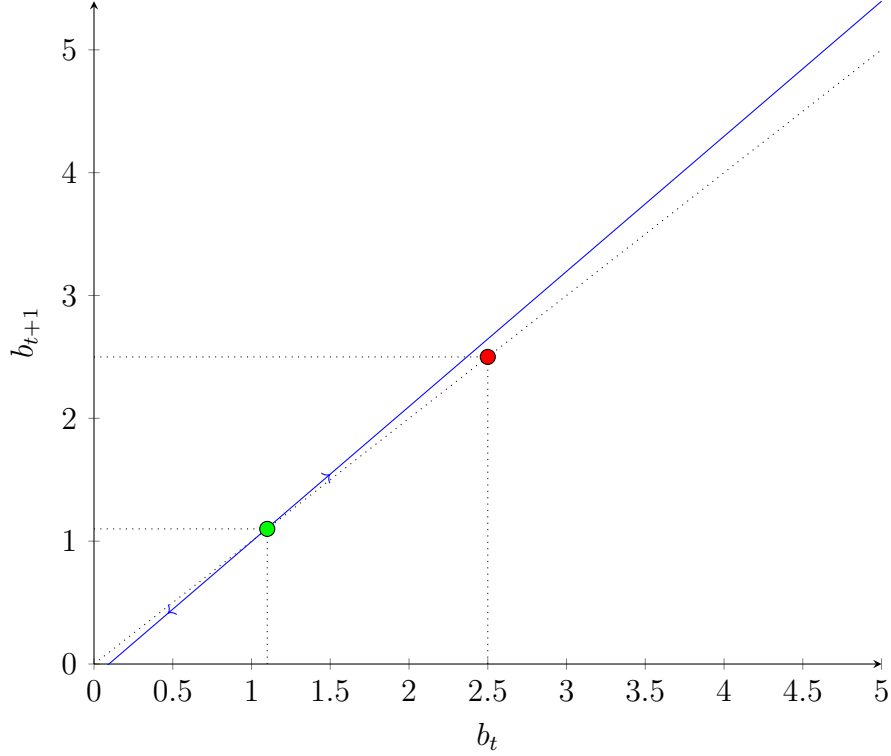


Figure 3.3: The phase diagram dynamically visualizes the firm's debt trajectory given a static capital stock ( $\Delta k = 0$ ), operationalized within a model characterized by the parameters  $\delta = 0.1$  (depreciation rate),  $r = 0.1$  (interest rate),  $\alpha = 0.8$  (capital output elasticity),  $Z = 0.5$  (total factor productivity),  $d = 0.8$  (constant dividend payout), and a steady-state capital ( $\hat{k} = 3$ ). The blue line embodies the trajectory of debt, guided by the finite difference equation  $b_{t+1} = (1 + r) \cdot b_t - (f(\hat{k}) - \delta \hat{k} - d)$ , where  $f(\hat{k})$  denotes the firm's output at the steady state of capital. This equation encapsulates the interplay between the interest on existing debt and the firm's obligations due to dividends and depreciation. The red dot marks the threshold beyond which debt cannot exceed capital, effectively serving as a limit on debt. The green dot represents the equilibrium or steady-state debt level, where the firm's financial obligations are perfectly balanced with its repayment capacity. The distance between the red and green dots illustrates the magnitude of the firm's equity buffer, serving as a measure of financial health and resilience against market fluctuations. This diagram is pivotal in understanding how dividend policies and productivity rates interlink to shape the firm's leverage strategy and long-term financial stability.

the firm's output is precisely adequate to cover dividends, depreciation, and interest on its steady-state debt. In essence, the graph conveys how steady-state conditions are shaped by dividend policy and productivity, with the former influencing the firm's financial leverage and the latter determining its capital efficiency.

### 3.3 Ramsey-Cass-Koopmans reinterpreted

This section outlines the intertemporal maximization problem faced by the firm in the absence of debt, which is a Ramsey-Cass-Koopmans revisited model, where there is a firm that seeks to maximize the utility of consumption of the shareholders (= dividends). The objective function is:

$$V_0 = \sum_{t=0}^{+\infty} \beta^t U(d_t),$$

where  $U' > 0, U'' < 0$ . Let's assume that the firm's investment is entirely financed by equity ( $b_t = 0$  for all  $t$ ), this leads to a simplified flow-of-funds constraint equation:

$$k_{t+1} = k_t(1 - \delta) + f(k_t) - d_t. \quad (3.23)$$

The maximization problem is tackled using a Lagrangian method, where the Lagrangian is defined as:

$$L_0 = \sum_{t=0}^{+\infty} [\beta^t U(d_t) - \beta^t \lambda_t [k_{t+1} - k_t(1 - \delta) - f(k_t) + d_t]].$$

The first-order conditions for  $d_t, k_t$ , for all periods  $t = 0, 1, \dots$  yield:

$$U'(d_t) = \lambda_t, \quad \forall t,$$

$$\beta^t \lambda_t = \beta^{t+1} \lambda_{t+1} [f'(k_{t+1}) + (1 - \delta)], \quad \forall t,$$

This approach delineates the optimal strategy for dividend distribution and capital allocation in a debt-free case. In the infinite horizon model, the transversality condition reads:

$$\lim_{t \rightarrow \infty} \beta^T U'(d_t) k_{T+1} = 0 \quad (3.24)$$

From these first-order conditions (FOCs), we derive the Euler equation for dividends:

$$U'(d_t) = \beta U'(d_{t+1}) [f'(k_{t+1}) + (1 - \delta)] \quad (3.25)$$

indicating that the marginal utility of distributing 1 unit of output as dividends at time  $t$  should match the discounted marginal utility of not distributing dividends in  $t$ , saving, investing in  $t$ , using the additional capital to produce and distribute the corresponding dividends at time  $t+1$ .

**Steady state condition for dividends** Imposing the steady state condition for dividends  $d_t = d_{t+1} = \hat{d}$  in 3.25, we equate the marginal utilities across two consecutive periods:

$$\begin{aligned} U'(d_t) &= U'(d_{t+1}), \\ \frac{1}{\beta} &= f'(k_{t+1}) + (1 - \delta), \end{aligned} \quad (3.26)$$

This condition is satisfied if:

$$f'(k_{t+1}) = \frac{1}{\beta} - (1 - \delta), \quad (3.27)$$

Using the Cobb-Douglas production function and taking the derivative with respect to capital, we get:

$$f'(k_{t+1}) = Z\alpha k_{t+1}^{\alpha-1}, \quad (3.28)$$

From 3.26, we get:

$$\begin{aligned}\frac{1}{\beta} &= 1 - \delta + Z\alpha k^{\alpha-1}, \\ Z\alpha k^{\alpha-1} + (1 - \delta)\beta &= 1, \\ \hat{k} &= \left[ \frac{\alpha\beta Z}{1 - \beta(1 - \delta)} \right]^{\frac{1}{1-\alpha}}.\end{aligned}\tag{3.29}$$

The locus of points on the  $(k_t, d_t)$  plane such that dividends are constant is therefore  $k_t = \hat{k}$ , whose representation in the vertical line in figure 3.4.

**Steady state condition for capital** Imposing the steady state condition for capital ( $k_t = k_{t+1} = \hat{k}$ ) in the law of motion of capital 3.23 we get:

$$d_t = f(k_t) - \delta k_t \tag{3.30}$$

This locus represents the set of points where capital stock remains constant over time. Hence, we can determine the level of dividends that ensures both capital and dividends are maintained at steady-state levels. By incorporating the steady-state level of capital from Equation 3.29 and the production function from Equation 3.9 into the equilibrium condition for capital from Equation 3.30, the steady-state level of dividends, can be deduced:

$$\hat{d} = Z \left( \frac{\alpha\beta Z}{1 - \beta(1 - \delta)} \right)^{\frac{\alpha}{1-\alpha}} - \delta \left( \frac{\alpha\beta Z}{1 - \beta(1 - \delta)} \right)^{\frac{1}{1-\alpha}} \tag{3.31}$$

In this manner, we ascertain the steady-state levels for both capital and dividends.

### 3.3.1 Phase diagram

In this section, we will plot the phase diagram for capital and dividends exploiting steady-state conditions for capital and dividends.



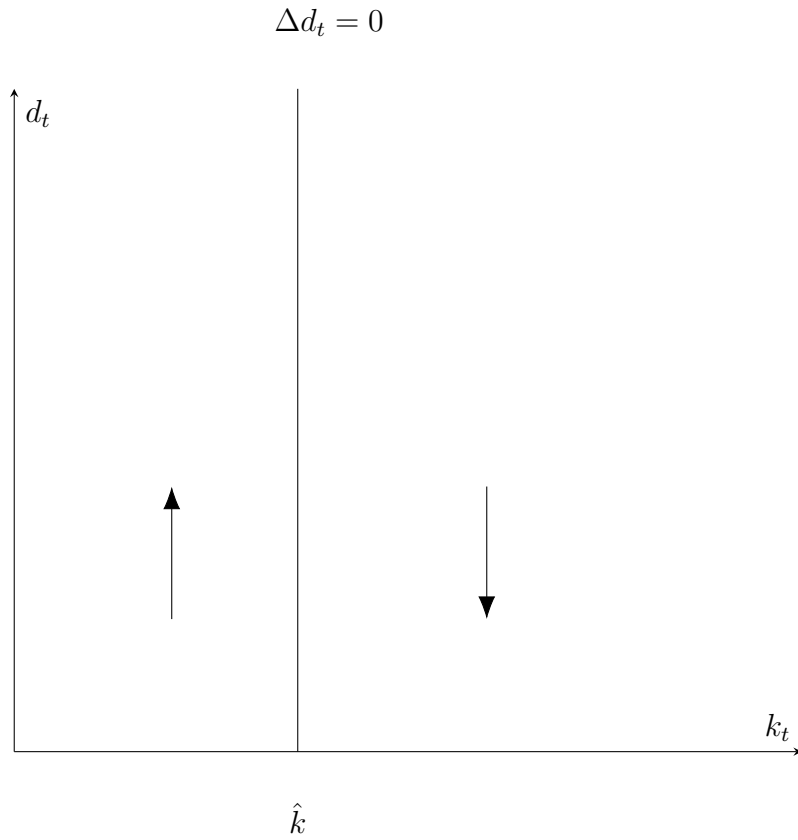


Figure 3.4: The phase diagram illustrates locus of points such that  $d_t = d_{t-1}$ . The vertical line at  $\hat{k}$  represents the steady-state level of capital, where the rate of change in dividends  $\Delta d_t$  is zero. To the left of  $\hat{k}$ , where capital is below its steady-state level, the firm increases dividend payments. Conversely, to the right of  $\hat{k}$ , where capital exceeds the steady state, dividend payments decrease.

The 3.4 portrays the dynamics of dividends ( $d_t$ ) in relation to the capital ( $k_t$ ) of a firm, with a particular focus on the behavior when capital is below or above the steady-state level, denoted by  $\hat{k}$ .

When capital is below the steady-state level ( $k_t < \hat{k}$ ), thus on the left of the vertical line, for the firm it is optimal to increase dividends over time ( $d_t < d_{t+1}$ ) as represented by the arrow pointing upward. When instead  $k_t > \hat{k}$ , dividends must shrink over time ( $d_t > d_{t+1}$ ). Let's look at the locus in which capital is stationary  $\Delta k = 0$  is given by the f-of-f constraint 3.30:

$$d_t = f(k_t) - \delta k_t \quad (3.32)$$

In our case, as obtained in the above section, the locus in which capital is stationary becomes 3.30:

$$d_t = Zk_t^\alpha - \delta k_t \quad (3.33)$$

This function starts at the origin since ( $f(0) = 0$ ), with a maximum in  $\underline{k}$  (defined as capital level such that  $f'(\underline{k}) = \delta$ ). The level of capital  $\underline{k}$  is:

$$\underline{k} = \left[ \frac{\alpha Z}{\delta} \right]^{\frac{1}{1-\alpha}} \quad (3.34)$$

It is easy to see that  $\hat{k} < \underline{k}$ :

$$\begin{aligned} \frac{\alpha \beta Z}{1 - \beta + \beta \delta} &< \frac{\alpha Z}{\delta}, \\ \frac{\beta}{1 - \beta + \beta \delta} &< \frac{1}{\delta}, \\ \beta \delta &< 1 - \beta + \beta \delta, \\ 1 - \beta &> 0 \end{aligned}$$

We denote  $\bar{k}$  the capital level such that  $d_t = 0$ , thus it's obtained by solving  $f(\bar{k}) - \delta \bar{k} =$

0, using the Cobb-Douglas production function 3.9, we get:

$$\begin{aligned} Z\bar{k}^\alpha &= \delta\bar{k}, \\ \bar{k} &= \left[ \frac{Z}{\delta} \right]^{\frac{1}{1-\alpha}} \end{aligned} \tag{3.35}$$

It is easy to see that  $\underline{k} < \bar{k}$ , since:

$$\begin{aligned} \left[ \frac{Z}{\delta} \right]^{\frac{1}{1-\alpha}} &> \left[ \frac{\alpha Z}{\delta} \right]^{\frac{1}{1-\alpha}}, \\ \frac{Z}{\delta} &> \frac{\alpha Z}{\delta}, \\ 1 &> \alpha \end{aligned}$$

Considering transitivity, the sequence for  $\underline{k}, \hat{k}, \bar{k}$  is:

$$\hat{k} < \underline{k} < \bar{k}$$

For a given level of capital  $k_0 \in [0, \bar{k}]$ , the corresponding dividends level that guarantee the stationarity of capital is:

$$d_0 = f(k_0) - \delta k_0$$

If the firm distributes more dividends than  $d_0$  the capital stock must decrease over time: since dividends are too high the firm is consuming part of her capital. More precisely the firm is distributing more dividends than  $d_0$ , which guarantees that the difference between production, and dividends is exactly equal to the replacement of depreciated capital. This behavior is represented by the arrows above the curve pointing to the left. If the firm distributes fewer dividends than  $d_0$ , the opposite happens: the firm increases its capital since there is a positive net investment. This behavior is represented by the arrows below the curve pointing toward the right.

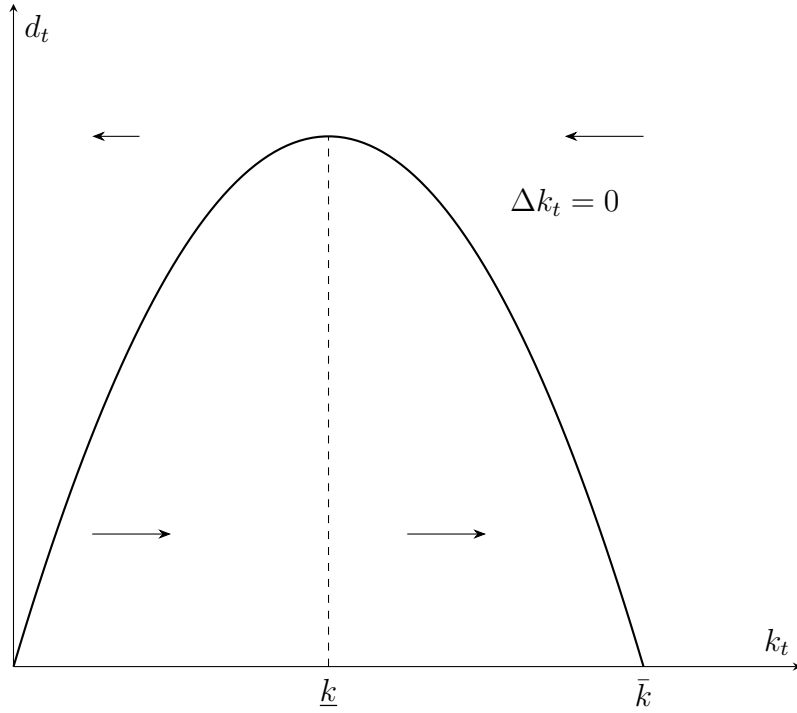


Figure 3.5: This phase diagram displays the set of points at which the capital stock  $k_t$  is unchanging from one period to the next ( $k_t = k_{t-1}$ ). The capital level at  $\underline{k}$  represents the maximum sustainable dividend payout without affecting the capital stock. Arrows above the curve pointing leftward indicate a reduction in capital resulting from dividend levels that exceed the sustainable steady state, while arrows pointing to the right below the curve signify the accumulation of capital due to dividend levels that are below the steady state, leading to an increase in capital stock over time.

**Steady state for capital and dividends** Plotting both loci we get a phase diagram that represents the condition for stationarity. Notice that there exists 3 steady states: one at the origin due to the assumption  $f(0) = 0$ , the point  $(\bar{k}; 0)$ , and finally point B  $= (\hat{k}, \hat{d})$ . Point B was obtained by equations 3.29 and 3.30 and represented the point in which dividends and capital are at a steady state, and both are strictly positive. This point is a saddle point. The blue line depicts a possible saddle path towards B. Starting at A, the firm chooses exactly the dividend level that leads to the stationary point B. This path not only fulfills the difference equations 3.25 and 3.30, but also, the transversality condition 3.24. Indeed as  $t \rightarrow \infty$ , capital and dividends approach their steady-state level, which are both positive and finite, thus the marginal utility of dividends at  $\hat{d}$  is also finite, hence 3.24 is valid.

To conclude, this section has outlined the derivation of steady-state levels for capital and dividends, and these conditions have been visually represented in a phase diagram. The upcoming section will undertake a similar analysis but will incorporate debt and financial friction into the model. Additionally, it is important to note that in the steady state, where output  $\hat{y}$  is given by  $f(\hat{k})$ , the production level is exclusively influenced by the productivity parameter  $Z$ , signifying that financial elements do not alter the fundamental connection between the production function and output.

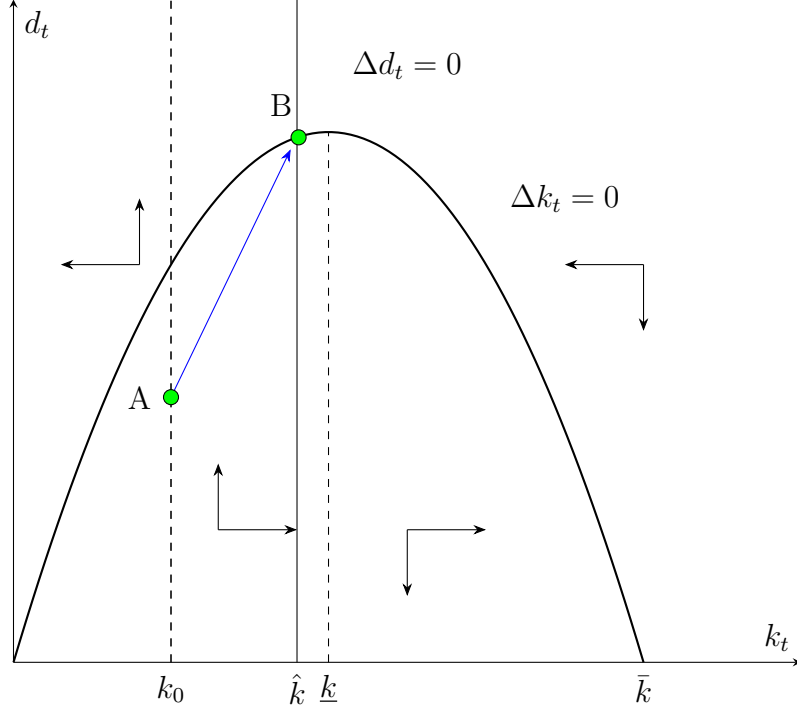


Figure 3.6: The phase diagram visualizes the relationship between dividends and capital. The vertical line marks where the dividend level remains constant, and the solid concave curve traces where the capital remains constant. Point B indicates the equilibrium where both dividends and capital are stationary, with the steady-state capital at  $\hat{k}$ . This value of  $\hat{k}$  is notably lower than  $\underline{k}$ , which is the capital level that would maximize dividends while maintaining a steady capital stock.  $\bar{k}$  represents the capital quantity at which the system reaches a stationary state for  $k$  with zero dividends. The arrows illustrate the dynamics of dividends and capital in case of the firm finding itself outside the stable loci. Point A is a possible starting point  $(k_0, d_0)$ . The blue arrows indicate a potential trajectory, known as a saddle path, leading towards saddle point B.

## Chapter 4

# Optimization under Financial Frictions

This chapter delves into a firm's optimization in a context where debt financing is entwined with financial frictions. We dissect two pivotal constraints:

The fixed leverage constraint restricts a firm's debt-to-equity ratio, thereby shaping its capital structure and investment choices. This fixed ratio ( $0 < l < 1$ ), where  $b_t = lk_t$ , is enforced to mitigate default risk. It remains invariant over time, disallowing leverage adjustment in response to productivity shocks, thereby reducing the optimization problem to capital and dividend decisions.

We also explore the participation constraint with monitoring costs for financial intermediaries. These intermediaries incur costs to ensure borrowers' compliance and solvency, influencing the cost of borrowing and affecting loan terms and credit access.

Incorporating these frictions, the model aims to mirror the real-world financial conditions of firms. We investigate the impact of these frictions on firms' steady-state behavior, particularly on capital and dividend dynamics, vital for understanding the broader economic impact of financial frictions.

Following the analysis of participation constraints, we address the firm's maximization problem in the face of financial frictions. Using a Lagrangian formulation, we

determine the stationary conditions for dividends and capital, visualized in a phase diagram. The firm's problem is then reformulated via a Bellman equation and solved using iterative techniques.

The chapter concludes with Monte Carlo simulations to model firm heterogeneity in leverage and productivity, incorporating continuous productivity shocks and an exit condition based on a return on capital threshold. This exit mechanism serves as a test of the 'cleansing effect' on the economy's output, both with and without monitoring costs, to determine if a cleansing effect persists in the presence of financial frictions.

## 4.1 Participation constraint of the financial intermediaries

The subsection delves into the constraints facing financial intermediaries within the model. Initially, the model assumed an exogenous interest rate, unaffected by the volume of debt, leading to an unrealistic scenario where interest rates remain constant. To address this, the model incorporates a financial market in which the interest rate is set based on market-clearing conditions, with financial intermediaries functioning in a perfectly competitive environment aimed at profit maximization.

According to Bernanke and Gertler [1986], lending should yield a profit equivalent to the opportunity cost. Lenders earn interest plus the principal if borrowers repay successfully (with probability  $p$ ) or acquire the firm's production assets (net of monitoring cost:  $1 - \mu$ ) in case of bankruptcy. Moreover,  $(1 - \mu)f(k_t)$  represents monitoring cost. The lender's participation constraint is:

$$R_t \cdot b_t p + (1 - p)\mu f(k_t) = R_f b_t,$$

where  $R_f$  represents the risk-free rate, the opportunity cost of lending. This framework allows for the derivation of the interest rate as a function of  $p, f(k_t), \mu, b_t$ , and  $R_f$ .



The participation constraint can be rewritten as:

$$R_t = \frac{R_f}{p} - \frac{1-p}{p} \frac{\mu f(k_t)}{b_t}. \quad (4.1)$$

Investigating the asymptotic behavior of  $R_t$  with respect to  $p$  provides critical economic insights. Specifically, as  $p \rightarrow 0$ , indicating an increasingly likely default,  $R_t$  escalates without bound, reflecting the infinitely rising premium a lender would require to counterbalance the heightened risk. Conversely, as  $p \rightarrow 1$ , the default risk vanishes, and  $R_t$  converges to  $R_f$ , the risk-free rate, consonant with the absence of default risk necessitating no premium above the risk-free return. When examining the behavior of the interest rate formula as the debt amount  $b_t$  trends towards infinity, the resulting limit is given by:

$$\lim_{b_t \rightarrow +\infty} \frac{R_f}{p} - \frac{1-p}{p} \frac{\mu f(k_t)}{b_t} = \frac{R_f}{p}$$

As the denominator  $b_t$ , representing the total debt, increases without bound, the term involving the firm's productive output adjusted for recovery rate ( $\mu f(k_t)/b_t$ ) diminishes to zero. This indicates that, in scenarios of very large debt volumes, the fraction of recoverable assets ( $\mu f(k_t)$ ) compared to the outstanding debt becomes negligible in determining the interest rate  $R_t$ .

Therefore, under such conditions, the interest rate formula simplifies to  $\frac{R_f}{p}$ , underscoring that the loan's interest rate is fundamentally determined by the risk-free rate adjusted for the probability of successful repayment  $p$ , independent of the firm's asset recoverability or productivity levels. This elucidates an important economic principle: for vast sums of debt, the critical factors shaping lending rates pivot away from the specifics of asset recovery towards broader financial metrics—namely, the prevailing risk-free rate and the inherent risk of default.

The breakeven threshold for  $R_t$ , where the return on the loan is nonnegative, is formalized by the condition:

$$R_f b_t \geq b_t p + (1 - p) \mu f(k_t). \quad (4.2)$$

This inequality dictates that to achieve a return rate on the loan that is greater than or equal to one, the opportunity cost of capital must be greater than the expected profit from the firm's production, adjusted for default probability and asset recoverability post-default. This ensures the lender receives a return that compensates for the risk undertaken, juxtaposed with the risk-free alternative. Let's present a specific scenario for clarity: Imagine we have a constant capital level  $k$ , and the recovery rate in case of default  $\mu$  is complete, meaning  $\mu = 1$ . In this instance, the depreciation rate  $\delta$  is 0.1, the output elasticity of capital  $\alpha$  is set at 0.8, while the technology factor  $Z$  is 0.5. Additionally, the firm's dividends level  $d$  is 0.8, and the capital stock at time  $t$ ,  $k_t$ , equals 4. The risk-free rate  $R_f$  is given as 1.05.

Within this framework, consider two firms that are identical in every aspect except for their probability of returning profit, denoted by  $p$ . For the first firm,  $p$  is 0.95, suggesting a 5% default risk. For the second firm,  $p$  drops to 0.9, indicating a higher default risk of 10%. The graphical representation suggests that as debt levels increase, so do interest rates, reflecting the risk-return dilemma for lenders. A higher risk profile, denoted by a more elevated red line necessitates greater returns to compensate for default risks. It's important to note that while the graph assumes constant capital, real-world scenarios often see debt increases leading to higher capital and, consequently, greater production capacities.

The analysis indicates that the blue curve, representing the rate of return for a riskier firm, is positioned above the red curve under a specific condition:

$$\mu f(k_t) < R_f b_t \quad (4.3)$$

This condition implies that the net output from employing capital  $k_t$ , after accounting for monitoring costs, must be less than the opportunity cost associated with lending

the sum  $b_t$ . Should this not hold, firms with a higher risk profile would end up incurring lower interest charges on their loans. To elucidate, consider the following scenario where  $p_h$ , denoting the probability of avoiding default for the less risky firm, is higher than  $p_l$ , the corresponding probability for the riskier firm. All other factors are assumed to remain constant across both firms:

$$\begin{aligned}
\frac{R_f}{p_h} - \frac{1-p_h}{p_h} \mu \frac{f(k_t)}{b_t} &< \frac{R_f}{p_l} - \frac{1-p_l}{p_l} \mu \frac{f(k_t)}{b_t}, \\
\left[ R_f - (1-p_h) \mu \frac{f(k_t)}{b_t} \right] p_l &< \left[ R_f - (1-p_l) \mu \frac{f(k_t)}{b_t} \right] p_h, \\
[-(1-p_h)p_l + (1-p_l)p_h] \mu \frac{f(k_t)}{b_t} &< R_f(p_h - p_l), \\
\mu \frac{f(k_t)}{b_t} &< R_f, \\
\mu f(k_t) &< R_f b_t.
\end{aligned}$$

This sequence of steps demonstrates that for the gross rate of return on loans to be positioned favorably for riskier firms, the expected output from the investment (after subtracting monitoring costs) must not exceed the lending opportunity cost.

The graph 4.1 captures the dynamics between the debt stock  $b_t$  and the interest rate applied to the loan  $r_t$ . An increase in the debt stock leads to a rise in the interest rate, reflecting the augmented risk perceived by lenders. Displayed are two distinct lines: one representing a riskier loan with a higher probability of default and the other indicating a safer loan with a lower default probability. As anticipated, the riskier loan scenario is characterized by a curve that lies above, dictating higher interest rates, if  $\mu f(k_t) < R_f b_t$  holds.

An alternative approach to illustrating the participation constraint of financial intermediaries involves graphing the gross interest rate,  $R$ , against the ratio of output to debt,  $\frac{f(k)}{b}$ , directly. The graph 4.2 delineates a critical boundary within the participation constraint framework: as leverage approaches unsustainable levels, the interest

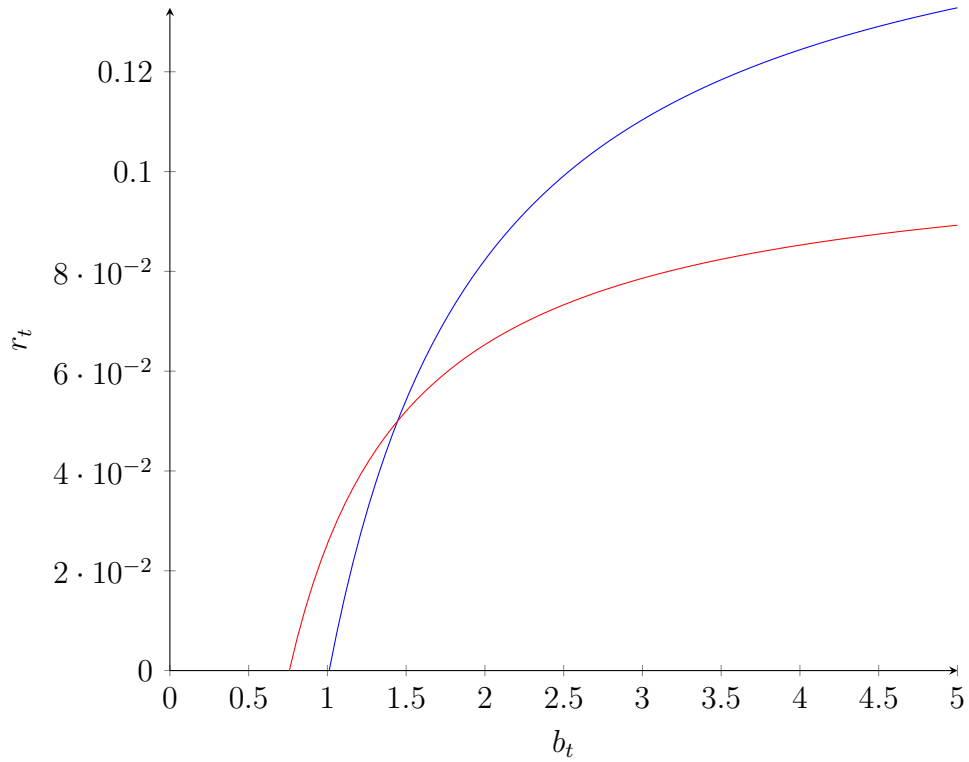


Figure 4.1: The figure presents a graphical analysis of the returns on loans as a function of the loan amount under a fixed capital level of  $k = 4$ . The red curve models the scenario where the default risk probability is  $1 - p = 0.05$ , implying a 5% chance of default, while the blue curve corresponds to a higher default risk at  $1 - p = 0.1$ , a 10% chance of default. Both curves reflect the increased interest rates required to compensate for the heightened risk as the debt stock grows. Notably, the opportunity cost of capital is maintained at 0.05 for the red one, while at 0.1 for the higher risk curve.

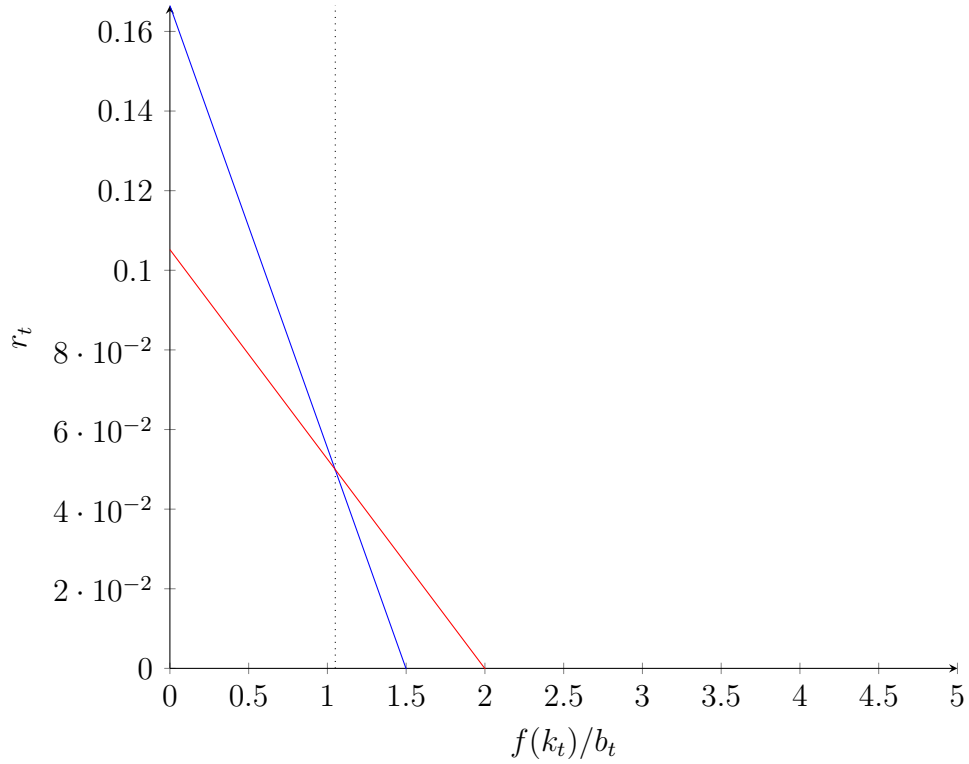


Figure 4.2: The figure presents a graphical analysis of the returns on loans as a function of the production over the debt level. The red curve models the scenario where the default risk probability is  $1 - p = 0.05$ , implying a 5% chance of default, while the blue curve corresponds to a higher default risk at  $1 - p = 0.1$ , a 10% chance of default. Both curves reflect the increased interest rates required to compensate for the heightened risk as the production-debt ratio grows. Notably, the opportunity cost of capital is maintained at 0.05.

rate escalates to a certain peak, signifying a cap on the maximum interest rate that deviates from the theoretical possibility of infinity. This ceiling on the rate is attributed to the fact that the probability of default, denoted by  $p$ , remains fixed and does not escalate alongside increasing leverage.

Ultimately, the participation constraint internalizes the interest rate of a loan as a function of the leverage, the opportunity cost of capital, and the default risk probability. By integrating this mechanism into the flow of funds model, the impact of debt on capital is mediated through the variable  $R$ , establishing a feedback loop where financial leverage influences and is influenced by the cost of borrowing.

## 4.2 The problem of the firm in the presence of financial frictions

The firm's objective is to maximize:

$$\max_{\{d_t\}_{t=0}^{+\infty}} V_0 = \sum_{t=0}^{+\infty} \beta^t U(d_t)$$

subject to:

1. the flow of funds constraint:  $I_t + Rb_t + d_t = f(k_t) + b_{t+1}$
2. the investment function  $I_t = k_{t+1} - k_t(1 - \delta)$
3. the financing constraint  $b_t = lk_t$
4. the participation constraint of lenders  $R_t = \frac{R_f}{p} - \frac{1-p}{p} \frac{\mu f(k_t)}{b_t}$

Consolidating the constraints we get the flow of funds constraints:

$$\begin{aligned} k_{t+1} &= \left\{ k_t(1 - \delta) - \left[ \frac{R_f}{p} - \frac{1-p}{p} \frac{\mu f(k_t)}{lk_t} \right] \cdot lk_t + f(k_t) - d_t \right\} (1 - l)^{-1} \\ k_{t+1} &= \left[ \frac{p + \mu - \mu p}{p} f(k_t) + \frac{p - \delta p - R_f l}{p} k_t - d_t \right] (1 - l)^{-1} \end{aligned} \quad (4.4)$$

The Lagrangian for this optimization problem is :

$$L = \sum_{t=0}^{+\infty} \beta^t U(d_t) - \beta^t \lambda_t \left[ k_{t+1} - \frac{p + \mu - \mu p}{p} f(k_t) - \frac{p - \delta p - R_f l}{p} k_t + d_t \right] (1 - l)^{-1}, \quad (4.5)$$

leading to the first-order conditions for optimizing dividends and capital over time:

$$U'(d_t) = \frac{\lambda_t}{(1 - l)}, \quad \forall t, \quad (4.6)$$

and the dynamic optimality conditions for capital allocation:

$$\lambda_t = \beta \frac{\lambda_{t+1}}{(1 - l)} \left[ f'(k_t) \frac{p + \mu - \mu p}{p} + \frac{p - \delta p - R_f l}{p} \right], \quad \forall t. \quad (4.7)$$

This formulation yields the Euler equation for dividends:

$$U'(d_t) = \frac{\beta}{(1 - l)} U'(d_{t+1}) \left[ f'(k_t) \frac{p + \mu - \mu p}{p} + \frac{p - \delta p - R_f l}{p} \right], \quad (4.8)$$

imposing  $(d_t = d_{t+1} = \hat{d})$ , we get:

$$\begin{aligned} \frac{(1 - l) p}{\beta} &= f'(\hat{k}) (p + \mu - \mu p) + (p - \delta p - R_f l) \\ f'(\hat{k}) &= \frac{p - pl - \beta p + \beta \delta p + \beta R_f l}{\beta (p + \mu - \mu p)} \end{aligned} \quad (4.9)$$

using the Cobb Douglas production function 3.28 into 4.9 we get:

$$Z\alpha\hat{k}^{\alpha-1} = \frac{p - pl - \beta p + \beta\delta p + \beta R_f l}{\beta(p + \mu - \mu p)}$$

$$\hat{k} = \left[ \frac{Z\alpha\beta(p + \mu - \mu p)}{p - pl - \beta p + \beta\delta p + \beta R_f l} \right]^{\frac{1}{1-\alpha}} \quad (4.10)$$

Similar to the scenario without debt, when the firm's capital falls below the steady-state threshold  $\hat{k}$ , it is advantageous for the firm to raise its dividend payouts over time. Conversely, when the firm's capital surpasses  $\hat{k}$ , it would be more beneficial for the firm to gradually reduce dividends. It can be readily demonstrated that when monitoring costs become entirely ineffective ( $1 - \mu = 0$ ), the firm operates without debt ( $l = 0$ ), and the probability of default is eliminated ( $1 - p = 0$ ), the resulting capital level aligns with that of the debt-free situation as specified in equation 3.29:

$$\hat{k} = \left[ \frac{Z\alpha\beta(1 + 1 - 1)}{1 - 0 - \beta + \beta\delta + 0} \right]^{\frac{1}{1-\alpha}},$$

$$\hat{k} = \left[ \frac{Z\alpha\beta}{1 - \beta(1 - \delta)} \right]^{\frac{1}{1-\alpha}}.$$

Imposing s.s. condition for capital ( $k_t = k_{t+1} = \hat{k}$ ) into the flow of funds constraint 4.4:

$$\hat{d} = \frac{p + \mu - \mu p}{p} f(\hat{k}) - \left( \frac{lR_f + \delta p - lp}{p} \right) \hat{k} \quad (4.11)$$

It can be straightforwardly demonstrated that by setting the monitoring cost to  $1 - \mu = 0$ , eliminating debt with  $l = 0$ , and removing the risk of default by setting  $1 - p = 0$ , we arrive at an identical level of dividends as observed in the scenario without debt 3.30.



### 4.3 Phase diagram

The goal of this section is to portray the phase diagram in two cases: one with monitoring costs and one without. However, we will use a less heuristic approach compared to the phase diagram of the free debt case, using parameters similar to Osotimehin and Pappadà [2017]:

Parameter	Symbol	Value
Discount factor	$\beta$	0.956
Risk-free rate	$R_f$	1.04
Depreciation rate	$\delta$	0.07
Returns to scale	$\alpha$	0.80
Aggregate productivity	$\bar{Z}$	0.5
Monitoring cost	$1 - \mu$	0, 0.75
Productivity	$Z$	0.2
Probability of default	$1 - p$	0.6

Table 4.1: Parameters

Moreover, we assume a fixed leverage of  $l = 0.8$ , since for the moment we want to understand the effect of monitoring cost leaving all the other parameters equal.

The phase diagram illustrated in 4.3 depicts the capital accumulation dynamics under scenarios of fixed leverage and varying monitoring costs. While the overall dynamics remain consistent across both scenarios, the equilibrium capital level is notably reduced in firms that incur monitoring costs, in contrast to those without such costs. As a result, firms with monitoring costs settle into a steady state equilibrium for dividends, which leads to diminished dividend distributions compared to firms that do not bear these costs.

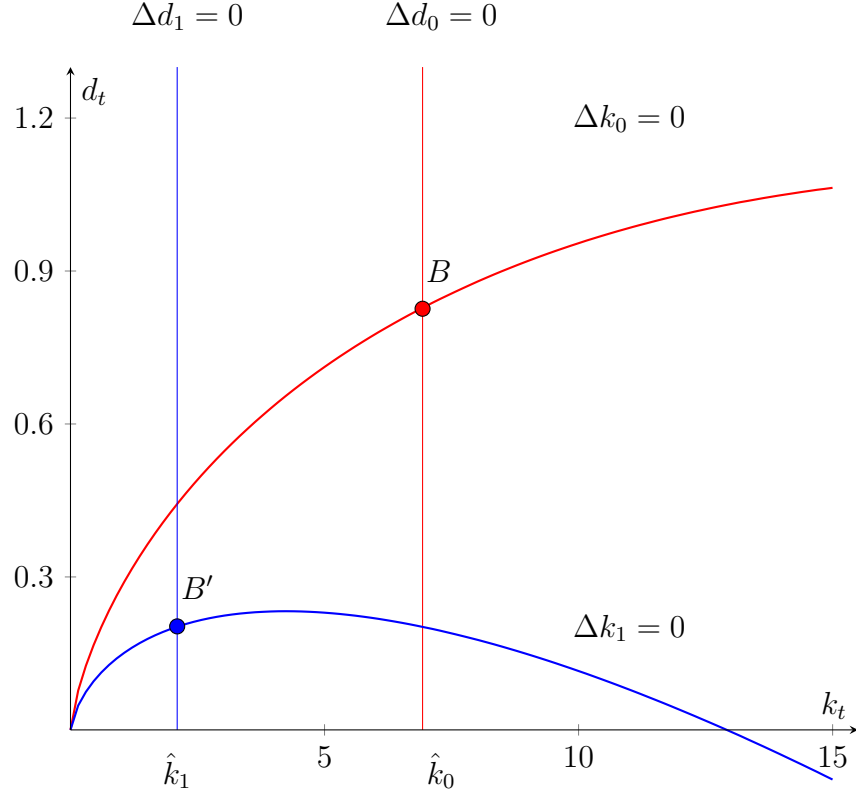


Figure 4.3: This phase diagram illustrates the relationship between dividends ( $d_t$ ) and capital ( $k_t$ ) for two different scenarios of a firm. The red curve represents a firm (Firm 0) that has debt but incurs no monitoring costs, while the blue curve represents another firm (Firm 1) that does have monitoring costs. The curves, labeled  $\Delta d_1 = 0$  and  $\Delta d_0 = 0$ , represent the loci where dividends remain constant. The vertical lines, labeled  $\Delta k_1 = 0$  and  $\Delta k_0 = 0$ , denote the loci where capital is stationary. The intersection point  $B$  on the red curve indicates the equilibrium for Firm 0 where both capital and dividends are stationary, located at  $(7.25, 0.9)$ . In contrast, the intersection point  $B'$  on the blue curve represents the corresponding equilibrium for Firm 1 with monitoring costs, positioned at  $(2.5, 0.28)$ . It is evident that Firm 1, which bears monitoring costs, sustains lower dividends while keeping capital constant, and also requires a lower level of capital to maintain constant dividends when compared to Firm 0.

## 4.4 Finding the optimal path

Addressing the dynamic optimization problem with an initial condition  $k_0$ , we employ a logarithmic utility function and frame the issue through a Bellman equation:

$$\max_{\{d_t\}_{t=0}^{\infty}} V_0 = \max_{\{d_t\}_{t=0}^{\infty}} \left\{ U(d_0) + \beta \left[ \sum_{t=1}^{\infty} \beta^{t-1} U(d_t) \right] \right\}$$

subject to a dynamic capital accumulation constraint:

$$k_{t+1} = \left[ \frac{p + \mu - \mu p}{p} f(k_t) + \frac{p - \delta p - R_f l}{p} k_t - d_t \right] \cdot (1 - l)^{-1} \quad \forall t,$$

The aim is to determine the optimal dividend strategy  $d_t^*$  and the consequent capital levels  $k_{t+1}^*$  across all periods. The optimal policy  $d_t^* = \varphi(k_t)$  links dividends and capital in a time-invariant manner, deduced from the constraint:

$$k_{t+1} = \left[ \frac{p + \mu - \mu p}{p} f(k_t) + \frac{p - \delta p - R_f l}{p} k_t - \varphi(k_t) \right] \cdot (1 - l)^{-1}$$

Given the continuous and differentiable nature of capital and dividends, the optimal dividend path can be represented as a function of initial capital, thereby defining the maximum value function  $V(k_1)$  in terms of overall utility maximization. The revised problem formulation becomes:

$$\begin{aligned} V(k_0) &= \max_{d_0} \{U(d_0) + \beta V(k_1)\} \\ \text{s.t. } k_1 &= \left[ \frac{p + \mu - \mu p}{p} f(k_0) + \frac{p - \delta p - R_f l}{p} k_0 - \varphi(k_0) \right] \cdot (1 - l)^{-1} \\ k_0 &\text{ given.} \end{aligned} \tag{4.12}$$

The method of 'guess and verify' involves working through the transition equation

defined as:

$$k_1 = \left[ \frac{p + \mu - \mu p}{p} f(k_0) + \frac{p - \delta p - R_f l}{p} k_0 - d_0^* \right] \cdot (1 - l)^{-1}$$

The first order condition (FOC) is specified as  $d_0^* = [\beta V'(k_1)]^{-1}$ . When this FOC is incorporated into the transition equation, the formulation of the problem becomes a system of equations outlined as follows:

$$\begin{cases} V(k_0) = U(d_0^*) + \beta V(k_1), \\ k_1 = \left[ \frac{p + \mu - \mu p}{p} f(k_0) + \frac{p - \delta p - R_f l}{p} k_0 - d_0^* \right] \cdot (1 - l)^{-1}, \\ d_0^* = [\beta V'(k_1)]^{-1}, \\ k_0 \text{ given.} \end{cases}$$

Our initial guess for the solution is:

$$V(k_t) = e + f \ln k_t,$$

leading to a refined system:

$$\begin{aligned} e + f \ln(k_0) &= \ln \left( \frac{k_1}{\beta f} \right) + \beta [e + f \ln(k_1)] \\ k_1 &= \left\{ \frac{p + \mu - \mu p}{p} f(k_0) + \frac{p - \delta p - R_f l}{p} k_0 - \left[ \frac{k_1}{\beta f} \right] \right\} \cdot (1 - l)^{-1}. \end{aligned} \tag{4.13}$$

Solving the above system we find:

$$k_1 = \frac{\beta f}{\beta f(1 - l) + 1} \left( \frac{p + \mu - \mu p}{p} f(k_0) + \frac{p - \delta p - R_f l}{p} k_0 \right) \tag{4.14}$$

Using  $d_0^* = k_1(\beta f)^{-1}$  in the above equation we get:

$$d_1 = \frac{1}{\beta f(1-l) + 1} \left\{ \frac{p + \mu - \mu p}{p} f(k_0) + \frac{p - \delta p - R_f l}{p} k_0 \right\} \quad (4.15)$$

Assuming  $p - \delta p - R_f l = 0$ , and using the Cobb-Douglas production function 3.11 simplifies to:

$$\begin{aligned} k_1 &= \frac{\beta f}{\beta f(1-l) + 1} \left\{ \frac{p + \mu - \mu p}{p} Z k_0^\alpha \right\} \\ d_1 &= \frac{1}{\beta f(1-l) + 1} \left\{ \frac{p + \mu - \mu p}{p} Z k_0^\alpha \right\} \\ e + f \ln(k_0) &= \ln \left\{ \frac{1}{\beta f(1-l) + 1} \left\{ \frac{p + \mu - \mu p}{p} Z k_0^\alpha \right\} \right\} \\ &\quad + \beta \left\{ e + f \ln \left[ \frac{\beta f}{\beta f(1-l) + 1} \left( \frac{p + \mu - \mu p}{p} Z k_0^\alpha \right) \right] \right\}, \\ e + f \ln(k_0) &= -\ln(1 + (1-l)\beta f) + \ln(p + \mu - \mu p) - \ln p + \\ &\quad + (\alpha \ln Z + \alpha \ln k_0) + \beta e - \beta f \ln(1 + (1-l)\beta f) + \\ &\quad + \beta f \ln(p + \mu - \mu p) - \beta f \ln p + \beta f \ln(\beta f) + \beta f(\alpha \ln Z + \alpha \ln k_0) \end{aligned}$$

The above equation must be satisfied for any  $k_0$  and for any admissible value of the parameters  $Z, \beta, \alpha, \mu, p, R_f, l$ . Therefore, must be true that:

$$f = \frac{\alpha}{1 - \alpha\beta} \quad (4.16)$$

$$\begin{aligned} e &= [-\ln(1 + (1-l)\beta f) + \ln(p + \mu - \mu p) - \ln(p) \\ &\quad + \alpha \ln(Z) - \beta f \ln(1 + (1-l)\beta f) \\ &\quad + \beta f \ln(p + \mu - \mu p) - \beta f \ln(p) + \beta f(\alpha \ln(Z)) + \beta f \ln(\beta f)] (1 - \beta)^{-1} \end{aligned}$$

Therefore, the transition and policy functions under financial frictions can be articulated as follows:

$$k_1 = \left[ \frac{p + \mu - \mu p}{p} Z k_0^\alpha \right] \frac{\alpha\beta}{1 - l\alpha\beta}, \quad (4.17)$$

Utilizing  $d_0^* = k_1(\beta f)^{-1}$  and in conjunction with 4.16, we can deduce:

$$d_0^* = \left[ \frac{p + \mu - \mu p}{p} Z k_0^\alpha \right] \frac{1 - \alpha\beta}{1 - l\alpha\beta}, \quad (4.18)$$

By setting  $k_1 = k_0 = \hat{k}$  in 4.17, the equation simplifies to:

$$\hat{k} = \left( \frac{Z\alpha\beta(p + \mu - \mu p)}{p(1 - \alpha\beta l)} \right)^{\frac{1}{1-\alpha}} \quad (4.19)$$

This expression elucidates the steady-state capital level,  $\hat{k}$ , in relation to the parameters  $\alpha$ ,  $\beta$ ,  $l$ ,  $p$ ,  $\mu$ , and  $Z$ .

To derive the optimal trajectories for capital and dividends, as well as the steady-state locus for capital in the context of no debt and financial friction (assuming  $l = 0$ ,  $\mu = 1$ , and  $p = 1$ ), the following expressions are obtained:

$$k_1 = Z k_0^\alpha \alpha \beta, \quad (4.20)$$

$$d_0^* = Z k_0^\alpha (1 - \alpha\beta), \quad (4.21)$$

$$\hat{k} = [Z\alpha\beta]^{\frac{1}{1-\alpha}}. \quad (4.22)$$

In conclusion, the optimal capital and dividend paths have been derived under specific financial conditions. Key assumptions, particularly  $p - \delta p - R_f l = 0$ , critically simplify the dynamics, implying that the net effect of the discount rate, the probability of repayment, and the cost of debt on capital growth is neutral. This assumption allows for a direct relationship between the capital level and the dividend policy, as depicted by the transition and policy functions. The closed-form expressions for  $k_1$ ,  $d_1$ , and  $\hat{k}$  emphasize the steady-state capital level's sensitivity to these parameters, underscoring the pivotal role of  $p$  in shaping the firm's financial trajectory. Under the no-debt and no-financial-friction scenario ( $l = 0$ ,  $\mu = 1$ ,  $p = 1$ ), the model further reflects how the absence of these frictions leads to straightforward growth dynamics, reinforcing the importance of these financial parameters in determining the firm's optimal strategies.

## 4.5 Monte Carlo Simulations

To explore the distinctions between scenarios with and without financial frictions, we conduct a simulation exercise employing parameters similar to those used in the Oso-timehin and Pappadà [2017] study:

Parameter	Symbol	Value
Discount factor	$\beta$	0.956
Risk-free rate	$R_f$	1.04
Depreciation rate	$\delta$	0.07
Returns to scale	$\alpha$	0.70
Aggregate productivity	$\bar{Z}$	1

Table 4.2: Benchmark calibration

This section presents a simulation study to compare scenarios with and without financial frictions, employing parameters from the Osoimehin and Pappadà [2017] study. The simulation explores the effects of financial frictions by setting different monitoring costs for two firms, with firm 0 facing no monitoring cost and firm 1 experiencing a monitoring cost of  $25\%\mu = 0.75$ . The key assumption for the simulation is  $p - \delta p - R_f l = 0$ , leading to a calculated probability of repayment ( $p$ ) of approximately 0.559 for both firms.

Figure 4.4 explicitly demonstrates the impact of monitoring costs on reducing the steady-state capital level. The observed discrepancy in steady-state capital levels between the two firms is quantified as follows:

$$\begin{aligned}\hat{k}_0 &= 7.077, \\ \hat{k}_1 &= 2.713, \\ \Delta\hat{k} &= \hat{k}_0 - \hat{k}_1 = 4.364.\end{aligned}$$

Hence, imposing a 25% monitoring cost on the output, under a fixed leverage ratio of

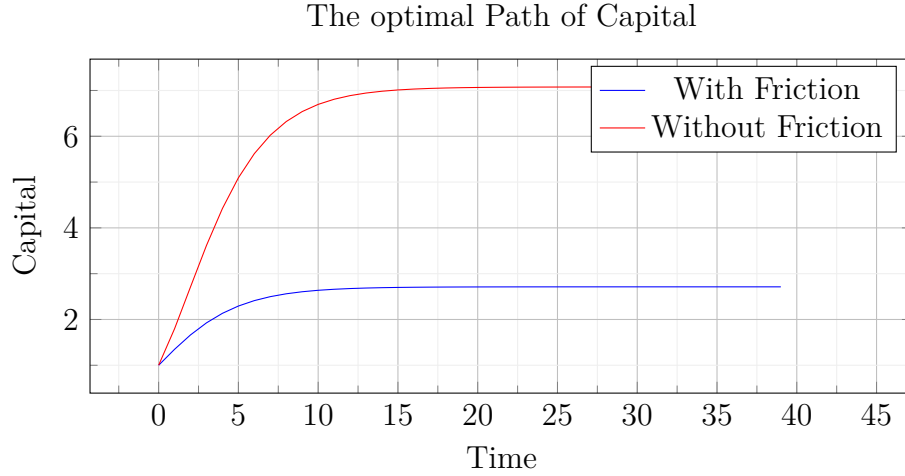


Figure 4.4: The graph illustrates the optimal trajectory for capital as defined by equation 4.17. It features a red line that remains above the blue line across all periods, symbolizing the optimal capital path towards the steady state in the absence of monitoring costs. Conversely, the blue line delineates the optimal path for firms subjected to a 25% monitoring cost. Apart from the monitoring cost, all other parameters are held constant. It is evident from the graph that monitoring costs have a significant impact on the steady state, notably reducing it.

0.5, results in a 69% reduction in the steady-state level of capital.

Additionally, Figure 4.5 illustrates the optimal dividend paths for the same two firms, one burdened by monitoring costs and the other not. Following the policy function detailed in 4.18, derived from the solution to the Bellman equation.

In the 4.5 The dividend trajectory is notably higher in scenarios without financial frictions, emphasizing the significant role these frictions play in reducing returns. In a steady-state analysis, monitoring costs lead to a 78% decrease in dividend levels, given a constant leverage ratio of 0.5. In the forthcoming sections, the analysis will expand to simulate an economy with heterogeneous agents, aiming to dissect the broader implications of financial frictions on overall output. This simulation will contrast environments with and without financial frictions, with a particular focus on the cleansing effect that such frictions may exert in economic systems. Through this comparative approach, we aim to deepen our understanding of how financial frictions influence economic resilience, performance, and the potential for innovation and growth amidst challenges. Next, we



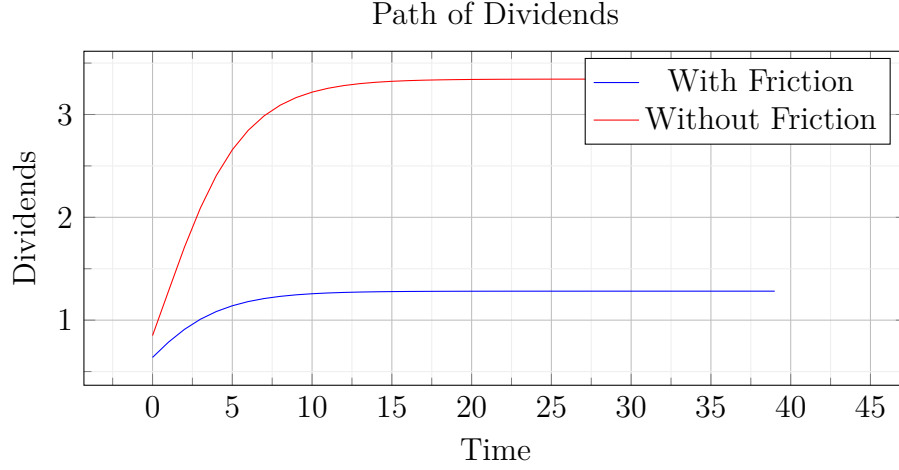


Figure 4.5: The figure illustrates the optimal trajectory of dividends as derived from equation 4.18. Here, the red line, consistently above the blue across all periods, indicates the optimal progression toward the steady-state level when monitoring costs are not factored in. In contrast, the blue line represents the trajectory under the influence of a 25% monitoring cost. With all other parameters held constant, it is evident that monitoring costs exert a downward pressure on the steady-state level of dividends.

will simulate an economy with heterogeneous agents to assess the overall output in environments with and without financial frictions. This analysis aims to explore the cleansing effect of financial frictions, providing insights into their influence on economic performance and growth potential.

#### 4.5.1 Heterogeneity and Aggregation Mechanism

To refine our model, we introduce heterogeneity among firms, marking a departure from uniform productivity. Specifically, productivity levels ( $Z_i$ ) now vary across firms, introducing a spectrum of efficiency within the model. Additionally, we diversify leverage ratios, ensuring no direct correlation between a firm's productivity and its leverage. This heterogeneity is captured from the outset by simulating the initial distribution of capital, leverage, and productivity, setting the stage for a dynamic interplay of firm

characteristics. The aggregate output at time  $t$  for a population of  $N$  firms is :

$$K_t = \sum_{i=0}^N Z_{i,t} k_{i,t}^\alpha \quad (4.23)$$

The business cycle is modeled through a sine function, impacting the productivity factor  $Z$  uniformly across all firms in the economy. Furthermore, the maximum influence the business cycles can exert on productivity is limited to 10% of  $Z$ . Consequently, the cycle is represented as follows:

$$\Delta Z_t = 1 + 0.1 \sin(t) \quad (4.24)$$

The firm determines an optimal level of output at time  $t_0$  for the subsequent time  $t_1$ , based on equation 4.17. However, the actual output may deviate from this optimal level due to fluctuations in the productivity factor  $Z$ , which is influenced by the business cycle, as described in Equation 4.24. To differentiate between these two scenarios, the term 'optimal' will refer to the firm's chosen level of output, while 'actual' will describe the output level that the firm ultimately achieves.

Productivity ( $Z$ ) and leverage ( $l$ ) follow truncated normal distributions:

$$l \sim \mathcal{N}(0.05, 0.1), \quad 0.01 \leq l \leq 1, \quad (4.25)$$

$$Z - 1 \sim \mathcal{N}(0.5, 0.1), \quad 1.01 \leq Z \leq 1.1. \quad (4.26)$$

The exit mechanism for firms in this model is based on criteria where a firm's exit is contingent on its return on capital being below the risk-free rate and also being among the lowest two within the entire firm population. This approach ensures that at each evaluation point, the potential for market exit is limited to the two firms with the least efficient capital utilization, provided their returns are less than the risk-free rate. Consequently, this mechanism inherently caps the maximum proportion of firms that can exit the market at any given time to prevent unrealistic, explosive market

dynamics.

By introducing a natural cap that theoretically limits maximum exits to 20% of the firm population, the market maintains a dynamic equilibrium, facilitating the exit of the least productive firms and preventing scenarios where excessive market exits lead to implausible economic conditions.

For a firm  $i$  at time  $t$ , the return on capital is calculated as follows:

$$R_{i,t} = \frac{d_{i,t-1}}{k_{i,t}} + \frac{k_{i,t} - k_{i,t-1}}{k_{i,t}} \quad (4.27)$$

A firm is mandated to exit the market if its return on capital ranks among the lowest two and falls below the risk-free rate ( $R_f$ ). This criterion is applied systematically at each simulation step, aligning the market's evolutionary process with economic efficiency principles.<sup>1</sup> Through this mechanism, the model illustrates a market that rewards efficiency while ensuring a balanced impact of exits on the economic landscape.

## 4.5.2 Findings

In our investigation, financial frictions are integrated into the economic model, characterized by a monitoring cost parameter  $1 - \mu = 0.15$ . The aim is to discern the repercussions of such frictions on the economic dynamics. To this end, we conduct two distinct simulations within the environment of financial frictions: one where an economy is subject to an exit and capital reallocation mechanism, and another where this mechanism is absent, inhibiting the movement of capital.

The analysis is robust, comprising 100 Monte Carlo simulations to determine the sample mean and variance of each variable. Central to our inquiry is whether a recession induces a 'cleansing effect,' wherein less efficient firms exit the market, leading to a potential increase in aggregate productivity. Accordingly, we simulate two economic setups: one where firms operate without an enforced exit, and another where firms are

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<sup>1</sup>The exit criteria, focusing on the two lowest returns below the risk-free rate, are assessed at each step of the simulation to identify firms for market exit.

mandated to exit under certain conditions. In both setups, firms face financial frictions manifested as monitoring costs, consistent with  $1 - \mu = 0.15$ . The ensuing figures present the sample mean and 95% confidence intervals for total output, comparing scenarios where exits are permitted to those where no reallocation occurs.

Visual representation (4.6) of total output over a 20-step horizon, including 100 iterations among a group of 10 firms, illustrates the comparative trajectories. Under financial frictions, the economy with the exit mechanism in play consistently registers a superior aggregate output level. This finding corroborates the notion of a market-driven ‘cleansing effect’—the process through which less productive firms are culled, freeing up resources for redistribution to more efficient entities. Notably, this effect is not merely sustained amidst financial frictions; it is measurably impactful, enhancing production output. This observed phenomenon underscores the potential for policy-driven capital reallocation mechanisms to bolster economic efficiency, even when financial barriers are present.

The presence of a forced reallocation mechanism contributes to a higher overall capital ( $k$ ) at each step, substantiating the notion that a cleansing effect persists even amidst financial frictions, resulting in greater production compared to scenarios where firms are barred from exiting. Evidently, these variations in overall capital are markedly pro-cyclical, aligning with the findings in Davis and Haltiwanger [1992]. In the subsequent figure 4.7, we delve into the nuances of this impact by examining the mean log difference in total production between the two scenarios, accompanied by a 95% confidence interval. The data underscores a positive and a statistically significant difference in overall output, indicative of the beneficial role played by the exit mechanism in the context of financial frictions. This effect echoes the theoretical insights discussed earlier, where the exit mechanism serves as a pivotal driver of economic efficiency and productivity.

Graph 4.7 illustrates the effect of firm exits and capital reallocation on total output in two different economic scenarios, factoring in the impact of monitoring costs. The red line represents economies with monitoring costs equating to 15% of recoverable

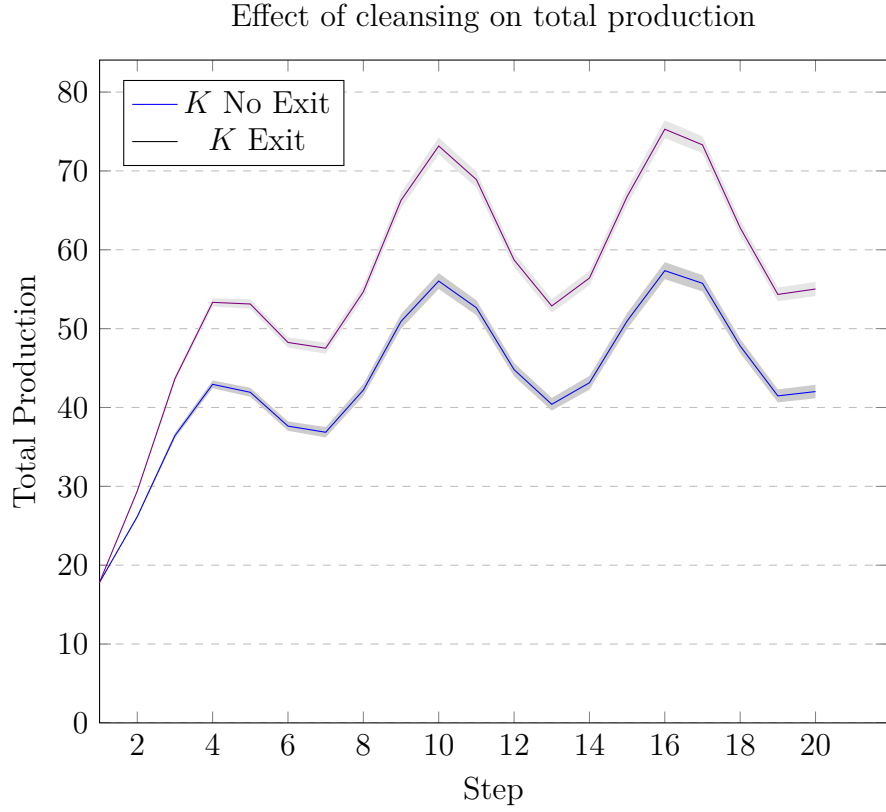


Figure 4.6: The plot presents the outcomes of a 20-step simulation involving 10 firms, contrasting the total output ( $K$ ) in an economy with an exit and reallocation mechanism (red line) against an economy lacking such mechanisms (blue line). Both scenarios are subject to 15% monitoring costs and experience a sinusoidal continuous shock affecting productivity. The visualization illustrates that the incorporation of exit and reallocation strategies enhances the overall output of the economy despite the presence of financial frictions. Given that the total number of firms is held constant at ten, the aggregate production can be interpreted as average productivity by dividing by ten. The data suggest the presence of a cleansing effect within the economy, even when financial frictions are factored in. The confidence intervals are depicted at a 95% level, derived from 100 Monte Carlo simulation iterations.

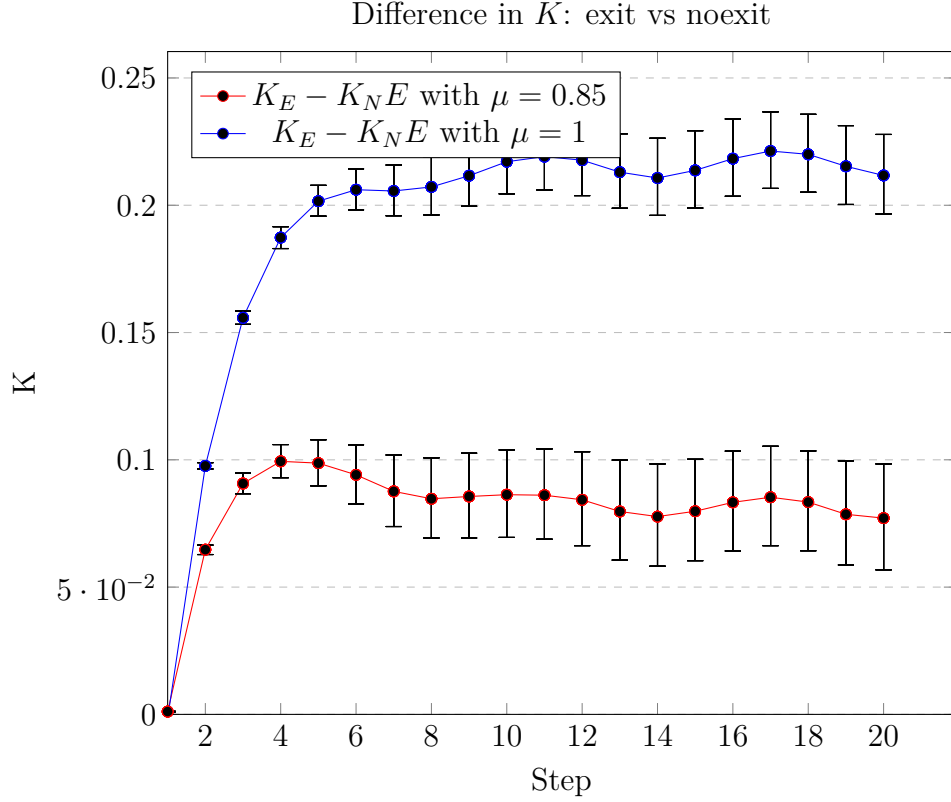


Figure 4.7: The graph presents the percentage difference in total output between two economic scenarios: one with firm exit and capital reallocation and another with no firm exit, with a consideration of monitoring costs. The red line indicates economies where monitoring costs amount to 15% of recoverable assets ( $1 - \mu = 0.15$ ), and the blue line represents economies without monitoring costs ( $1 - \mu = 0$ ). The 'cleansing effect' of market exit on overall output is depicted by the difference between these lines. In the absence of monitoring costs, the cleansing effect results in a 20% increase in output, while in the presence of monitoring costs, the increase in output is positive but smaller, at approximately 7%. Additionally, the error bars indicate a 95% confidence interval (CI), highlighting the statistical reliability of the observed differences.

assets ( $1 - \mu = 0.15$ ), while the blue line depicts economies without any monitoring costs ( $1 - \mu = 0$ ). The contrast between the two lines showcases the 'cleansing effect' of firm exits: in the absence of monitoring costs, this effect prompts a 20% rise in output, whereas, with monitoring costs, the output boost is more modest, at about 7%. The error bars on the graph denote a 95% confidence interval, affirming the statistical significance of the results.

Figure 4.7 affirms that capital reallocation following firm exits can enhance productivity, even under financial constraints represented by a 15% monitoring cost. Despite the asymmetric information challenges between financial intermediaries and firms, the positive impact on production is not only present but also accumulates over time, suggesting a magnifying effect. Therefore, two otherwise identical economies in terms of productivity and capital distribution will ultimately diverge in output if one incorporates the mechanism of firm exits and capital reallocation, despite the existence of financial frictions.

# Chapter 5

## Conclusions

This thesis presents a comprehensive theoretical model that elucidates the intertemporal optimization problem of firms contending with financial frictions. By integrating mechanisms for financing through retained earnings and debt within the framework of the Ramsey-Cass-Koopmans model, this work embarks on an analytical journey starting with the application of Lagrangian methods to establish steady-state conditions. It progresses to leveraging the Bellman equation, in conjunction with guess and verify techniques, to extract explicit solutions for the paths of capital accumulation and dividend distribution across an infinite timeline. This rigorous approach facilitates an in-depth exploration of the impacts of financial frictions, such as monitoring costs and financing constraints, on the formulation of firms' optimal strategies for capital and dividend management.

Empirical analysis, informed by the parameterization in Osotimehin and Pappadà [2017], demonstrates that substantial monitoring costs — 25% of recoverable assets — can lead to a significant reduction in the steady-state level of capital, by up to 69%. This highlights the profound effect of financial frictions on the dynamics of firm valuation and asset management.

Monte Carlo simulations further extend this analysis to a heterogeneous firm population, characterized by diverse productivity levels and leverage ratios. These simulations



assess the impact of capital reallocation following firms' exits in a financial friction-laden environment. Results reveal that such reallocation can boost the economy's total output by approximately 10% under a financial framework with 15% monitoring costs. Remarkably, the absence of monitoring costs escalates the enhancement in total output to around 20%, validating that while financial frictions may reduce the cleansing effect's magnitude, its overall impact remains positive. This aligns with findings from Osotimehin and Pappadà [2017], reinforcing the intricate relationship between financial frictions, firm exit strategies, and economic productivity.

This thesis contribution is to elucidate the dynamic interplay between financial frictions, firm operational behavior, and the broader market ecosystem. It ascertains that financial frictions, albeit challenging, do not fully negate the benefits derived from market-induced capital reallocation. Market dynamics, through inherent exit and entry mechanisms, significantly mitigate the adverse effects of financial frictions, maintaining or even amplifying economic output under certain conditions.

Future research avenues are manifold and promise to enrich our understanding by introducing uncertainty into the model to increase its realism and applicability across different economic scenarios. Incorporating stochastic shocks into firm productivity and the intensity of financial frictions could provide insights into firms' strategic responses under uncertainty. Additionally, examining policy interventions targeting firms under financial duress could yield recommendations for minimizing unwarranted firm exits and enhancing economic output. Extending the model to account for endogenous firm exit and entry decisions, broadening the spectrum of firm heterogeneity, and exploring the role of financial institutions in mediating financial frictions' effects could unravel further dimensions of the complex relationship between financial markets and real economic activity.

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