Three Essays in Dynamic Corporate Finance

by

Robert Jay Kahn

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Business Administration)
in The University of Michigan
2019

Doctoral Committee:

Professor Toni Whited, Chair
Associate Professor Christopher House
Professor Uday Rajan
Associate Professor Martin Schmalz, University of Oxford
Professor Jagadeesh Sivadasan

Robert Jay Kahn

rjaykahn@umich.edu

ORCID: 0000-0002-8277-6309

For my grandmother, Jean France, and grandfather, Jay Kahn.

ACKNOWLEDGEMENTS

I am immensely indebted to my committee members for their advice and support. To Toni Whited, my chair, I am particularly thankful for her help throughout my doctoral studies, first at Rochester and then at Michigan. Since arriving at Michigan, Uday Rajan has been an inexhaustible source of guidance, and without his patience I could not have gotten through. Both my writing and my understanding have benefited from Martin Schmalz's keen intuition and generosity with his time. Chris House's diligent and thoughtful comments pushed me to be more precise in my thinking. Finally, Jagadeesh Sivadasan gave me an invaluable outside perspective on my research.

At Michigan, I have been lucky to have the support of many friends inside and outside the doctoral programs at Ross. I would like to thank all the students who participated in the seminars at Ross and in the economics department. I would also like to thank Steve Hou, Greg Levda, Ben Lipsius, George Malikov, Evan Mefford, Giacomo Mellie, Virginia Traweek and Sarah Wesley for their support in my final years at Michigan. My life generally and my dissertation in particular have benefited from knowing Laurien Gilbert. Finally, my parents, Virginia France and Charles Kahn, are constant sources of wisdom and encouragement.

The first chapter of this dissertation was presented at the 2018 Trans-Atlantic Doctoral Conference and at the Federal Reserve Board. The second chapter was presented at the Federal Reserve Board, the University of Minnesota, the University of Texas-Austin, the 2014 FIRS Meetings, the 2014 WFA Meetings and the 2014 Summer Meetings of the Econometric Society. For both chapters, I thank participants at these seminars.

Finally, I thank the Federal Reserve Board for financial support during the completion of this research.

TABLE OF CONTENTS

DEDICATION ii

ACKNOWLEDGEMENTS iii

LIST OF FIGURES viii

LIST OF TABLES x

LIST OF APPENDICES xii

ABSTRACT xiii

CHAPTER

I. Corporate Demand for Safe Assets and Government Crowding-In 1

1.1 Introduction 1
1.1.1 Literature review 8
1.2 Empirical motivation 12
1.2.1 Alternate explanations 19
1.3 A dynamic equilibrium model of corporate safe assets . . . 22
1.3.1 Corporate demand for safe assets 24
1.3.2 Supply of safe assets and equilibrium 36
1.3.3 Distortions and extensions 49
1.4 Estimating the dynamic model 55
1.5 Data 56
1.5.1 Identification 59
1.5.2 Results 63
1.5.3 Determination of equilibrium 64

1.6 Supply of safe assets and corporate investment 68
1.6.1 Baseline 70
1.6.2 Household demand for safe assets and corporate net-lending 76
1.6.3 Pledgeability of capital and the private supply of safe assets 78
1.7 Discussion 81
1.8 Extensions 83
1.8.1 Agency frictions 83
1.9 Mechanism validation 85
1.10 Conclusion 89

II. Estimating and Testing Dynamic Corporate Finance Models . . . 94

2.1 Trade-Off Model 101
2.1.1 Optimal policies 105
2.2 Benchmarks and Estimation 108
2.2.1 Empirical policy functions 108
2.2.2 Indirect inference 110
2.2.3 Inference and tests 116
2.3 Estimation 120
2.3.1 Data 120
2.3.2 Estimation results 122
2.4 Monte Carlo Simulations 126
2.4.1 Baseline results 128
2.4.2 Test power 135
2.5 Robustness 136
2.6 Conclusion 143

III. Corporate Taxation, Investment, and the Return on Safe Assets . 158

3.1 Introduction 158
3.2 An equilibrium model of corporate taxation and rates of return 164
3.2.1 Firms 164
3.2.2 Households 169
3.2.3 Government 171
3.3 Equilibrium 172

3.4 Effect of taxes in the baseline parameterization 176
3.5 Asset market segmentation and the effects of taxation . . . 183
3.6 Pledgeability and the effects of taxation 186
3.7 Conclusion 189

APPENDICES 191
A.1 Construction of data variables 192
A.1.1 Corporate cash holdings in the Financial Accounts of the U.S. 192
A.2 Computation 195
A.2.1 Solution of the firm's dynamic problem 195
A.2.2 Steady state distribution and market clearing . . . 196
A.3 Details of estimation 198
A.3.1 Market clearing in the GMM estimation 198

BIBLIOGRAPHY 202

LIST OF FIGURES

Figure

1.1	Returns to capital and liquid funds.	14
1.2	The composition of corporate liquid asset holdings.	16
1.3	The current debt position of U.S. firms.	18
1.4	Identification of select parameters.	65
1.5	Determination of equilibrium at model estimates.	67
1.6	Effect of precautionary demand on the return on safe assets.	69
1.7	Government borrowing, interest rates and financing in the baseline model.	71
1.8	Government borrowing, the liquidity premium, and taxes.	73
1.9	Government borrowing and investment.	75
1.10	Pledgeability, the liquidity premium, and investment.	80
1.11	Empire building and the liquidity premium.	84
1.12	Corporate liquid assets, government debt, and the liquidity premium over time.	91

1.13 Scatter plot of corporate safe asset holdings, government debt, and the liquidity premium. 92

2.1 Theoretical policy functions. 153

2.2 Distribution of chi-squared test statistics: Large sample size. . . . 154

2.3 Distribution of chi-squared test statistics: Small sample size. . . . 155

2.4 Specification test power in the EPF-based estimators. 156

2.5 Specification test power in the moments-based estimators. 157

3.2 Effect of taxes on interest income on equilibrium. 179

3.4 Effect of dividend taxes on equilibrium. 181

A.1 Cash and short-term investments of select U.S. firms. 194

LIST OF TABLES

Table

1.1 Detail on the composition of corporate liquid asset holdings. . . . 21

1.2 Summary statistics for Compustat data. 57

1.3 GMM estimates for the 2000-2016 period. 62

1.4 Increases in government borrowing: baseline model. 77

1.5 Increases in government borrowing: household demand. 79

1.6 Government borrowing, corporate liquid assets and returns. . . . 90

2.1 Summary statistics: State and control variables. 145

2.2 Estimations of trade-off model with different benchmarks. 146

2.3 Monte Carlo comparison of simulation estimators: Large sample size. 147

2.4 Monte Carlo comparison of simulation estimators: Small sample size. 148

2.5 Monte Carlo comparison of specification tests. 149

2.6 Monte Carlo comparison of simulation estimators: Covariance moments, high order EPFs, and transformed EPFs. 150

2.7 Monte Carlo comparison of simulation estimators: Model with fixed adjustment costs. 151

2.8 Monte Carlo comparison of simulation estimators: Decreasing returns to scale model. 152

3.1 Parameter estimates from *Kahn* (2019). 177

3.2 Counterfactual tax policies, constant share of lump sum taxes in output. 182

3.3 Counterfactual tax policies, constant present value of lump sum taxes. 184

3.4 Counterfactual dividend tax under alternative market segmentation.186

3.5 Counterfactual effect of a interest income tax decrease for different levels of pledgeability. 187

3.6 Counterfactual effect of a dividend tax increase for different levels of pledgeability. 188

LIST OF APPENDICES

Appendix

A. Chapter I supporting material 192

B. Chapter II supporting material 200

ABSTRACT

This dissertation is composed of three essays. Jointly, the essays emphasize the importance of using microeconomic data combined with dynamic models of the firm to address broader economic questions of relevance to policy makers. The first and third chapter apply dynamic models of the firm to a broader question: how fiscal policy interacts with firms' financing and investment decisions. They show that dynamic models of firm financing and investment estimated from micro data can produce drastically different results for, in Chapter 1, the costs of government borrowing, and, in Chapter 3, the effects of taxation than standard macroeconomic models, where constraints on debt issuance are binding and dynamic financing behavior is therefore limited. The second chapter concerns best practices in disciplining these dynamic models using micro data, and establishes a set of features of the data that can be used across a wide array of models to estimate parameters and test models.

Chapter 1 examines how government borrowing affects firms' financial decisions and thus investment. Given firms' financial decisions, government borrowing increases interest rates, and thus harms investment. However, government debt also constitutes a savings behicle for firms. When government borrowing increases, this savings vehicle becomes more plentiful, allowing firms to avoid fi-

nancial short-falls in the future and invest with less cost. This second effect hinges critically on the dynamic nature of the financing problem firms face, as the precautionary demand they have for the savings vehicle the government provides is inherently dynamic. Estimating parameters which describe this dynamic problem from panel data on corporate financing and investment since 2000, I find that government borrowing actually increases corporate investment through this dynamic effect.

Chapter 2, work with Santiago Bazdresch and Toni Whited, explores how the parameters of dynamic models of corporate finance ought to be estimated from the micro data. In particular, we explore the finite sample properties of simulated method of moments estimators, which are ubiquitous in the literature. Which moments provide good performance in terms of parameter recovery and ability to detect misspecification, and how should these moments be weighted? We establish a set of moments based on the policy functions of firms which can be applied across a wide variety of models in order to recover parameters. Using a Monte-Carlo design, we show that SMM estimators in general have excellent parameter recovery, that test statistics with optimal weight matrices are appropriately sized, and that the tests easily detect even slight misspecification.

Chapter 3 explores an extension of the work in Chapter 1. When government debt adds value to the corporate sector by providing a store of liquidity, how should the surpluses which back government borrowing be provided? I consider using taxes on interest income and dividends as means to supply safe assets to the corporate sector. I find that taxes on dividend income can improve outcomes by transferring resources from firms which will be unconstrained tomorrow to firms who desire insurance against financing costs today. Again, the nature of the problem firms face is important: I explore alternative values for pledgeability and costs of financial shortfalls, and find qualitatively different results for the sensitivity of macroeconomic aggregates to corporate taxation. This underscores the importance of using dynamic models whose parameters are estimated from the data for assessing policy counterfactuals.

CHAPTER I

Corporate Demand for Safe Assets and Government Crowding-In

1.1 Introduction

Since 2000, the U.S. corporate sector has been characterized by tepid investment despite high measured returns. Simultaneously, real returns on government debt have fallen. This widening gap between returns on government bonds and on private investment has led to a surge of interest in how government borrowing affects economic activity. For instance, Olivier Blanchard's 2019 presidential address called for "a richer discussion of the costs of [government] debt and of fiscal policy than is currently the case" (*Blanchard*, 2019). One component of these costs is that greater government borrowing may raise the cost of capital of firms, "crowding-out" private investment. This effect is a result of the competition between corporate debt and government debt in providing safety and liquidity to the economy. However, corporate finance has long emphasized that in the presence of financial constraints firms are also sources of demand for safety and liquidity in order to meet their investment needs. Despite this conflict, little attention has been paid to integrating the supply of safe and liquid assets with realistic models of firm financing and investment.

In this paper I present a framework which relates government borrowing to the financing and investment decisions of non-financial corporations. The framework is based on an equilibrium model which features dynamic firms who face a rich set of financing decisions. My focus is on the role that the government plays in providing a safe and liquid store of value to the economy. In my model, the market for safe and liquid assets is endogenously segmented from other asset markets. Corporations participate in the market for safe assets in two ways. The first is by providing close substitutes to government debt in terms of safety and liquidity through their borrowing in highly-rated short-term debt such as commercial paper. The second is by holding treasuries and close substitutes in the form of interest bearing bank accounts and money market mutual funds. My model highlights two conflicting channels along which government borrowing affects corporate investment: a "cost-of-capital" channel and a "precautionary savings" channel. Along the "cost-of-capital" channel, short-term debt issued by the corporate sector is in competition with the government in supplying safety and liquidity. When the government borrows more, rates on short-term debt rise, driving the cost of capital for corporations up and crowding-out investment. Along the "precautionary savings" channel, the corporate sector benefits from an increased supply of safe assets because it reduces the cost of retaining earnings for the precautionary purpose of avoiding future financing costs. When the government borrows more along this channel, it allows corporations to avoid more financing costs, increasing investment. To discipline the relative sizes of these two channels, I estimate the model from data on the panel of firms in Compustat since 2000, delivering novel quantitative and qualitative results.

In particular, in contrast to the traditional crowding-out effect of government borrowing, my model suggests the size of government debt and corporate investment are complements. This net effect depends on the parameters I estimate which describe firms' dynamic financing and investment problem. The size of the cost-of-capital channel is limited by the extent to which corporations can pledge their capital in order to create safe assets. The size of the precautionary savings channel is governed by the costs of financial shortfalls. There is no reason that this second, precautionary savings channel cannot dominate the cost-of-capital channel. In fact, estimating the model from data on public U.S. firms shows that a 1% increase in government borrowing would lead to a 13 basis point increase in aggregate corporate investment, and a 60 basis point increase in rates of return. Therefore, at my parameter estimates government borrowing does not crowd out corporate investment, but rather crowds investment in by reducing the cost of corporate savings. That my model shows a crowding-in effect of government borrowing on corporate investment emphasizes that, at least in the post-2000 economy, other limits on the size of government debt such as costs of sovereign default, inflation and dead-weight losses of taxation are more important than limits due to competition with the corporate sector for providing safety and liquidity.

Several features in the data motivate the construction of my model. First, since 2000, measured real returns on corporate capital have remained constant, while the rate of return on safe assets such as treasuries has fallen. Second, I examine how firms participate in the market for safe assets. Firms supply close substitutes to government debt in the form of short-term highly rated debt such as commercial paper, which commands similar returns to treasuries and serves similar purposes. But the returns on longer-term and lower rated debt have departed from the returns on treasuries since 2000, suggesting limited substitutability. I then examine firms' demand for safe assets. I use a variety of data sets to show that much of firms' cash holdings are in safe assets which will command similar returns to government debt, such as interest bearing bank accounts, money market mutual funds, commercial paper and direct holdings of treasuries. Yet despite the attraction of low interest rates on safe assets, firms' issuance of safe assets has fallen while their cash holdings have risen. As a result, since 2000 the corporate sector has become a net-lender in safe assets. This motivates my focus on limits to the provision of these securities from within the corporate sector.

Having established these motivating facts, I then present and estimate my model of the supply and demand for safe assets from the corporate sector. In the model, firms supply safe assets by issuing one period debt, which I assume is a perfect substitute for government debt. Motivated by limited corporate issuance of short-term safe debt, I assume firms' ability to issue safe assets is limited by the extent to which they can pledge their capital. The limited pledgeability of capital governs the extent to which the cost of capital of firms depends on the rate of return on safe assets. Higher pledgeability means that a greater amount of capital investment can be funded by issuing safe debt against the value of capital, leading to a closer substitutability between capital and government debt. As a result, higher pledgeability leads to larger crowding-out of investment when government borrowing increases.

At the same time, firms demand safe and liquid assets like government debt because they represent an option to avoid future financing costs. Because they face the possibility of future financial constraints, firms desire to retain earnings to invest in future periods without incurring these costs. Safe assets in the form of direct treasury and government security holdings, money market mutual funds, and interest bearing bank accounts are the primary technology available to firms to retain their earnings and fund future investment while avoiding financing costs. This option has value to firms because of their future anticipated investment needs. The extent of firms' demand for safe assets therefore depends on their investment needs and the costs of financing shortfalls. Higher costs of shortfalls mean a greater demand for safe assets from firms, and a larger crowding-in of investment when government borrowing increases.

In order to determine the net effect of government borrowing on corporate investment, I estimate the parameters of my model from the panel of Compustat firms. Estimating the response of corporations to government borrowing directly is made difficult by the fact that there is little exogenous variation in government borrowing, the limited time series available for government debt and corporate investment, and the fact that large changes in government borrowing are rare. Instead, I turn to firm-level data and estimated parameters which describe the net effect of government borrowing on investment. In particular, this net effect depends on the production function of firms and their investment behavior, as well as parameters which describe the costs of financial shortfalls and the pledgeability of capital. Once again, estimating these parameters is made difficult by the fact that precautionary demand is unobservable and endogenously related to investment needs and financial position. As such, I estimate the parameters which describe the firms' financing and investment decisions using generalized method of moments to match the steady state distribution of firms implied by the model to the distribution of firms in the data. I then calculate the net effect of government borrowing on liquidity premia and investment by considering counterfactuals in which government borrowing increases. The relationship between government borrowing, liquidity premia and corporate investment I find is thus based on a micro-founded model, and on explicit data on the financial holdings and issuance of firms. This method is complementary to reduced-form studies of the effect of government borrowing on corporate financing and investment such as *Graham et al.* (2014) and *Ayturk* (2017), and to studies of the effect of government borrowing on liquidity premia such as *Krishnamurthy and Vissing-Jorgensen* (2012) and *Nagel* (2016), which are based on macroeconomic data on returns and borrowing but do not examine microeconomic data of agents' participation in the market for safe debt.

While the response of corporate investment to government borrowing is interesting in its own right, my results also speak to the relationship between rising corporate cash holdings and falling interest rates. When the supply of safe assets from other sectors is limited, firm's precautionary demand for safe assets endogenously segments the market for safe debt from the market for their other securities. Because safe assets allow the firm to avoid future financing costs, the firm is willing to hold these assets despite the fact that they offer a lower return than the discount rate applied to the firm's cash flow to investors even in the absence of aggregate risk. The spread of the discount rate on the firm over the rate of return on safe assets constitutes a liquidity premium in the sense of *Holmström and Tirole* (2011). As corporate cash demand rises, the model predicts that the liquidity premium will rise as returns on safe assets are driven down. I validate this prediction of the model by examining the long time series of corporate liquidity demand and liquidity premia. I show that increases in corporations' demand for safe assets for a fixed government supply are associated with a rising liquidity premium.

Finally, while my model considers an exogenous supply of safe assets provided by the government, I relate the results to more general models of the supply of safe assets which include financial intermediaries as creators of liquidity and safety. In these models, intermediaries are typically constrained from issuing safe debt such as interest bearing deposits or commercial paper by either their own pledgeability or regulatory limits on issuance. Government borrowing in an environment with intermediation has the effect of crowding out safe debt issuance by intermediaries as well as firms. Nevertheless, I show that the relationship between rates of return on safe assets and corporate investment will persist, while the quantitative relationship between government borrowing and corporate investment will be muted as a result of the crowding out of intermediaries. The results I show are therefore relevant to the costs of regulating intermediaries and costs of unconventional monetary policy.

1.1.1 Literature review

In this paper I consider the effect of government policy on investment and rates of return through the lens of the government's ability to supply safe assets to corporations. Through this channel I find that government borrowing increases investment. This effect stands in contrast to a standard intuition whereby government borrowing crowds out investment. *Friedman* (1978) points out that this intuition is flawed, and that effects of government borrowing on corporate investment, or indeed private demand for any asset, depend on the nature of substitutability between that asset and the services government assets provide. A recent strand in the literature emphasizes a particular form of this substitutability: the substitutability of corporate assets for government assets in providing safe, liquid stores of value to households and intermediaries. In particular, *Krishnamurthy and Vissing-Jorgensen* (2015) and *Graham et al.* (2014) find that intermediaries substitute government bonds for short-term, relatively safe corporate debt when government borrowing increases, while *Greenwood et al.* (2010) finds that corporations issue more long-term debt as the maturity structure of government debt shortens. My model is consistent with the findings in these papers in that I find that corporations issue less safe assets in response to decreases in government borrowing. However, corporations also hold safe assets in the form of cash and short-term investments. The net effect of these two frictions is unclear, and depends on the nature of corporations' precautionary savings.

As such my paper emphasizes the special role that government debt plays as a vehicle for the precautionary savings to firms. Much debate surrounds the exact source of the "specialness" of U.S. government securities such as treasuries. Specifically, whether government debt is special because of its safety in terms of lack of exposure to aggregate risk (*Gorton and Ordoñez*, 2013; *Caballero and Farhi*, 2018), because of its liquidity and similarity to money (*Holmström and Tirole*, 2011; *Krishnamurthy and Vissing-Jorgensen*, 2012), because of its insensitivity to private information (*Gorton and Pennacchi*, 1990; *Chemla and Hennessy*, 2016), or because of its value as collateral for intermediaries (*Gertler and Karadi*, 2013; *Krishnamurthy and Vissing-Jorgensen*, 2015). In many models these attributes are difficult to separate: government debt is liquid because it is safe and insensitive to private information, and usable as collateral because it is liquid. It shares all these attributes to some degree with a limited set of private securities, usually short-term in nature, such as highly rated commercial paper, notes and short-term corporate bonds.

It is not my intention in this paper to parse the uniqueness of these assets in great detail, only to note that these assets have attributes which make them especially useful to corporations for retaining their earnings, but also difficult for corporations to supply. As in *Chemla and Hennessy* (2016), my focus is on the relation between government borrowing and the non-financial corporate sector. Unlike *Chemla and Hennessy* (2016), my focus is on a unified dynamic model of both the competition of corporate debt with government debt and the demand from corporations for holding government debt. In particular, financing costs in my model mean that firms receive benefits from assets which guarantee returns tomorrow. However, these same financing costs also mean that firms face costs to supplying these safe returns. The closest point of comparison to my paper is thus *Holmström and Tirole* (2011). Similar to my paper, their study features a provision of securities both by the corporate sector and the government, which adds value when corporations ability to provide safe assets is limited. While their study features deeper microfoundations for the relation between the provision of these securities and corporations' demand, it is a three-period model which does not allow for a quantitative treatment of firms' investment.

Focusing on corporate safe asset holdings allows me to link this literature on the specialness of government debt to a literature on dynamic corporate finance and the precautionary savings of firms. My paper then contributes to this literature on firms' precautionary savings by emphasizing the supply of safe assets as vehicles for these savings. The problem of the firm in my model closely follows *Gamba and Triantis* (2008), *Riddick and Whited* (2009), and *Bolton et al.* (2011). In all these papers, corporations' liquid assets earn a lower after-tax return than the discount rate on the firm as the result of a penalty or "carry cost" of cash holding. I emphasize that, just as the frictions in these models create a demand for safe assets they also limit the ability of the corporate sector to supply these assets. This endogenizes the carry cost of cash holding as the result of a liquidity premium attached to scarce safe assets. Similarly, *Rampini and Eisfeldt* (2005) consider the effects of corporate precautionary demand on liquidity premia over the business cycle. Like my paper, theirs features costly financing which leads to a demand for safe assets from the corporate sector. Our papers differ both in our focus and in how we model the supply of safe assets. In their paper, the supply to a representative firm is restricted by investors to prevent waste due to agency frictions. In mine, investors are unable to create safe assets without capital, and supply from within the heterogeneous corporate sector is restricted by the same costly financing which leads to demand for safe assets.

An important conclusion of my paper is the role of the net-lending position of firms in determining the relationship between rates of return on safe assets and investment. This conclusion links my paper to a recent literature describing the net-lending of firms, such as *Armenter and Hnatkovska* (2011). *Gruber and Kamin* (2016), *Gruber and Kamin* (2017), and *Chen et al.* (2017). It also links my paper to two recent papers describing consequences of net-lending behavior for the allocation of investment across firms (*Perez-Orive and Caggese*, 2017), and the stability of the financial system (*Li*, 2018). Both of these papers link rising safe asset demand from firms to increases in the intangible share of investment. I focus solely on rising safe asset demand and consider the provision of safe assets by the private and public sector. Relative to *Perez-Orive and Caggese* (2017), who focuses on corporate net lending and the misallocation of investment, my main contribution is to emphasize the importance of government borrowing and distortions to firms demand for the equilibrium interest rate and investment, and to focus on differences between the rate of return on safe securities and other corporate securities. Relative to *Li* (2018), my main contribution is to link the supply of safe assets from the government and intermediaries to their investment through endogenous safe asset demand.

My results point to an important role for the safe asset demand of firms in the widening gap between short-term safe interest rates and the returns to capital. By focusing on differences between the securities firms issue and those they hold for precautionary purposes, my paper related to explanations of low investment which focus on an aggregate scarcity of safe assets, especially *Caballero et al.* (2008) and *Caballero and Farhi* (2018). Whereas these papers largely focus on reasons for a decrease in the aggregate supply of these assets, I focus on changes to their demand in the corporate sector, and quantify consequences for aggregate investment. One important distinction between our models is the channel through which they occur. In their models, safe assets are demanded by consumers because of a lack of exposure to aggregate risk, and their supply is limited by a binding zero-lower bound. In my model safe assets are demanded by firms because of a lack of exposure to idiosyncratic risk, and their supply is limited by binding pledgeability constraints on non-corporate, non-government sectors. While their model has the advantage of providing a direct link to monetary policy at the zero lower bound, my model links the gap between safe rates and returns to capital to the anomalous financing behavior of firms since 2000, and provides insights into how tax policy might affect this gap.

1.2 Empirical motivation

In this section I review the motivating facts of this paper. Since 2000, interest rates on liquid securities have remained low while investment has been tepid. At the same time firms' cash holdings have increased. It is not immediate that this rise in firms' liquid asset holdings should have an impact on the return these assets receive, since if cash holdings are stored in the same types of assets that firms issue, cash holdings of one firm simply represent funds available for investment by another. However, I show that a large amount of these cash holdings are in safe, liquid assets which firms have limited abilities to issue. The return on these assets has fallen relative to the return on comparable corporate assets, suggesting increasing segmentation between these two markets. I then turn to my model, which relates the limited supply of these assets to firms' precautionary demand for liquid assets, interest rates and investment.

The key facts which motivate my paper are summarized in Figure 1.1. All of these facts are established in the literature, my point in presenting them is to relate their evolution over time, and to connect changes in returns to changes in corporate financing. The first panel shows non-financial corporate investment over profits. It shows that since 2000, investment has been declining relative to profits. This series is similar to *Gutiérrez and Philippon* (2016). The second panel shows real returns on government securities, using the yield on 3-month treasury bills and 10-year treasuries, less expected inflation as calculated using the Cleveland Federal Reserve series, and the average return to capital, calculated using non-financial corporate profits divided by the book value of real assets. The panel shows that since 2000, returns to government securities have been declining, and departed from returns to capital. This series is similar to that in *Caballero et al.* (2017). The third shows total Compustat cash holdings scaled by total Compustat assets. Rising cash holdings are documented by *Graham and Leary* (2017) and *Faulkender et al.* (2017).

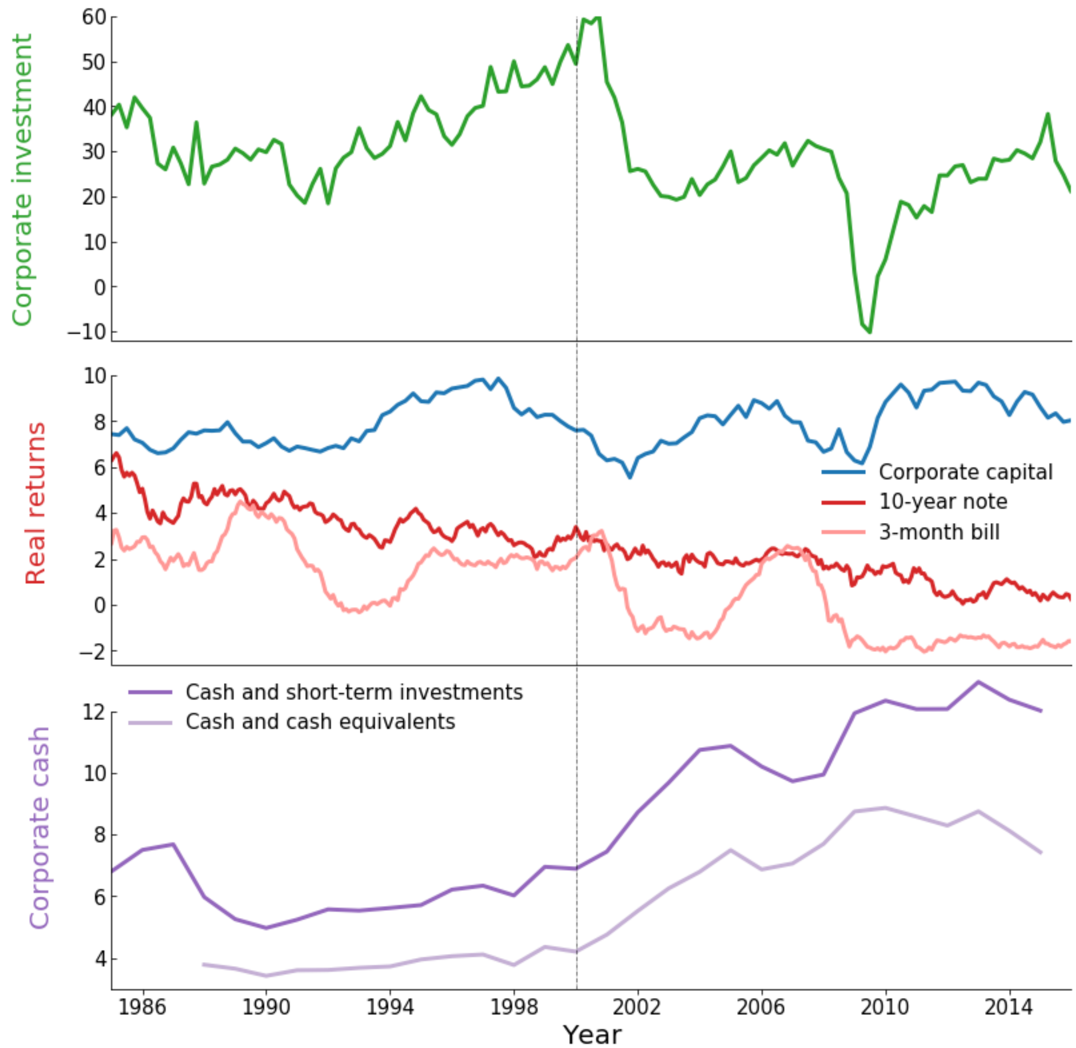


Figure 1.1: **Returns to capital and liquid funds.** This figure shows returns to capital as measured by the earnings to capital ratio and earnings to value ratio from Compustat data along with returns to 10-year and 3-month treasury securities from the Federal Reserve.

These three facts are puzzling in concert. High returns on investment and low interest rates suggest that firms should be borrowing at safe rates and using the proceeds to invest. Instead, firms are investing less and holding higher levels of cash.[1] If corporate capital assets and government securities are substitutes, an increase in the price of government securities (decrease in their return) should increase demand for physical capital. In my model this puzzle is resolved by the different attributes of securities corporations provide, which determine their cost of capital, and government securities, which they hold. In particular, government securities are both safe and liquid, whereas most corporate securities are neither. If demand for government securities increases, but corporations find it costly to issue safe securities to invest in physical capital, a decrease in the return to safe securities need not increase corporate investment.

One large source of demand for safe assets is the corporate sector itself. Figure 1.2 shows a breakdown of corporate liquid asset holdings in the data from the Federal Reserve's Financial Account. While a large amount of corporate liquid assets are in money market mutual funds, I have broken them out into the ultimate provider of the security. I detail this procedure in Appendix A.1 below, as well as discussing issues in comparing liquid assets in the flow of funds to Compustat cash holdings. I have categorized these holdings into government securities, bank securities, and other assets. Government securities held by corporations include treasuries, agency and GSE debt, and municipal securities. The majority of these securities are holdings of treasuries and agency debt. Corporate securities include

[1] This relationship is not mechanical: firms can always pay out cash holdings, and pay outs have indeed risen over this period.

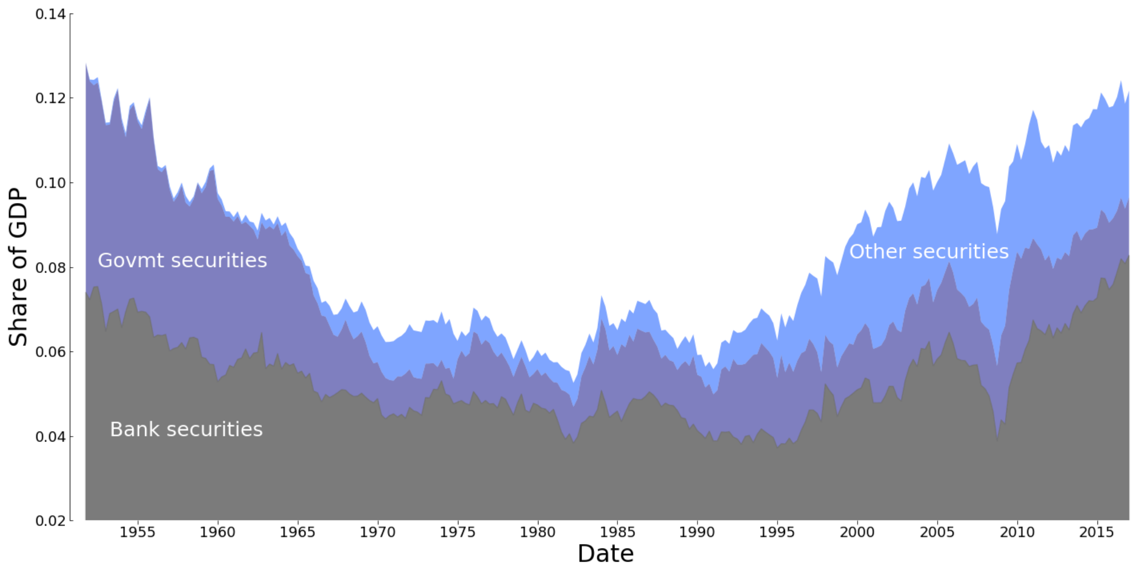


Figure 1.2: **The composition of corporate liquid asset holdings.** Data for all series are ultimately from the Federal Reserve's Financial Account data, the construction is described in Appendix A.1. Assets are categorized into bank assets (deposits, repurchase agreements and physical currency) government securities (treasuries, agency debt, GSE and municipal securities) and other private securities (corporate bonds, commercial paper and equity mutual funds). Holdings are normalized by GDP.

commercial paper and equity mutual funds.[2] Bank securities include deposits, savings accounts and repurchase agreements.

Three facts about these cash holdings are worth noting. First, as *Azar et al.* (2016) points out, almost all cash holdings in the corporate sector are in interest bearing assets. These assets are distinguished by their relative safety and liquidity: they are primarily invested in short-term corporate and financial intermediary debt, in

[2]Financial Accounts data do not distinguish between financial and non-financial commercial paper holdings of non-financial firms, so some of this commercial paper is likely issued by financial firms. This will tend to overstate the amount of liquid assets which are supplied by the corporate sector.

interest-bearing deposit accounts or in government securities. Finally, as corporate cash has risen, the ultimate supplier of corporate cash holdings has changed. Prior to the 1970s, the ultimate suppliers of corporate liquid assets were the government and financial intermediaries. However, as this figure shows, the rise in cash holdings from the 1990s to the 2000s was primarily in the form of increases in “other securities”, neither government securities nor conventional deposits. This increase reflects the rising role of money market mutual funds in the provision of liquidity to the corporate sector. Table A.1 shows, the breakdown of these assets over time of corporate assets across banks, direct government holdings and money market mutual fund holdings. As a percentage of total liquid assets, money market mutual funds roughly tripled between the 1990s and the 2000s. The growth in these funds was in turn primarily backed by holdings of commercial paper and short-term corporate debt, by far the largest components of the “other securities” category.

How do firms on net contribute to this market for safe debt? Because so much of the rise in corporate cash holdings has been in money market mutual funds which hold largely short-term debt, I limit my attention to firms holdings of cash and short-term securities and their issuance of short-term debt. These are the securities which *Krishnamurthy and Vissing-Jorgensen* (2015) argue are in competition with government debt as a source of safety and liquidity. Figure 1.3 shows corporations contribution to this market. I use notes payable to proxy for the supply of safe short-term debt, though this is likely to overstate the amount of corporate debt which can substitute for government securities. I also include

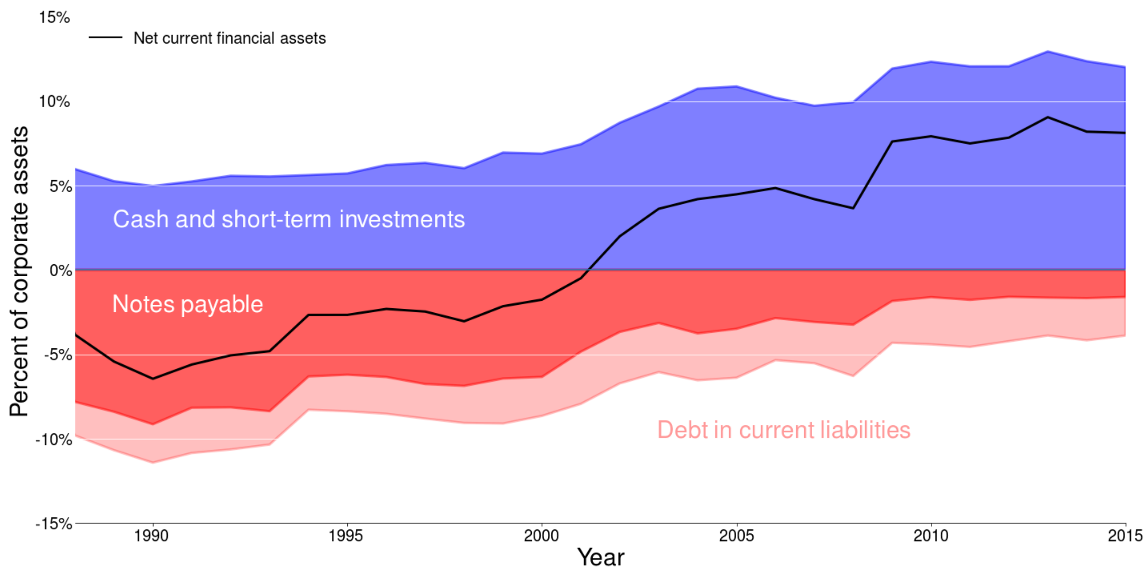


Figure 1.3: **The current debt position of U.S. firms.** Data for all three series are ultimately from Compustat, 1987-2000. Each series is aggregated over the Compustat sample, and divided by total Compustat assets.

debt in current liabilities, a broader category, for comparison. The total supply of short-term debt from firms has declined over time, while cash and short-term investments rose dramatically in 2000. As a result, in 2000 the firm switched form a net-borrower in the safe debt market to a net-lender.

My model ties costly private safe asset issuance and large safe asset demand by firms to the decline in investment since 2000. If supply by the private sector is costly, then large safe asset holdings will tend to drive up the price of safe assets, and drive down the interest rate. If it is costly for other firms to issue safe assets in response to a rise in demand, investment will tend to fall as the corporate sector is unable to meet safe asset demand internally. My model can then explain the joint behavior of these three series since 2000.

1.2.1 Alternate explanations

While several explanations have been offered for the anomalous behavior of interest rates and investment since 2000, I argue most are not consistent with the rise in corporate cash holdings.

1. **Declines in long-run productivity / the growth rate** *Summers* (2018) argues that low interest rates and investment can be explained by declines in the growth potential of firms. However, high measured returns on investment suggest this is not the case, as has been pointed out by *Gomme et al.* (2015). Meanwhile, high corporate cash holdings are difficult to reconcile with low growth rates, as the corporate sector should anticipate less investment in the future.

2. **Cyclical variation in interest rates and investment** The post-2000 period has featured two long recessions. It is possible that low investment since 2000 has been the result of low aggregate demand, while high cash holdings are the result of anticipated increases in future profitability relative to today. Meanwhile, Federal Reserve actions would lower short-term interest rates. However, the yields on long-term government securities are also low. Low rates of return on these long-term bonds are difficult to reconcile with Fed policies, especially before the beginning of quantitative easing.

3. **Declines in competition / rising markups** *Gutiérrez and Philippon* (2016),

Barkai (2016), and *Loecker and Eeckhout* (2017) argue that high measured returns on investment are the result of increases in firm level markups, possibly related to declining product market competition in the corporate sector. However, the relationship between competition and corporate cash holdings is unclear. In particular, if the effect of decreases in competition is to lower corporate investment, precautionary demand for cash holdings should decline as firms will expect to invest less in the future. More generally, with cash holding earning such low returns, a more attractive option would seem to be to return money to shareholders and allow them to invest in other, possible competition-enhancing projects.

A final explanation of the changes in these three variables is rising risk premia. Increases in risk premia would increase the precautionary demand of firms, increase the required return on capital, and decrease investment. To the extent that rises in uncertainty represent increases in the premium on assets backed by capital, as in *Caballero and Farhi* (2018), I view my paper as complementary to these explanations. Their paper focuses on increases in the premium attached to government securities from limits on the ability of actors to supply safe assets, where safety is relative to capital's exposure to aggregate risk. Mine focuses on limits within the corporate sector of the provision of safe assets where safety is relative to capital idiosyncratic uncertainty. In this context, adding aggregate risk would only increase the premium attached to safe assets by firms. To the extent that increases in risk premia represent increasing uncertainty, they will be difficult to empirically distinguish from my channel. Below, I attempt to distinguish between these two

	Bank securities	Money market funds	Government securities	Other
1950-1964	61.52	0.00	37.34	1.14
1965-1999	67.56	5.01	17.73	9.71
2000-2018	48.44	29.19	5.25	17.12
Subperiods:				
1990-1999	58.16	11.55	18.54	11.75
2000-2008	49.42	26.65	6.69	17.24
2008-2018	47.64	31.27	4.06	17.03

Table 1.1: **Detail on the composition of corporate liquid asset holdings.** This table presents the percent of liquid asset holdings in the Flow of Funds data attributable to various providers. Bank securities are time and savings deposits, government securities are treasuries, agency securities and municipal debt. Other securities include commercial paper, equity mutual funds and repurchase agreements.

explanations by focusing on liquidity premia attached to corporate bonds.

If providing perfect substitutes for the liquid securities they demand is costly for firms, what are the consequences for interest rates on liquid assets and the relationship between these rates and investment? It is difficult to assess these consequences empirically since they rely on counterfactual changes in equilibria that depend on interest rates and firms' precautionary demand. A natural experiment where, for instance, interest rates on liquid assets change without a shift in the precautionary demand of firms or their desire to invest is hard to imagine, and would not allow me to clearly examine other counterfactual interest rates or government policies. Instead, I construct a model below which relates firms' precautionary demand for safe assets, the equilibrium interest rate on safe securities, and investment, and then explore how this precautionary demand relates to the interest rates and investment since 2000. I estimate this model, showing it is consistent with the panel of firms since 2000, and then discuss its predictions for the effects of government supply of safe assets on investment.

1.3 A dynamic equilibrium model of corporate safe assets

I now present a dynamic equilibrium model which relates investment, corporate demand for safe assets, the supply of safe assets from outside the corporate sector, and the interest rates these assets receive. There are three agents in the model: the government, a representative household, and firms. I include an additional agent, intermediaries, in my discussion of general equilibrium to make the exposition of market clearing more explicit and to discuss the relationship between intermediary safe asset production and the liquidity premium, but I argue for my purposes they can be treated as largely a veil. In the model, all financial assets are ultimately backed by capital, which is owned by firms. Firms can issue two types of claims on this capital: safe claims, which guarantee repayment tomorrow, and "costly" claims, which do not guarantee repayment tomorrow and are subject to a transaction cost in issuance. I model these costly claims as equity, but they can be understood as including other forms of financing under the assumption that the issuance of these claims incurs similar transaction costs. The corporate sector is limited in its ability to issue safe claims by the pledgeability of their capital. In addition to their ability to create safe claims, corporations can also hold safe assets for their precautionary savings. Meanwhile, the government can produce safe assets through their ability to tax households and firms.

Two important features of the model imply that government borrowing adds value through its provision of safe assets, and that corporate financing choices will affect the equilibrium interest rate these assets receive.

1. Firms have precautionary demand for safe assets.

2. Non-government actors are limited in their ability to produce safe assets.

The first feature can be thought of as a break in the Modigliani-Miller theorem, the second as a break in Ricardian equivalence (*Barro*, 1974). These two features in combination imply that a steady state equilibrium of the model exists where:

- The return on safe assets will be lower than the discount rate applied to firms' cash flows.

- Increasing government supply of safe assets decreases the spread between these two rates.

- Firms' investment will increase as the return on safe assets increases.

The precautionary demand of firms for safe assets segments the market for safe assets, while the limited ability of firms to issue safe assets restricts their private supply. The spread which emerges between the return on safe assets and the discount rate applied to firms' cash flows, which constitutes a liquidity premium, is the key equilibrium price in the model. I begin by reviewing the dynamic problem of the firm, which supports the first feature of the model, that firms have a precautionary demand for safe assets. I then turn to describing the ability of other agents in the model to supply safe assets to the corporate sector. Finally, I discuss the model's equilibrium, and under what conditions the discount rate and the interest rate on safe assets will diverge and lead to a positive liquidity premium.

1.3.1 Corporate demand for safe assets

In this section, I present a standard dynamic model of financing and investment which relates the demand for safe assets from corporations to the rate of return on safe assets and their investment behavior. When issuing financing is costly, firms desire to pursue investment using internal funds. Saving profits in the form of safe assets allows firms to build a buffer of internal funds and invest in the future while avoiding costs of financial shortfalls. The purchase of safe assets today then represents an option to invest with lower cost tomorrow. The return on safe assets determines how costly this option will be to a firm, relative to paying out their profits today and relying on capital markets tomorrow. Corporate finance recognizes numerous distortions to firms' precautionary demand for safe assets, such as agency frictions, taxes on interest income and taxes on dividends. A key focus of this paper will be on quantifying the general equilibrium consequences of these distortions. However, I will abstract from tax and agency distortions for the moment in order to clearly illustrate the equilibrium relationship between firms' demand for safe assets and the return on safe assets. I show that as the return on safe assets rises there are two effects on the firm. First, to the extent that firms can issue safe assets to fund their investment, their cost-of-capital rises. As a result, aggregate investment falls. Second, the option to avoid financing costs becomes cheaper. Firms then hold more of these assets, and are better able to avoid costs of financing in the future. As a result, aggregate investment rises. I discuss how different parameters determine the magnitude of both these effects.

1.3.1.1 Profits and investment

There is a continuum of firms, each producing output $y_{i,t}$ using a decreasing returns to scale production function with slope parameter, α, from capital, $k_{i,t}$. Total profits for the firm are $\pi_{i,t} = z_{i,t}k_{i,t}^{\alpha}$, which reflect capital investments along with profitability, $z_{i,t}$. Each firm differs in their history of profitability draws, but the firms are ex-ante homogeneous. Profitability follows an auto-regressive process:

$$\log z_{i,t+1} = \chi \log z_{i,t} + \epsilon_{i,t+1}$$

This persistent process drives heterogeneity among firms in their expected returns to investment and creates a motive to allocate resources among firms according to their expected profitability.

Firms choose capital tomorrow through investment today, before profitability is observed. Their choice of investment is thus based on expected profitability tomorrow. Capital depreciates gradually, and accumulates following the standard law of motion:

$$k_{i,t+1} = (1 - \delta)k_{i,t} + I_{i,t}$$

Investment, $I_{i,t}$, can be positive, representing purchases of capital, or negative, representing a sale of assets. In addition to its direct costs, investment comes with adjustment costs. The firm's choice of investment is subject to fixed and variable adjustment costs:

$$\Phi(k_{i,t}, I_{i,t}) = \phi_0 1_{|I_{i,t}|>0} k_{i,t} + \frac{\phi_1}{2}\left(\frac{I_{i,t}}{k_{i,t}}\right)^2$$

As I will show, these adjustment costs again increase the needs for firms to hold safe assets, since capital cannot freely be sold. It is not necessary to have either fixed or variable costs to adjustment for the key results of my model, however including both types of costs allows for a much better match to the data. Since firms' precautionary demand for safe assets is directly related to their investment behavior, a reasonable fit to the data on investment is necessary to quantify the importance of safe asset supply in equilibrium.

1.3.1.2 Financing

Firms demand for safe assets is a result of their need to finance investment. After using their profits, firms are left with a financing gap of $I_{i,t} - \pi_{i,t}$. They can fund this gap with retained earnings, or by issuing costly finance. Earnings can only be retained through investing in safe assets.[3] The firm begins the period with safe asset holdings, $a_{i,t}$. They then choose safe asset holdings for tomorrow, $a_{i,t+1}$ by buying or selling their current holdings at a price $\frac{1}{1+r}$. This can be though of either as trading treasuries or as reducing or increasing deposits in a bank or money market mutual fund which backs these deposits by holding treasuries.

[3]The assumption that firms do not retain their earnings as physical currency in a safe is without loss of generality, since retaining funds as physical currency is dominated by safe assets so long as their interest rate is above zero.

Firms are free to hold any positive amount of safe assets. I also allow firms to have negative holdings of safe assets. These negative holdings have two interpretations. The first is that they represent credit lines extended to the firm by a bank. The second is that they represent commercial paper issuance by the firm, which receives similar rates to safe assets provided by the government and intermediaries. In matching my model to the data, I will employ this second interpretation, since the commercial paper issuance of firms is easy to observe. The issuance of safe assets by firms is constrained by their ability to guarantee these assets by pledging collateral:

$$a_{i,t+1} \geq -\theta k_{i,t+1}$$

I interpret this constraint as a result of limited enforcement, in particular that the firm is able to default on their safe debt and retain their profits along with $(1-\theta)k$ of their capital. Their safe debt issuance is therefore only incentive compatible if the total amount of repayment is less than θk.

In addition to firms' issuance of safe debt, they can participate in a market for uncollateralized, costly finance. I denote their net issuance of costly finance as $e_{i,t}$. They can return funds to investors in costly finance, $e_{i,t} \geq 0$, or issue new finance $e_{i,t} < 0$. Issuance comes with a transaction cost, $\Lambda(e_{i,t})$. As in *Gomes* (2001) and *Hennessy and Whited* (2007), I assume this cost has fixed and variable components, λ_0 and λ_1. Specifically, to issue e dollars of finance costs the firm

$$\Lambda(e) = \frac{\lambda_0 + \lambda_1 e}{1 - \lambda_1}$$

dollars of internal funds. This functional form maintains the same form as other papers in dynamic corporate finance, but levies the cost on firms. Levying the cost on firms does not change the quantitative or qualitative nature of these costs, but makes the market clearing conditions easier to express.

1.3.1.3 Cash flow identities and firm value

The cash flow identity of the firm reflects the fact that any financing above revenues this period must be obtained from safe assets or costly financing. These funds are then used for investment, next period's safe asset holdings, dividends, or payments of adjustment and external financing costs:

$$x_{i,t} - \Lambda(x_{i,t}) + a_{i,t} + \pi_{i,t} = I_{i,t} + \left(\frac{1}{1+r}\right) a_{i,t+1} + d_{i,t} + \Phi(k_{i,t}, I_{i,t}) \tag{1.1}$$

It is convenient to represent payments to costly financing as net payments, $e_{i,t} = d_{i,t} - x_{i,t}$. As is standard in dynamic models, firms will never issue costly financing and repay their costly financing in the same period.

Again mirroring the traditional treatment of equity, the firm acts to maximize the value of its costly financing. Managers and the firm are thus aligned, though I will discuss departures from this alignment later on. For now, I will also assume that payments to costly financing are discounted at an exogenous rate ρ. In equilibrium, I will show this rate will be determined by households' time preference.

The firm solves:

$$
\begin{aligned}
V(a,k,z) = \max_{e,I,a,k'} \; & e + \frac{\mathrm{E}\left[V(z',k',a')|z\right]}{1+\rho} \qquad (1.2)\\
\text{such that} \; & \pi(k,z) + a = I + \Phi(I,k) + \Lambda(e) + \left(\frac{1}{1+r}\right) a' \\
& k' = (1-\delta)k + I \\
& a' \geq -\theta k'
\end{aligned}
$$

as well as the law of motion for profits and investment opportunities. This problem has no closed form solution, and so I solve it using value function iteration. In addition to the value function, this process yields a policy function $[k', a'] = g(s)$ where $s = [z, k, a]$.

1.3.1.4 Precautionary safe asset demand

The firm chooses safe asset holdings to ensure liquidity inside the firm and avoid external financing costs. When the pledgeability constraint does not bind, their first-order condition equates the cost of a dollar of funds today with the benefit of a dollar of internal finance tomorrow:

$$
1 + \lambda_1 1_{e<0} - \gamma_{a' \geq -\theta k'} = \left(\frac{1+r}{1+\rho}\right)(1 + \lambda_1 \mathrm{P}\left(e' < 0\right)) \qquad (1.3)
$$

where $\gamma_{a \geq -\theta k}$ is a multiplier on the constraint on issuing safe debt. On the left-hand side, the first two terms reflect the marginal cost of a dollar of extra funding today, which depend on whether the firm is issuing in the costly finance market, and therefore paying transaction costs, or returning funds to investors. On the right-hand side is the return on safe assets, discounted by the manager's discount rate, and multiplied by the expected cost of a dollar of extra funding tomorrow.

I now turn to the relationship between the return on safe assets and firms' safe asset holdings. In this discussion I will hold the discount rate applied to the firms' cash flows fixed, which will be justified by my discussion of equilibrium in the next section. For firms who are constrained, γ is greater than zero, and their safe asset holdings are determined by the constraint $a' = -\theta k'$. For firms who are unconstrained, this first-order condition can be simplified:

$$\left(\frac{1+r}{1+\rho}\right) \lambda_1 \, \mathrm{P}\left(e' < 0\right) = 1 - \frac{1+r}{1+\rho} = \frac{\rho - r}{1+\rho} \tag{1.4}$$

The left-hand side of this equation reflects the benefit of safe asset holdings, which is the ability of firms to access financing when they are constrained tomorrow. The right-hand side reflects the cost of safe asset holdings. Holding a dollar of safe assets for a firm who is unconstrained means forgoing a dollar of dividends today. Because safe assets command a lower return than the discount rate of the firm, holding these assets is costly, as the discounted return is less than one. Following *Holmström and Tirole* (2011) and *Krishnamurthy and Vissing-Jorgensen* (2012) I will refer to the cost on the right as the liquidity premium for safe assets. It reflects the low return firms receive on their safe assets in unconstrained states.

The firm holds safe assets to the extent that their liquidity premium is offset by the benefit firms receive in avoiding future costs of financing. While in unconstrained states, the safe assets the firm holds yield less than the firms' discount rate, in constrained states the extra dollar of internal funds these safe assets provide are more valuable. The left-hand side of the equation reflects the value of a dollar of safe assets in terms of $1 + r$ dollars of internal funds in constrained states. In these states, a dollar of internal funds allows the firm to avoid λ_1 dollars of financing costs. These states occur with probability $\mathrm{P}(e' < 0)$. Taken together, the left-hand side then reflects the discounted expected benefit of safe assets in avoiding financing costs tomorrow.

Examining only this intensive margin of unconstrained participants, as the return on safe assets falls, firms are willing to take on a greater probability of incurring external financing costs tomorrow. In general, this can be accomplished two ways: the first is by reducing holdings of safe assets today, while the second is by increasing investment in constrained states tomorrow. However, the firms' investment plans tomorrow are pinned down by their first-order conditions for investment tomorrow in which the return on safe assets, so that safe asset holdings must still fall in response to a fall in the return on safe assets. For firms in unconstrained states, this equation thus describes an implicit demand curve along which safe asset holdings must fall as returns fall. This demand curve also holds for constrained firms, whose holdings are pinned down by the equation $a' = -\theta k'$. Therefore, in combination the constraint on issuance of safe asset holdings and demand for safe asset holdings from firms provide a net demand curve for safe assets from the corporate sector as a whole.

1.3.1.5 Safe assets and investment

Corporate holdings of safe assets have an important role in my model through their effect on investment. As safe assets become more costly, the firm is more exposed to costs of external finance, and investment falls. To make this point clearly, I consider a simple case where adjustment costs and fixed costs of external finance are zero. I then discuss the effect of fixed and quadratic adjustment costs.

A sufficient statistic for investment in this model is the return on capital, which is generally decreasing in investment. The return on capital is easily derived from the firms' first-order conditions. The first-order condition for the manager's problem equates the cost of a dollar of funds today with the benefits of a dollar of investment tomorrow:

$$(1+\rho)(1+\lambda_1 1_{e<0}) = \mathrm{E}\left[(1+\lambda_1 1_{e'<0}) \times \mathrm{MPK}\right] + (1-\delta)(1+\mathrm{P}(e'<0)) + (1+\rho)\theta\gamma_{-a'>\theta k} \tag{1.5}$$

Substituting in the first-order conditional for safe asset holdings and rearranging, we arrive at a modified user cost of capital equation:

$$(1-\theta)\tilde{\rho}(e) + \theta r + \delta = \mathrm{E}\left[\tilde{\mathrm{MPK}}\right] \tag{1.6}$$

Here, the modifications reflect the liquidity needs of the firm. On the right-hand side, I have $\tilde{\mathrm{MPK}} = \frac{1+\lambda 1_{e'<0}}{1+\lambda\,\mathrm{P}(e'<0)} \times \mathrm{MPK}$, so that the marginal product of capital is modified by the fact that the relative payoff of capital in states where the firm faces costly shortfalls.

Second, the user cost of capital on the left-hand side is modified to reflect both the pledgeability of capital and the costs the firm incurs from financial shortfalls. For a marginal dollar of investment, up to θ of that dollar can be funded by issuing safe assets against the capital at r. The remaining capital investment must be funded through reducing payments to uncollateralized finance. Without further altering its financing plans, the fund the remaining $1 - \theta$ dollars by reducing payments to uncollateralized finance today and increasing them tomorrow. Reducing payments today results in incurring further costs of shortfalls, while increasing them tomorrow reduces the expected cost of shortfalls tomorrow. The required return on this financing is:

$$\tilde{\rho}(e) = \frac{1 + \lambda 1_{e<0}}{1 + \lambda \, \mathrm{P}\left(e' < 0\right)}(1 + \rho) - 1$$

Crucially, the required return on costly financing varies with financial position. For firms who are unconstrained today, they are indifferent between a marginal dollar of uncollateralized finance and safe assets. Therefore, $\tilde{\rho}(e) = r$. For firms who are constrained, however, they would prefer to issue more safe debt. Therefore, $\tilde{\rho}(e) > r$ due to their binding pledgeability constraint.

With a binding collateral constraint, firms can be in one of two positions. First, they can be issuing costly financing. In this case:

$$\tilde{\rho}(e) = \frac{1 + \lambda}{1 + \lambda \, \mathrm{P}\left(e' < 0\right)}(1 + \rho) - 1 > \rho$$

These firms are financially constrained: their investment is low because they incur an additional cost to each marginal dollar of financing secured. On the other hand, firms may have a binding collateral constraint in a period in which they pay dividends, in which case:

$$\tilde{\rho}(e) = \frac{1}{1 + \lambda \, \mathrm{P}\left(e' < 0\right)}(1 + \rho) - 1 < \rho$$

These firms are, in essence, conducting arbitrage between the safe asset market and the market for uncollateralized assets: borrowing against their capital investment in the safe market and using the proceeds to return funds to higher return uncollateralized finance. Since their pledgeability constraint is binding, $\tilde{\rho}(e) > r$, and the firms are still investing less than they would be if they were unconstrained. However, $\tilde{\rho}(e) < \rho$, so they over-invest relative to the average firm in order to benefit from lower return safe financing.

The effect of the safe rate on investment in the model can be summarized by a "cost of capital" channel and a "precautionary savings" channel. Both can be seen on the left-hand side of Equation (1.6). First, a portion θ of the cost of capital of firms is due to the return on safe assets. This is because capital has value in being used to provide scarce safe assets whenever $r < \rho$. As the return on safe assets rises, this value decreases and investment is reduced. This channel represents a fairly traditional financial crowding-out mechanism. Without any precautionary demand from firms, the pledgeability constraint is always binding, and crowding-out through the firm's cost of capital would be the only link between safe asset supply and corporate investment.

Along the "precautionary savings" channel, the government borrowing has the effect of increasing investment by reducing the cost of precautionary savings. The firm reacts to a higher rate of return on safe assets by increasing their cash holding in unconstrained states, at the expense of their investment in these states. This is reflected in an increase in $\tilde{\rho}(e)$ for unconstrained firms as $1 + \lambda \, \mathrm{P}(e < 0)$ falls. However, because of the increase in their safe asset holdings, the firm is less likely to face states where they must pay costs of financial shortfalls. Firms that were constrained at the lower rate of return are now less likely to be constrained. Therefore, while the average cost of capital remains equal $(1 - \theta)\rho + \theta r + \delta$, the variance of this cost of capital falls. Since the firm's production technology exhibits decreasing returns to scale, the reduction in the variance of the cost of capital means that average investment will increase. Ultimately, this increase is a result of the government's provision of a liquid savings technology to firms, which crowds their investment in.

As we shall see when the corporate sector is a net-lender in safe assets, the cost of capital effect is dominated by the precautionary savings effect. This is because the corporate sector is in the aggregate acting to increase segmentation between safe assets and their own cost of capital. Greater issuance of safe assets by the government thus increases investment. To see this, we need only turn to the case when θ is zero, so that the firm must lend. In this case, the cost of capital effect will be zero, since the firm cannot pledge their capital to create safe assets. However, the precautionary savings channel will still lead to a positive association between investment and the rate of return on safe assets because the firm still desires to hold safe assets in order to avoid financing costs. When the firm is a large enough net-borrower in safe assets, which can only occur in equilibrium if safe assets are demanded by other sectors, the cost of capital effect can dominate. In this case, the firm is acting as an arbitrageur and competing with the government in its supply of safe assets to other sectors. As government borrowing increases, it limits the returns to this arbitrage, decreasing investment.

The fact that these two channels imply opposing signs for the relationships between safe rates of return and investment means that it is necessary to establish their relative quantitative signs. In the full model, I therefore include a richer set of costs on investment and financing than deployed in this section in order to provide a more realistic picture of the financing and investment problem of firms which can be brought to the data. While the fixed and quadratic adjustment costs of investment and fixed costs of financial shortfalls I include make the effect of the return on safe assets on investment more complicated, they do not alter the basic intuition of these two channels. I will return to this issue below.

1.3.2 Supply of safe assets and equilibrium

As the section above established, firms have a precautionary demand for safe assets in order to reduce their reliance on costly financing. The next section of this paper covers how this demand is met in general equilibrium. The supply of safe assets determines the premium these assets receive. I begin by showing that in a steady state, there will in general be a shortage of these assets from within the corporate sector, that is that the corporate sector does not supply enough of these assets to eliminate the premium they receive. As such, corporations are reliant on other sectors to provide safe assets. I consider three other sectors: households, intermediaries and the government. When non-government agents are limited in their ability to supply safe assets due to their own limits on pledgeability, the premium for safe assets will persist in general equilibrium so long as government supply of safe assets is sufficiently low. Government policy in the form of treasury issuance, monetary policy, and tax policy then plays an important role in determining the ability of firms to avoid financing costs. The remainder of the paper will be dedicated to estimating parameters which govern firms' demand for safe assets and studying the effects of government policy on the investment of firms.

1.3.2.1 Supply from within the corporate sector

In general, firms will not supply enough safe assets to eliminate the liquidity premium in a steady state. More formally:

Theorem I.1. *In the absence of taxes or other distortions, the rate of return on safe assets, r, and the discount rate of the firm, ρ, will be equal in a steady state if and only if the constraint on firms' safe debt issuance is never binding.*

Proof. Taking expectations of both sides of Equation (1.3) and rearranging, we find:

$$1 + \lambda_1 \operatorname{P}(e < 0) - \left(\frac{1+r}{1+\rho}\right)(1 + \lambda_1 \operatorname{P}(e' < 0)) = \operatorname{E}\left[\gamma_{a \geq -\theta k}\right]$$

In a steady state, the probability of relying on costly finance next period is equal to the probability this period. Therefore:

$$\left(\frac{\rho - r}{1 + \rho}\right)(1 + \lambda_1 \, \mathrm{P}(e < 0)) = \mathrm{E}\left[\gamma_{a \geq -\theta k}\right]$$

As a Karush-Kuhn-Tucker multiplier γ is greater than or equal to zero, with equality only when $a > -\theta k$. If this constraint is binding with positive probability, then $\mathrm{E}\left[\gamma_{a \geq -\theta k}\right] > 0$. All other terms on the left-hand side are positive, so ρ must be greater than r. Similarly, if ρ is greater than r, then the left-hand side of this equation is strictly greater than zero, so that the constraint on the right-hand side must be binding with positive probability. □

The intuition that firms' financial constraints will be binding only if the return on safe assets is less than the discount rate they apply to cash holding is straightforward and has been highlighted before. Financial constraints are costly, as they require the firm to pay a cost to participate in the market for costly finance. Firms will only choose to face these constraints in a steady state if holding safe assets is also costly.

More important for my setting is the other direction of implication: that the corporate sector will be unable to provide adequate safe assets internally so long as there is any state where a firm finds itself relying on costly financing with positive probability. So long as firms face some probability of having to rely on costly financing in the future, safe assets will command a premium over the firm's discount rate. Therefore, unless there is an external provider of safe assets who is able to freely convert firms costly financing into safe assets, a premium will persist.

1.3.2.2 Households

The household sector is necessary for my model as a recipient of payout, a source of funds for intermediaries and as a potential source of demand for safe assets. I assume that households cannot issue safe assets, because they cannot pledge their future income. However, they can hold safe assets, and they can borrow and lend freely to intermediaries. In the baseline model, however, the households receives no utility from the convenience of safe assets. This means that when the return on safe assets is below the return on their borrowing from the intermediary, households will not hold safe assets in equilibrium.

Households in my model receive income from their loans from intermediaries, government transfers and deposits in safe asset holdings and use their income for consumption and to purchase financial holdings for next period. For simplicity, I model the sector using an infinitely lived, representative consumer, who maximizes their lifetime utility of consumption by choosing consumption, C_t, loans from intermediaries, L_t and safe assets holdings, D_t.

$$\max_{\{C_t, D_{t+1}, L_{t+1}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t U(C_t)$$

The household pays for consumption with income from financial securities, L_t and D_t, and government transfers, G_t. They also choose financial holdings for next period, L_{t+1}, D_{t+1}. Their budget constraint is:

$$C_t + D_{t+1} - L_{t+1} = \frac{1}{1+r} D_t - \frac{1}{1+\rho} L_t + G_t$$

The household takes the interest rate and the policies of firms as given, and chooses its financial holdings to smooth consumption over time.

I assume households cannot borrow in the safe asset market, that is I apply the restriction $D_t \geq 0$. This can be thought of as resulting from a condition that they cannot pledge their future income. However, households are unconstrained in their participation in the costly finance market.[4] The standard first-order condition of households implies then implies that the ratio of their marginal utility of consumption today over their discounted marginal utility tomorrow must be equal to the expected return on costly finance:

$$U'(C_t) = (1 + \rho)\beta U'(C_{t+1}) \tag{1.7}$$

The first-order condition for deposit rates, including the KKT multiplier ζ on household's safe asset borrowing constraint is then:

$$U'(C_t) = (1 + r)\beta U'(C_{t+1}) + \zeta_{D_t > 0} \tag{1.8}$$

As was suggested above, these two equations in combination imply that when $r < \rho$, households will never hold safe assets in equilibrium. I will extend this baseline below to allow households to hold positive amounts of safe assets in equilibrium despite their low returns through a convenience benefit of safe asset holdings.

[4]It is possible that some of households' uncollateralized borrowings can be securitized by intermediaries to form safe debt. I will consider limits to this securitization in discussing the intermediaries' problem.

1.3.2.3 Government

In my model, the government plays a role in creating safe assets which are ultimately used by households and firms. The unique role of treasuries as collateral in this model can be thought of as a result of the government's special ability to commit to repayment, an extension of their ability to tax agents and enforce contracts. The role that government debt plays as a collateral guarantee has been previously highlighted by *Krishnamurthy and Vissing-Jorgensen* (2012, 2015).

To create safe debt, the government must have revenue from taxes to borrow against. The government's tax bill will eventually come from their taxes on corporations, however for now I consider lump-sum taxes on households. Net transfers to households, G_t, are used to service a constant amount of safe debt, T. Assume that government debt commands an equilibrium return, r_g. Then servicing costs are:

$$-G_t = r_g T$$

As a result, the creation of safe assets by the government comes with aggregate costs as an increasing amount of resources must be diverted to covering the government's debt, requiring either reductions in transfers to households or increases in taxes.

One way to think of the government's role in this model is as producing safe claims from the risky income of households. *Holmström and Tirole* (2011) consider the cost of this taxation as inefficiencies in government expenditure. This matches their focus on exploring the optimal level of government supply of liquid securities.

While introducing a dead-weight loss to government taxation is of general interest, I will leave this issue for now to return to it in discussing government taxation of corporations later on.

1.3.2.4 Intermediaries

Financial markets in the model are cleared by an intermediary. Like households, the intermediary is subject to a limited pledgeability constraint which prevents them from freely issuing safe debt. This prevents the intermediary from exploiting what would otherwise be an arbitrage opportunity between the market for costly claims and the safe asset market.

The intermediary in my model takes deposits from households, $D_{i,t+1}$, and firms, $A_{i,t+1}$, purchases government debt T, purchases a share of firms' costly securities, $s_{i,t+1}$, and makes loans to households, L_{t+1}. I consider a representative competitive intermediary who operates for a single period. The budget constraint is:

$$\int_i s_{i,t+1} V_{i,t} - \int_i s_{i,t+1} e_{i,t} + \frac{1}{1+r_g} T = \frac{1}{1+r} \left(A_{t+1} + D_{t+1}\right) + \frac{1}{1+\rho} L_{t+1}$$

Their expected profits from these investments are:

$$\int_i s_{i,t+1} \, \mathrm{E}\left[V'_{i,t+1}\right] + T - L_{t+1} - A_{t+1} + D_{t+1}$$

Intermediaries are subject to a constraint on their issuance of deposits:

$$\Omega\left(\int_i A_{t+1} + D_{t+1}\right) \leq T$$

This constraint can be justified in two ways. The first is that intermediaries can default on a fraction $(1 - \Omega)$ of deposits, in which case their treasuries are seized by the depositors. This assumption would be unreasonable for FDIC insured commercial banks, but a large amount of firms' deposits are in uninsured money market mutual. The second justification of assuming a constraint of this form on intermediaries is that it represents a reserve requirement imposed by the Federal Reserve. This second interpretation applies to commercial and investment banks, though it is less applicable to other intermediaries.

I now solve the problem of the intermediary. Take ξ_T to be the multiplier on the safe asset issuance constraint and ξ_L to be the multiplier on the intermediary's budget constraint. Then the following must hold, due to the first-order conditions with respect to L and T:

$$\frac{\partial}{\partial L_{t+1}} \Rightarrow \xi_L = \rho \tag{1.9}$$

$$\frac{\partial}{\partial T} \Rightarrow \xi_T = \frac{\rho - r}{1 + r} \tag{1.10}$$

In other words, the intermediary discounts at a rate ρ, but applies a premium to funds which can be used as collateral in satisfying their pledgeability constraint when this constraint is binding. For assets which cannot be used as collateral, such as firms' uncollateralized financing, no arbitrage requires:

$$\frac{\partial}{\partial s_{i,t}} \Rightarrow V_i = e_i + \frac{1}{1 + \rho} \mathrm{E}\left[V_i'\right] \tag{1.11}$$

Firms' alignment with investors then requires that they discount profits at the rate which intermediaries promise on loans from households, ρ. Meanwhile, the return the intermediary offers for safe assets inherits the same properties as their cost of purchasing these safe assets, that is it reflects the KKT multiplier ξ_T to the extent that these assets require backing from government debt:

$$\frac{\partial}{\partial A_t} \Rightarrow \frac{\rho - r}{1 + r} = \Omega\left(\frac{\rho - r_g}{1 + r_g}\right) \tag{1.12}$$

The importance of a binding constraint on intermediaries is outlined in the following theorem:

Theorem I.2. *The discount rate applied to firms' cash flows and the interest rate will differ if and only if the intermediary's safe asset issuance constraint is binding.*

Whenever safe assets command a lower return than the rate at which firms are valued, the intermediary has an incentive to issue safe debt and use it to buy the firms' costly finance or issue loans to households. If, in equilibrium, these two returns differ it must then be that intermediaries are prevented from issuing safe assets by their pledgeability constraint.

1.3.2.5 Equilibrium

An equilibrium in my model is defined as follows:

Definition I.3. Stationary equilibrium: A stationary equilibrium in my model is defined by a return on safe assets r, return on bonds, ρ, a policy function which transforms states $s = [z, k, a]$ to choice variables, $[k', a'] = g(s)$, households' deposits, loans to intermediaries and consumption, D, L, C, intermediaries holdings of costly finance of firms s_i, and a cross-sectional distribution of firms over their state, $\Upsilon(s)$ such that:

1. Given ρ, r and r_g, households choices of consumption, loans to intermediaries and safe asset holdings are optimal.

2. Given ρ, r and r_g, $g(s)$ solves managers' problem.

3. Given ρ, r and r_g intermediaries holdings of firms s_i, loans to households, and choice of deposits from households and firms are optimal.

4. Intermediaries make zero profits.

5. The government's budget constraint is satisfied:

$$-G_t = r_g T$$

6. Markets clear, that is the intermediaries' choices of financing are consistent with households and firm choices, and the good market clears:

$$\begin{aligned}
D_t^{\text{Intermediary}} &= D_t^{\text{Household}} \\
L_t^{\text{Intermediary}} &= L_t^{\text{Household}} \\
A_t^{\text{Intermediary}} &= \int_i a_i \; d\Upsilon(s) \\
T^{\text{Intermediary}} &= T^{\text{Government}} \\
s_i^{\text{Intermediary}} &= 1 \;\forall\; i \in [0,1] \\
y(s) \; d\Upsilon(s) &= C + r_g T + \int I(s) + \phi(I(s), k) \; d\Upsilon(s)
\end{aligned}$$

7. The distribution of firms over states is consistent with firms' policy function, $g(s)$, and invariant over time:

$$\Upsilon(s) = \int 1_{[k',a'] \in g(s)} P(z'|z)\ d\Upsilon(s)$$

Some properties of this equilibrium are easy to establish from the first-order conditions of intermediaries and households. In particular:

Theorem I.4. *In any steady state equilibrium:*

1. $\rho = 1/\beta - 1$.
2. $V_i = e_i + \beta \, \mathrm{E}\left[V_i'\right]$.
3. *The goods market clears if and only if intermediaries make zero profits.*

The equivalence of the discount rate applied to firms with the rate of time preference of households is a result of the fact that the marginal source of funds for intermediaries is loans from households. The market clearing condition for firms' costly finance will only hold if these securities which cannot be used as collateral to issue deposits command the same return as the intermediaries cost of funds. Finally, to satisfy the budget constraint of households and the cash flow identities of firms, it must be the case that goods market clearing implies that the cash flows to financial intermediaries from firms and the government are met with cash flows from households to financial intermediaries. As a result:

$$\int_i V_{i,t+1} + T + L_{t+1} = \int_i a_{i,t+1} + D_t$$

That is to say, the expected value of securities held by firms and households is met by the value of securities issued by firms and the government.

How this value is split between deposits and costly financing depends on whether the intermediary's constraint on safe asset issuance is binding. When the constraint is not binding, intermediaries are able to create deposits freely from the expected value of their holdings. The return on these deposits will then be equal to the return on costly finance. When the constraint is binding, intermediaries are only able to create deposits up to:

$$\left(\frac{1}{\Omega} - 1\right) T$$

from the expected returns to uncollateralized financing issued to firms and households. The remainder of deposits must be backed directly by their purchases of treasuries. In this case the return on safe assets will be strictly below the return on firms' uncollateralized financing in equilibrium. Without distortions, the potentially binding nature of this constraint creates an important role for firms' participation in the safe asset market.

Theorem I.5. *When households do not receive a convenience benefit from their holdings of safe assets, the steady state equilibrium return on safe assets will be equal to the return on the firm whenever firms are net borrowers.*

If firms are net borrowers in equilibrium, then $\int a(s)\, d\Upsilon(s) < 0$, and market clearing along with intermediaries' collateral constraint implies that households must hold safe assets in equilibrium. When households do not receive convenience benefits from their holdings of safe assets, they will hold these assets only if they command the same return as their loans to intermediaries. The marginal investor in safe assets in this case receives no benefit from holding safe assets beyond their return, and therefore the return on these assets must be the same as their other available sources of financing.

On the other hand, if firms are net lenders, and their holdings are large enough that intermediaries are constrained in equilibrium, then the marginal investor in safe assets is a firm which receives benefits from their holdings of safe assets in avoiding future costs of costly financing. In this case, the return on safe assets will fall strictly below the return on their uncollateralized finance. In equilibrium, firms will inherit the aggregate shadow cost of providing safe assets from the intermediary as through the opportunity cost of safe asset holdings.

For the quantification below, I will assume that $\Omega = 1$: that is all safe assets issued by intermediaries must be backed by holdings of treasuries or holdings of the firm, so that $r_g = r$. This, admittedly, is a strong assumption, but not one that alters the directional implications of my model. It also does not require that private safe assets cannot be created, as firms can issue perfect substitutes in their safe debt issuance, which can then be used to fund deposits for households and other firms. However, this safe asset issuance by firms is costly, since it requires firms use up their limited capacity for borrowing.

The results of this equilibrium are stark across a number of dimensions. First, since households receive no convenience benefit from holdings of safe assets, their holdings of safe assets are always zero in an equilibrium where $\rho > r$. Second, the equilibrium conditions imply that no firms will ever be constrained in equilibrium when the corporate sector is an aggregate net borrower. In the following section I consider extensions to the model which allow households to hold positive safe assets in equilibrium even when $\rho > r$ and distortions to the firms' holdings of safe assets in the form of taxes which mean that they may face financial constraints even when they are net borrowers. Finally, I consider cases in which the manager is not aligned with the holders of their costly finance. I use this distorted equilibrium to estimate my model, and then quantify the importance of these distortions for the equilibrium behavior of investment and interest rates.

1.3.3 Distortions and extensions

I now present extensions to the model which I use in my estimation and explore in counterfactuals. The extensions fall into two primary groups: distortions in corporate demand for safe assets and additional detail on the supply of these safe assets to the corporate sector.

Corporate finance recognizes a number of distortions which affect firms' demand for safe assets. I consider three broad categories: government taxation of corporate profits, taxation of capital gains and dividends, and manager misuse of safe assets in the form of empire building. For the estimation it is important to include these distortions in order to match the empirical behavior of firms. To the extent that firms' demand for safe assets is the result of, for instance, differential treatment of their holdings under tax law, estimating the parameters of the model without taking these distortions into account will tend to overstate the precautionary demand of firms. Meanwhile, tax policy is another lever at the government's disposal for affecting corporate holdings of safe assets. Similarly, the importance of agency frictions for corporate investment has been previously highlighted by *Rampini and Eisfeldt* (2005), *Nikolov and Whited* (2014) and *Nikolov et al.* (2017).

In my counterfactuals, I also consider modifications to the supply of safe assets to the corporate sector. Specifically, I extend the model to allow for household holdings of safe assets.This modification is not directly related to my estimation of firms' demand, which depends on the interest rate and level of cash holdings in the corporate sector. However, household holdings of safe assets moderate my results as some of the government's increased borrowing does not reach the corporate sector.

1.3.3.1 Government taxation of firms

The government in my model levies two types of taxes: a tax on corporate profits, and a tax on corporate payments to investors. The government taxes profits at a rate τ_c. Depreciation and interest payments are deducted, while interest received from safe asset holdings are taxed at the same rate. The total income tax bill of the firm is then:

$$\tau_c \left[\pi(z_{i,t}, k_{i,t}) + r a_{i,t} - \delta k_{i,t} \right]$$

Payments are taxed at a rate τ_d, but only if these payments are positive. The value of the firm is then calculated recursively as:

$$V_{i,t} = (1 - \tau_d) 1_{e_{i,t}>0} e_{i,t} + (1 + \lambda_1) 1_{e_{i,t}<0} e_{i,t} + \beta \, \mathrm{E} \left[V_{i,t+1} \right]$$

While taxes on the firm are levied on households, the manager of the firm incorporates this rate into their decision-making through its effect on the value of the firm.

Taxes have two effects in my model. First, they alter firms' decisions on capital and safe asset holdings. In particular, taxes on interest income mean that firms find holding safe assets more expensive, while issuing safe debt has become cheaper. Meanwhile, taxes on payments to investors distort firms' precautionary motives, maxing external finance more costly. In particular, with the introduction of taxes Equation (1.3) becomes:

$$\frac{\rho - (1 - \tau_c) r}{1 + r} = \left(\frac{\lambda_1 + \tau_d}{1 - \tau_d} \right) \mathrm{P} \left(e' < 0 \right) \tag{1.13}$$

The left-hand side of this equation now reflects the after-tax cost of holding safe assets, which includes a reduction in the after-tax return on safe assets from taxes on interest income. The right-hand side reflects the after-tax cost of financial shortfalls. Taxes on payments to investors increases this effective cost, since the firm must now effectively offer returns to new external finance to compensate for the taxation of the proceeds of their investment.

The second effect of taxes in my model is to alter the government's budget condition. The proceeds from taxing the firm allows the government to reduce lump-sum taxes on households for the same level of borrowing. In particular, the government budget balancing condition becomes:

$$\int \tau(s) d\Upsilon(s) - G = r_g T \qquad \text{where} \qquad \tau(z,k,a) = \tau_d 1_{e(s)\geq 0} e(s) + \tau_c \left(\pi(z,k) + ra + \delta k\right)$$

Since all proceeds of the firm eventually belong to households, the reduction in lump-sum taxes is offset by the increase in the taxes paid by the firm. In the end, then, for the same level of government borrowing, taxes on the firm will only affect equilibrium outcomes by altering the incentives of firms to hold safe assets and invest.

1.3.3.2 Agency distortions

In addition to distortions to payout decisions and safe asset holdings from taxes, I assume firms are run by managers who differ from investors in their desired level of investment.[5] Specifically, managers receive "empire building" benefits from increasing the size of their firm beyond what is justified by their profits. Empire building has a long history in corporate finance, having first been proposed as a distortion to firms' investment and payout policies by *Easterbrook* (1984) and *Jensen* (1986). As in *Nikolov and Whited* (2014), I model empire building

[5] In contrast to several papers in the literature, I do not model agency costs as managers' diversion of funds to private benefits for two reasons. First, it would be difficult to assess the general equilibrium consequences of this diversion. Second, the effect on equilibrium safe rates would be a direct decrease in the rate of return on safe assets, which would be difficult to identify separately from liquidity premia, and would have essentially the same effect as taxes on interest income. However, the end result of empire building is similar to these models of manager diversion in that the equilibrium return on safe assets falls as empire building rises.

by assuming the manager of each firm receives a flow non-pecuniary benefit to their scale of $\psi k_{i,t}^{\alpha}$.[6] The flow utility to the manager is then:

$$(1-\tau_d)d_{i,t} - x_{i,t} + \psi k_{i,t}^{\alpha}$$

The effect of this friction is to increase managers' desire to invest beyond the level justified by cash flows to the firm from their investment. As a result, the precautionary motive of the firm is stronger, since episodes of low investments caused by costly external finance also come with losses to the non-pecuniary benefit of managers. Additionally, reliance on external finance is more common, as with a decreasing returns to scale technology free cash flows fall at higher levels of investment

1.3.3.3 Household safe asset demand

The final extension I consider in this paper is household demand for safe assets. Households, like firms, demand safe assets despite their low return because of their benefits in making transactions. I modify the model to capture household demand by assuming they receive direct utility from the convenience safe asset holdings provide, so that their total utility is:

$$U(C_t D_t^{\omega})$$

[6]Since the value function is scaling of this flow utility by a constant, ψ, can be interpreted as a residual of an essential benefit, $\tilde{\psi}$, when managers' own a share s_m of the firm, where $\psi = \tilde{\psi}/s_m$.

This form has been used previously by *Lucas* (2000), *Philippon* (2015), *Krishnamurthy and Vissing-Jorgensen* (2012), *Krishnamurthy and Vissing-Jorgensen* (2015) and *Nagel* (2016). Unlike in these models, I am specifically interested in the demand for safe assets across the corporate sector, which is micro-founded by their investment needs, and so consumer's demand for these assets primarily serves to increase the elasticity of supply that the corporate sector faces, since households are willing to decrease their holdings of these assets as corporate demand rises.

Including households' convenience utility alters the net-supply curve of safe assets the corporate sector faces. The first-order condition for the representative household yields:

$$D = \frac{(1+\rho)\omega C}{\rho - r} \tag{1.14}$$

Then all else equal, as the return on safe assets falls, demand for these assets from households falls as well. This equation determines the net supply curve of safe assets the corporate sector faces:

$$A^S = T - D = T - \frac{(1+\rho)\omega C}{\rho - r} \tag{1.15}$$

The elasticity of this demand curve is determined by ρ and ω. In particular, as ω increases, the interest rate becomes less sensitive to changes in corporate safe asset demand.

In equilibrium, the household now holds a positive quantity of safe assets.

They view these assets as substitutes for firms' costly finance:

$$T - \int a(s) d\Upsilon(s) = D = \left(\frac{(1+\rho)\omega}{\rho - (1 - \omega(1+\rho))r} \right) \int e(s) d\Upsilon(s)$$

As r decreases, the desired ratio of costly finance to safe assets in the household's portfolio shifts, and they trade safe assets for firms costly finance. This allows elasticity to the supply of safe assets in the corporate sector. However, the trade-off between costly finance and safe assets is now determined by household preferences as well as firms' precautionary demand. As a result, the rate on safe assets may become low enough that corporate sector is a net-borrower in safe assets. In this case, the firm is conducting arbitrage by using their capital to produce safe debt they can provide to households to meet their convenience utility. I will show that this arbitrage behavior can have important consequences for the relationship between government borrowing and investment when the corporate sector's net-borrowing position is sufficiently high.

1.4 Estimating the dynamic model

In order to assess the consequences of corporations' precautionary demand for liquidity on aggregate investment and interest rates, I estimate the parameters of my model using GMM. Without a fully specified model these consequences are difficult to quantify since they reflect an equilibrium relationship that is determined by the endogenous behavior of firms and households. However, the model has no closed form solution and several predictions depend crucially on relative parameter values. GMM estimation is therefore necessary to provide a reliable quantification to the responses of interest rates, output and investment to precautionary demand. I use a combination of firm data from Compustat, interest rate data from the Federal Reserve and data on consumption and household holdings of safe and liquid assets from the National Income and Product Accounts and the Flow of Funds to discipline the parameters of my model.

1.5 Data

To estimate my model, I use Compustat data from 2000 to 2016. Because the focus of this paper is on non-financial corporations in the U.S., I drop financials, regulated utilities and non-U.S. firms. I eliminate observations which are likely to contain errors, dropping firms with negative assets or sales. I am left with 43,877 firm-year observations. Summary statistics of this data are presented in Table 1.2.

To better match the setup of the model to accounting data in Compustat, I follow *Peters and Taylor* (2017) and capitalize intangible capital investment, adjusting investment and operating cash flows, measured by operating income before depreciation (OIBDP), to account for the expensing of R&D and selling and administrative expenses, and use this as my measure of $\pi_{i,t}$. Where OIBDP is missing, I fill the values using EBITDA. I also employ book values of intangible capital to construct a measure of the capital stock as the sum of tangible and intangible investment. Without these adjustments, the average return on capital among Compustat firms falls well above its return in the Flow of Funds data, and is rising dramatically over time.

	Mean	Standard deviation	25%	50%	75%
Capital stock (millions USD)	2231.487	8064.419	1271.167	2023.892	2306.701
Real investment (millions USD)	286.954	1183.644	155.587	264.524	296.647
Cash holdings (millions USD)	422.078	2625.527	282.450	393.340	431.404
Operating profit (millions USD)	585.912	2575.584	335.155	535.278	605.194
Investment over capital	0.155	0.085	0.107	0.155	0.195
Operating profit over capital	0.258	0.167	0.173	0.258	0.319
Cash to capital	0.170	0.134	0.095	0.161	0.220
Short-term debt to capital	0.039	0.065	0.012	0.031	0.044
Payments to costly finance over value	0.030	0.032	0.016	0.027	0.039
Value of costly finance over capital	2.501	2.115	1.626	2.341	2.871

Table 1.2: **Summary statistics for Compustat data.** This table presents summary statistics for the variables I use in my model estimation. Variables are constructed from Compustat data for the period from 2000 to 2016 as described in Section 1.5, with a sample size of 43,877. The first four rows are presented in millions of U.S. dollars, while the last six are ratios.

For financial variables, I measure the net safe asset position of firms using Compustat cash and short-term investments less notes payable. As discussed above, current debt is the most likely asset firms issue which is the most substitutable for treasuries. I treat notes payable as a perfect substitute for the assets firms hold as cash. I treat all other types of finance as costly. This is in contrast to previous structural work, which tends to include long-term debt, short-term debt and cash holdings together as net debt. Since I am specifically interested in firms participation in markets for safe assets, including all of these variables together would be understating the differences between cash and the securities firms produce. The introduction emphasized that cash holding is in safe, liquid securities. Long-term corporate debt is rarely treated as either safe or liquid in the literature, and so I exclude it from firms' safe asset position. However, to the extent that long-term debt acts as a substitute for government securities, it will tend to bias my estimates of segmentation downwards.

To measure flows to costly financing, I use interest payments on non-current debt plus dividends and repurchases. To measure the financing gap, the amount the firm must fund with either their safe asset holdings or costly financing, I use after-tax profits less investment. For the value of the firm to investors I use the market value of equity plus the book value of debt, less current debt. Finally, to estimate the safe asset holdings of households, I use a comparable measure to the Financial Accounts measures of liquid asset holdings of corporations: household and non-profit holdings of treasury debt, deposits, money market mutual funds, and commercial paper.

1.5.1 Identification

A subset of parameters in my model can be identified outside of the larger GMM system. Specifically for tax rates on corporate profits I use the statutory rate of 30% and for payments to costly financing I use the rate on dividends of 15%.

I am left with thirteen parameters to estimate: the returns to scale of the firm (α), fixed and linear external issuance cost (λ_0, λ_1), fixed and quadratic adjustment costs (γ_0, γ_1), the discount rate of consumers (β), the supply of safe asset normalized by output (T/Y), the variance and persistence of profitability (σ,ρ) the pledgeability of capital (θ), the empire building parameter (ψ), and consumer's liquidity preference (ω). I estimate these parameters jointly through GMM. To do so I compute moments of the steady state distribution of the model over firms and match these moments to their data counterparts.

Identification of parameters in this GMM system depends on close relationships between parameters and moments. I use sixteen moments to identify my parameters, each of which either bears a relationship to the parameters. I now summarize the identification of three of these parameters which are relatively novel in my model: the empire building parameter, ψ, the demand for safe assets from consumers, ω, the discount factor of households, β, and government's supply of safe assets, T/Y. Each of these parameters is pinned down through a monotonic relationship with a data moment. In the case of T/Y, I exploit this monotonic relationship to ease my estimation.

Empire building in my model is pinned down by the its relationship with the co-variance of Tobin's Q and cash holding. This relationship is presented in Figure 1.4a. The relationship is very intuitive. Up to the empire building parameter, the interests of managers and shareholders are aligned in holding safe assets. However, under empire building, firms with larger cash holdings are more likely to misuse their cash, over-investing and driving the value of the firm down. As such, a higher ψ means a lower correlation of cash holding and value.

The liquidity preference parameter of households is crucial to my analysis since it determined the slope of the net supply curve facing the corporate sector. To estimate this parameter, I rely on data from outside the corporate sector. Specifically, I use the personal consumption expenditure series from the National Income and Product Accounts and consumer holdings of safe assets from the Flow of Funds data, which I match to Compustat data by year. The liquidity preference for the household is then easily identified from their first-order condition:

$$\frac{C}{D} = \frac{\omega}{\beta(\beta^{-1} - 1 - r)}$$

Given an estimate for β and an equilibrium r, this ratio then exactly pins down ω.

As shown in Figure 1.4b, the discount factor the household applies to firms is pinned down by the ratio of payout to value. Again, this relationship is intuitive. Firms are priced by risk neutral households, and as such, their market-clearing price must be the discounted expectation of their future cash flows to investors. Since firms are ex-ante identical and operate in a steady state, this expectation can be gained from the cross-section. The expectation of dividends to value then pins down this rate perfectly. However, since investors in reality are not risk-neutral, it is worth noting that this discount rate is also identified through the average return on capital.

Finally, the supply of safe assets to the corporate sector is identified through its effect on r. The demand for safe assets is strictly increasing in the rate. Given the other parameters of the model, there is then a one-to-one mapping from the total demand for these assets and the interest rate to their supply. I exploit this mapping to greatly simplify the estimation of the model, by minimizing the GMM objective over the other parameters and the model's return to safe assets and then inverting the market clearing condition to recover T. I describe this technique in detail, and prove its equivalence to direct estimation of T, in Appendix A.3.1.

Data and model moments are linearly separable once the parameters of the model are taken into account. Therefore, to construct the weight matrix for these moments, I therefore use influence functions to calculate the optimal weight matrix, which has been shown to yield better finite sample performance (*Bazdresch et al.*, 2018). Since my model has a non-stochastic steady state and limited heterogeneity among firms, I limit the heterogeneity my model is required to match by demeaning all variables at the industry by year level before computing variances and correlations between variables. When calculating autocorrelation coefficients, I also account for firm-level heterogeneity using the method in *Han and Phillips* (2010). I cluster the weight matrix at the firm level to account for serial correlation in the data, after adding back the means of these variables to the influence functions to reflect industry and year variation in these variables.

Data and model moments

Moment	Actual	Model
Average earnings over capital	0.2577	0.2428
Variance of earnings over capital	0.0277	0.0048
AC(1) earnings over capital	0.6191	0.7632
Variance of investment over capital	0.0073	0.0094
Average payments to costly finance over value	0.0301	0.0257
Average cash over assets	0.1311	0.0747
Average investment over capital	0.1549	0.1530
AC(1) cash over assets	0.6365	0.5856
Co-variance of Tobin's Q and cash over assets	0.0941	0.0146
Variance of cash over assets	0.0179	0.0043
Variance of payments to costly finance over assets	0.0010	0.0015
Co-variance of earnings and investment	0.0059	0.0046
Probability of financing gap greater than cash holdings	0.0487	0.0515
Average consumer safe assets to capital	0.9346	0.9346
Average treasury yield	0.0146	0.0153
Probability cash less than short-term borrowing	0.0144	0.0183

Parameter estimates

Production parameters

	α	δ	ρ	σ	γ_0	γ_1
Estimate	0.7729	0.1479	0.8367	0.1721	0.0155	0.8463
SE	0.0108	0.0009	0.0170	0.0045	0.0031	0.2505

Financing parameters

	β	λ_0	λ_1	θ	ψ	ω	T/Y
Estimate	0.9736	0.9937	0.0862	0.0008	0.1190	0.0108	0.5429
SE	0.0004	0.4845	0.0380	0.0006	0.0240	0.0011	0.1549

Table 1.3: **GMM estimates for the 2000-2016 period.** The first panel shows moments from the data and model for joint GMM estimation from Compustat data for the period from 2000 to 2016 along with standard errors. The second panel shows estimated parameters from the joint estimation and standard errors.

1.5.2 Results

The estimates from my model as well as the implied fit are in Table 1.3. The model provides a reasonable match for most of the moments, though standard errors of these moments quite low. On two important dimensions the model is unable to match the data. First, it produces a lower variance of investment than is in the model. Likely this is because of the steady-state nature of the model, whereas firms in the data are at different stages of growth. Second, it produces lower cash holding than in the data at the current interest rates. Since I have used a broad definition of cash as cash and short-term investment, this is not surprising, and levels are roughly comparable to levels of cash equivalents.

The parameter estimates in Table 1.3 are mostly reasonable. My estimates of costs of financial shortfalls are somewhat higher than previous estimates, for instance *Gomes* (2001) uses a value of 2.8% for λ_1 and 0.42 for λ_0. Similarly, though the estimates in *Hennessy and Whited* (2007) are from a model with risk-free long-term debt, which should in general lead to higher costs of equity issuance and external finance, they estimate a value of λ_1 around 5% and λ_0 of 0.389, but include both fixed and quadratic costs. Estimates for σ and ν are higher than most estimates, but this is likely because of matching the within-industry variance in profits rather than within-firm variance. The estimates of quadratic adjustment costs are in the range of previous estimates, although the estimates of fixed costs are somewhat higher, which will play a role in the gains to increasing the supply of safe assets. Finally, the value of ψ is comparable to levels of empire building incentives over the manager's share of the firm implied by *Nikolov and Whited*

(2014).

Some parameters are relatively new in this setting, and so are difficult to compare to the previous literature. For ω, the closest comparable paper is *Philippon* (2006), who use a value of 0.0175. T/Y is consistent with the ratio of federal debt in the hands of domestic investors to corporate value added, around 0.5 in the latter half of my sample. The liquidity premium implied is around 110 basis points. This spread is large relative to previous estimates of liquidity premia, accounting for around half of spreads between AAA corporate bonds and long-term treasuries over this period. However, the model does not include risk premia, and so the resulting spread should be expected to only account for a limited portion of total spreads in cost of capital. As I will show, this small spread still implies large gains in investment and output from increasing the supply of safe assets.

1.5.3 Determination of equilibrium

In this section I discuss how the equilibrium in the estimated model is affected by the parameters which govern firms' production, the variance of their profitability and the costs of investment. In equilibrium, the total demand for household and firms for safe assets must be met by either firms' own issuance of these assets or by the fixed government supply. As parameters of the production process change, firms' need for safe assets changes as they are less or more exposed to needs for external finance. Changes to these parameters should not be interpreted as policy counterfactuals, but exploring these comparative statics serves to illuminate how equilibrium quantities are determined.

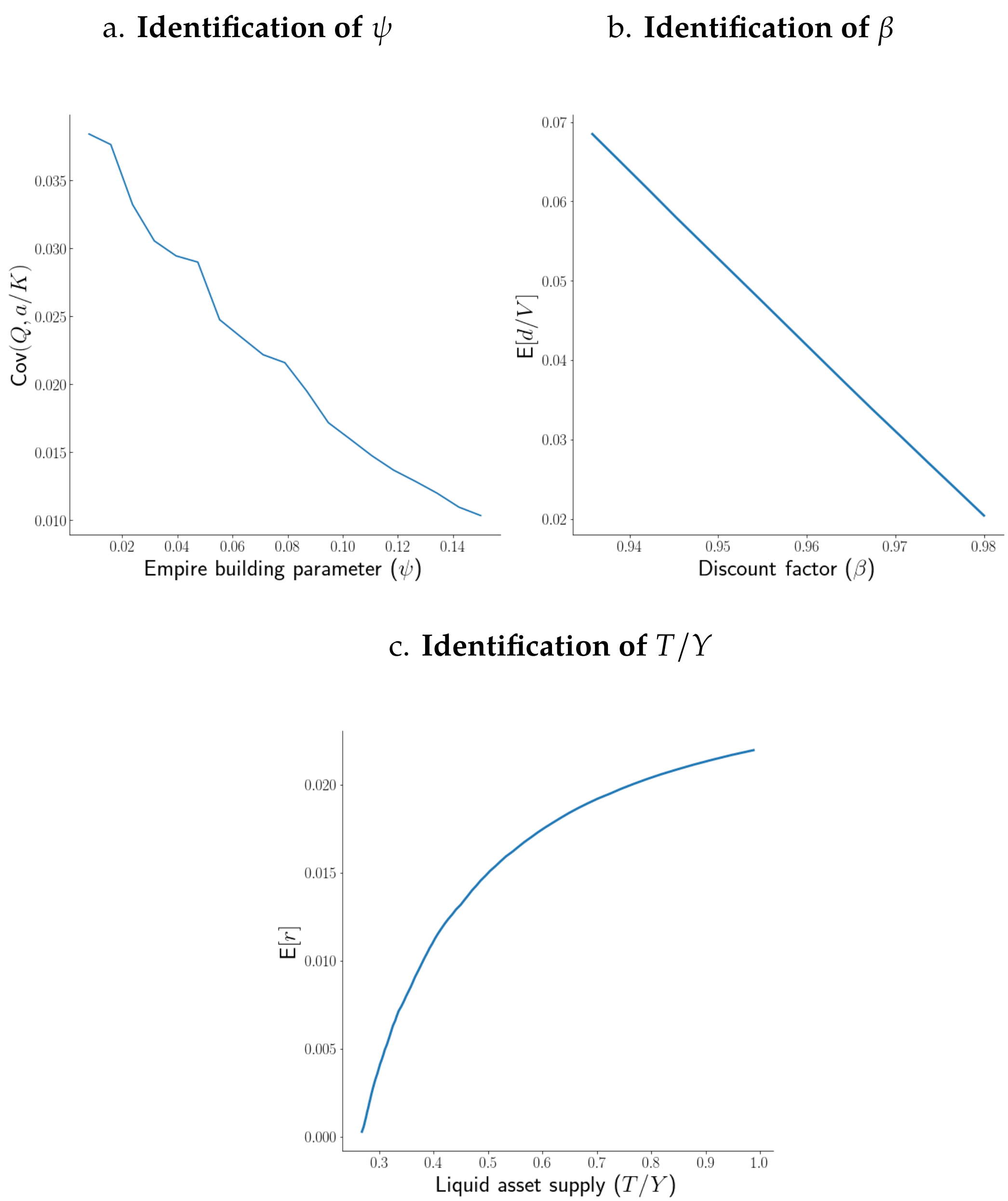


Figure 1.4: **Identification of select parameters.** This figure shows how empire building, safe asset supply and the discount factor of households are identified from moments in the data.

First, I turn to the actual determination of equilibrium at the estimates. Figure 1.5 shows the equilibrium determination of the estimated model. As discussed above, demand for safe assets from the corporate sector is increasing in their return. The nature of supply around the equilibrium value depends on the preferences of household for liquidity. As ω increases, the net supply to the corporate sector becomes more elastic, since the household sector has a greater store of these safe assets which can be used by corporations. For the extreme case where $\omega = 0$, the corporate sector faces a fixed net supply of safe assets, and the interest rate these assets receive is entirely determined by their demand.

How do features of the productivity and investment process affect the equilibrium return on safe assets? In previous sections, I have reviewed how external costs of finance affect firms' precautionary demand. I now turn to how investment needs affect this demand. Figure 1.6 shows the effect of altering parameters on the equilibrium rate. The most intuitive of these figures is the variance of productivity. A higher variance of capital lowers the equilibrium rate. As capital becomes riskier the precautionary demand of firms rises, and the interest rate must fall for a fixed supply of safe assets to the corporate sector.

However, the intuition behind figures for quadratic adjustment costs and fixed adjustment costs is more complicated, and relies on the dynamic nature of the firms' problem. The presence of fixed and quadratic adjustment costs mean that investment is lumpy in nature. The higher quadratic adjustment costs are, the smaller investment lumps will be, and the less likely the firm is to have to rely on financing beyond their revenues this period. Therefore, demand for safe assets

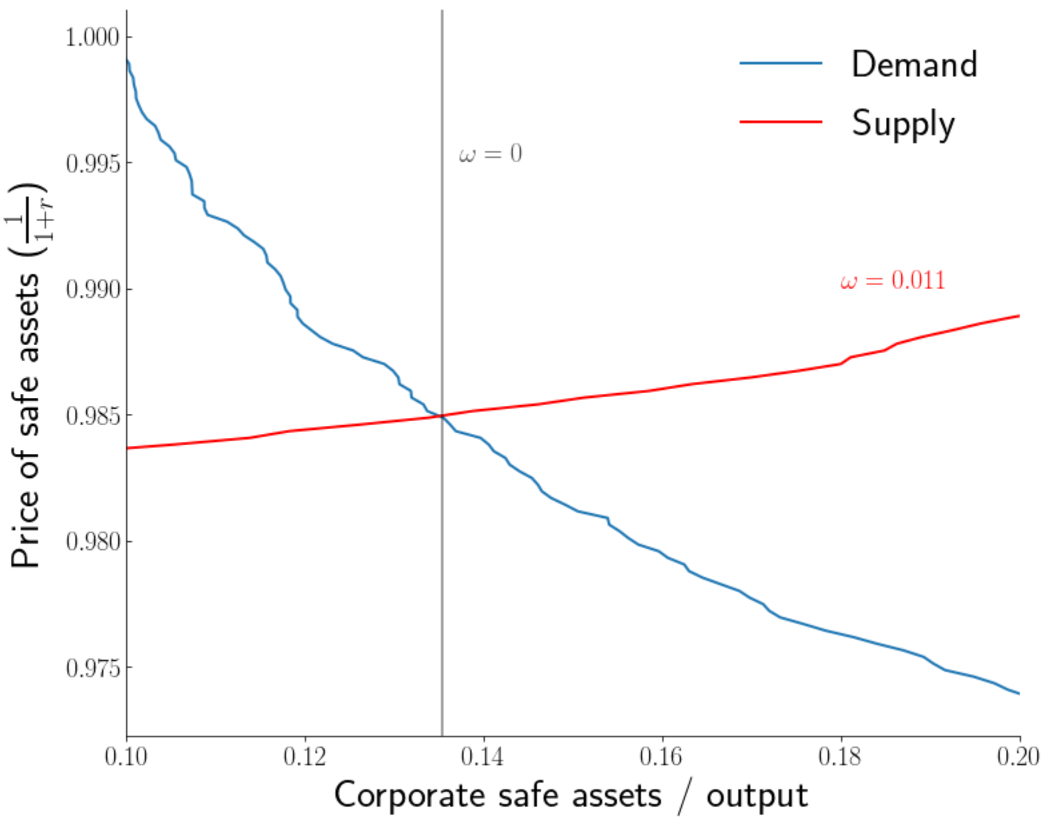


Figure 1.5: **Determination of equilibrium at model estimates.** This figure shows the net supply of safe assets to the corporate sector (that is, the supply of safe assets less household demand) and net demand (corporate safe asset holdings less issuance of safe debt) as the interest rate on safe assets varies. Equilibrium equates supply with demand, resulting in a return on safe assets of 1.53%.

increases, and the interest rate falls. Similarly, as fixed adjustment costs rise, the interest rate rises as firms have less variable investment needs.

In this context, the persistence of the productivity shock has an important, and perhaps counterintuitive, effect on interest rates. As persistence increases, the interest rate falls. In models such as *Moll* (2014) increases in the persistence of productivity allow firms to self-finance, and therefore decreases the losses from financial frictions. However, their model did not feature adjustment costs. With large fixed adjustment costs in place, as persistence rises the size of firms' lumpy investment increases. As such they are less likely to be able to finance the investment through revenues today, and demand for safe assets rises.

1.6 Supply of safe assets and corporate investment

I now turn to the core question of this paper: how government safe asset supply affects investment. I begin with a baseline case. In this case I set household demand for safe assets and empire building equal to zero. The entirety of government debt must therefore be held by corporations. I show that in the model increasing government supply is met by higher rates of return on safe assets and higher investment as the corporate sector faces fewer costs of financial shortfalls. The costs of meeting firms' precautionary demand are born by consumers, who face increasing lump sum taxes to fund the increase in government borrowing. I then extend the model to consider household demand for safe assets. Increases in government borrowing lead to smaller increases in corporate sector output in this context because as rates rise a greater share of safe assets are held by households

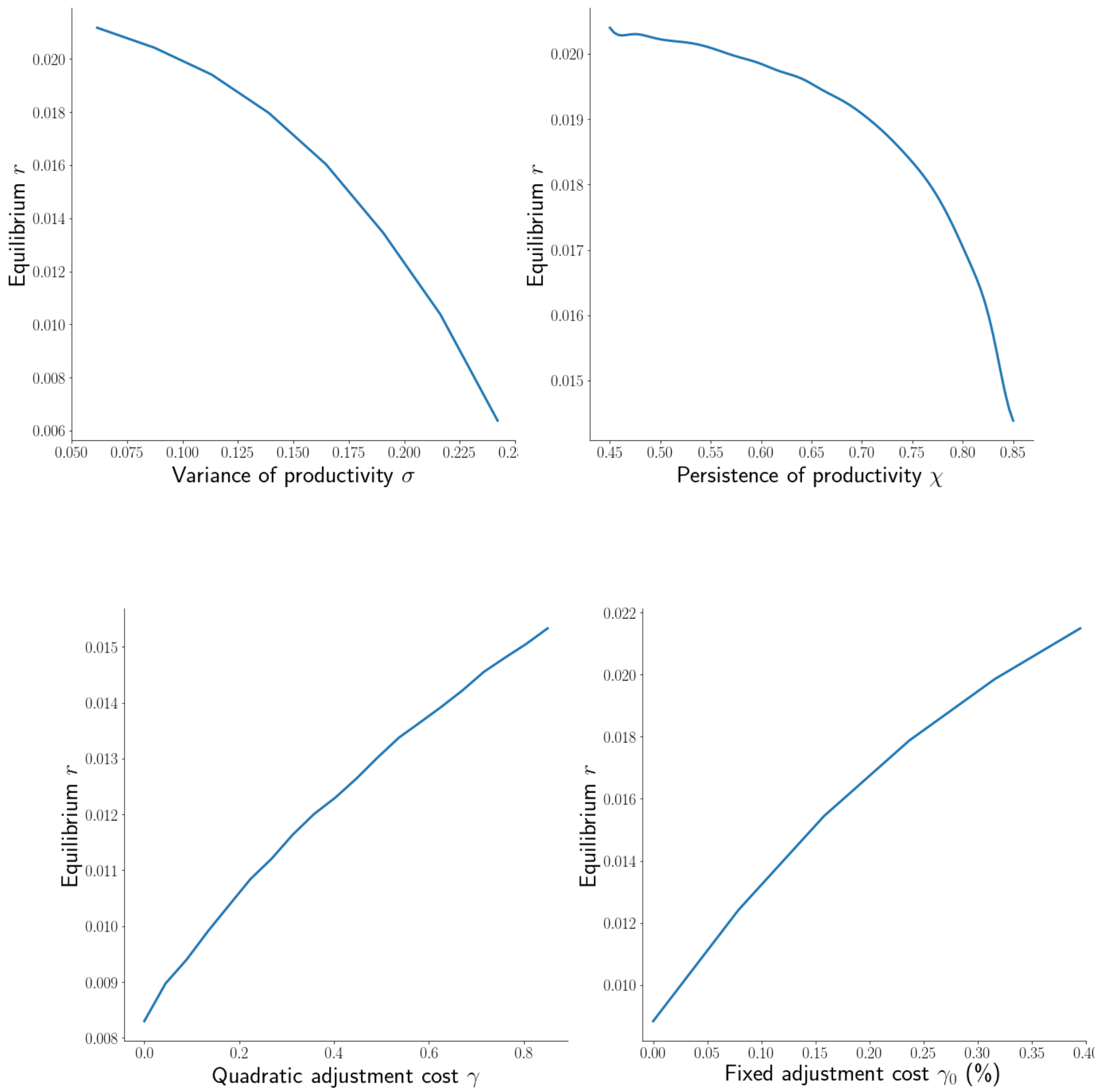


Figure 1.6: **Effect of precautionary demand on the return on safe assets.** These figures show the effects of various parameters determining firms' precautionary demand for safe assets on the interest rate.

and unavailable to firms. The costs of providing safe assets to the corporate sector thus rise.

1.6.1 Baseline

In order to explore the effects of increases in government borrowing on corporate sector investment, I now turn to the baseline model. In this baseline model expansions in government borrowing require that the corporate sector increase its net holdings of safe assets. Without household holdings of safe assets, this increase must be one for one. Increased safe asset holdings within the corporate sector come with the benefit of lower reliance on costly finance, but the cost of the liquidity premium on these assets. So, in order to induce the corporate sector to hold more safe assets, the rate of return on these assets must rise, and the liquidity premium fall.

Figure 1.7 shows the changes in rates of return and the probability of relying on costly finance due to increases in government borrowing. As government debt increases, the marginal effect on the probability of facing external finance falls. This is a consequence of the log-normal distribution of productivity, which allows for low probabilities of extremely bad productivity draws. To insure against the worst states is therefore difficult. The elasticity of rates with respect to government borrowing is not abnormal: a 1% increase in government borrowing leads to a 60 basis point decrease in the liquidity premium. This is within the range of previous estimates in *Krishnamurthy and Vissing-Jorgensen* (2012). As we shall see, this elasticity is reduced in the presence of household demand for safe assets.

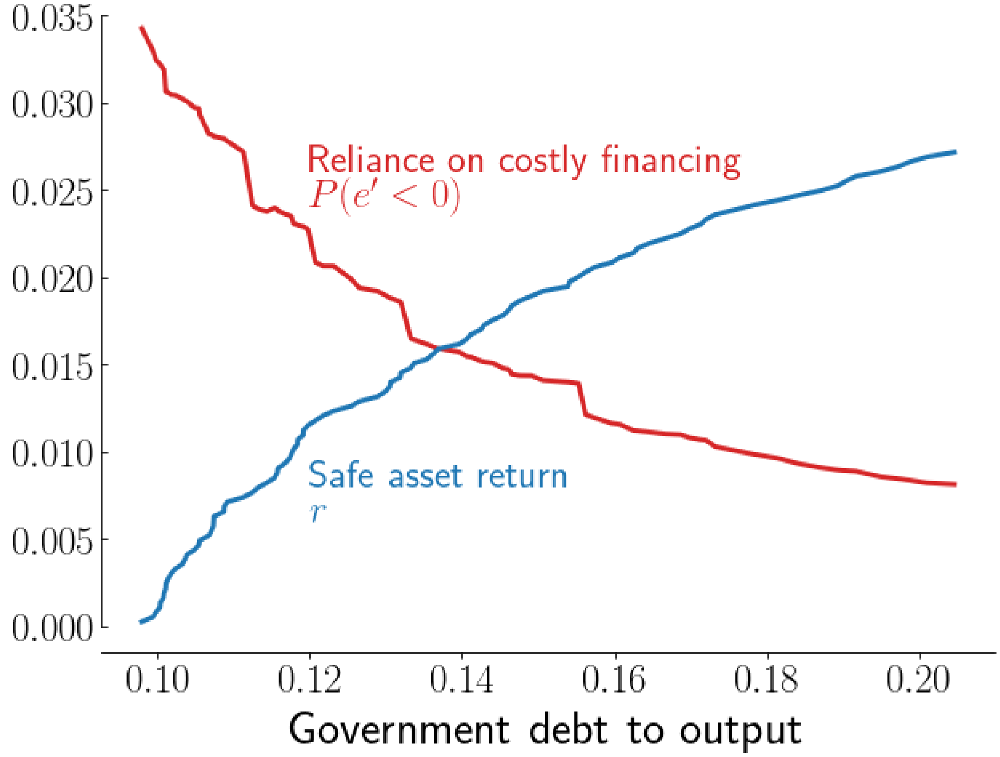


Figure 1.7: **Government borrowing, interest rates and financing in the baseline model.** This figure presents results for the effects of government borrowing on safe rates and on firms use of costly financing in the baseline model. The baseline model excludes household demand for safe assets and empire building incentives of managers. Otherwise, parameters are as described in Table 1.3.

Figure 1.8 describes this process in more detail. At low levels of government borrowing, the equilibrium liquidity premium lies strictly above the expected cost of financing next period because of binding constraints on safe asset issuance. These constraints prevent firms from fully insuring. As government borrowing increases, the expected costs of financing decline as firms are able to rely more on their safe asset holdings. Here, the expected cost of financing is the marginal reduction in costs of financing for a marginal increase in cash, including taxes imposed on investors:

$$\text{Expected cost of financing} = (1+r)\frac{\lambda_1 + \tau_d}{1+\tau_d}\,\mathrm{P}\left(e' < 0\right)$$

As this cost decreases, the liquidity premium must decrease to offset it. In an equilibrium without taxes, expected costs of financing would be zero when the liquidity premium was zero. Here, however, taxes on corporate interest income prevent this from occurring. This tax wedge rises as the liquidity premium falls, so that while at low levels of government borrowing the liquidity premium is high, but the interest tax wedge is low, at high level of government borrowing the liquidity premium is low but the tax wedge is high. The importance of taxes in driving equilibrium financing costs is thus inversely related to the importance of the liquidity premium.

As the government's supply of safe assets increases, expected costs of financing decrease, and as a result investment increases. In this baseline model, demand for government debt is determined entirely by the firms' precautionary needs. Therefore, higher levels of government debt must be compensated with higher

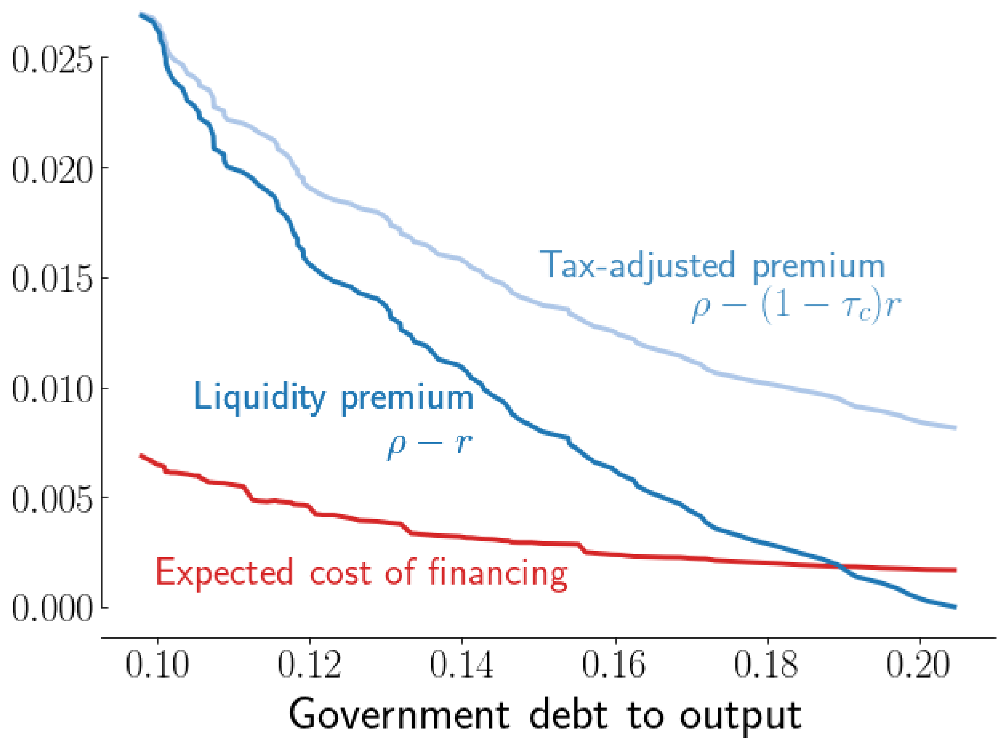


Figure 1.8: **Government borrowing, the liquidity premium, and taxes.** This figure presents results for the effects of government borrowing on the liquidity premium and expected costs of financing in the baseline model. The faded blue line represents the after-tax cost of holding safe assets for firms. The baseline model excludes household demand for safe assets and empire building incentives of managers. Otherwise, parameters are as described in Table 1.3.

payments to shareholders now or in the future. In order to increase these payments, the firms must invest more. Figure 1.9 presents my main results, which relate the supply of safe assets to aggregate investment. The increase in investment is essentially monotonic, despite the errors due to finite grid approximation of the firms' dynamic problem.

In particular, when government debt to GDP increases by 1%, it results in a 60 basis point increase in the return on safe assets and a 13 basis point increase in investment.

Table 1.4 shows the effect of increasing government borrowing on output components and corporate financing decisions. Because of the decreasing returns to scale technology in capital, the increase in output is more modest than the increase in investment. Increasing government borrowing by 1% only leads to a 10 basis point increase in output. However, this increase is costly, as it requires the government to issue more debt. Debt comes with a servicing cost, rT. These costs rise faster than government borrowing as the interest rate also rises. In equilibrium, they are born by households. At the parameter estimates, the cost of government borrowing is slight, and so increasing the safe rate results in a net increase in consumption.

Government borrowing affects investment through changing corporate financing behavior. Specifically, as can be seen in Table 1.5, costly financing declines while net safe asset holdings rise. Net operating income, that is profits and interest income less investment and taxes, increases slightly. Importantly, payments to investors increase as well. This increase represents the net effect of the govern-

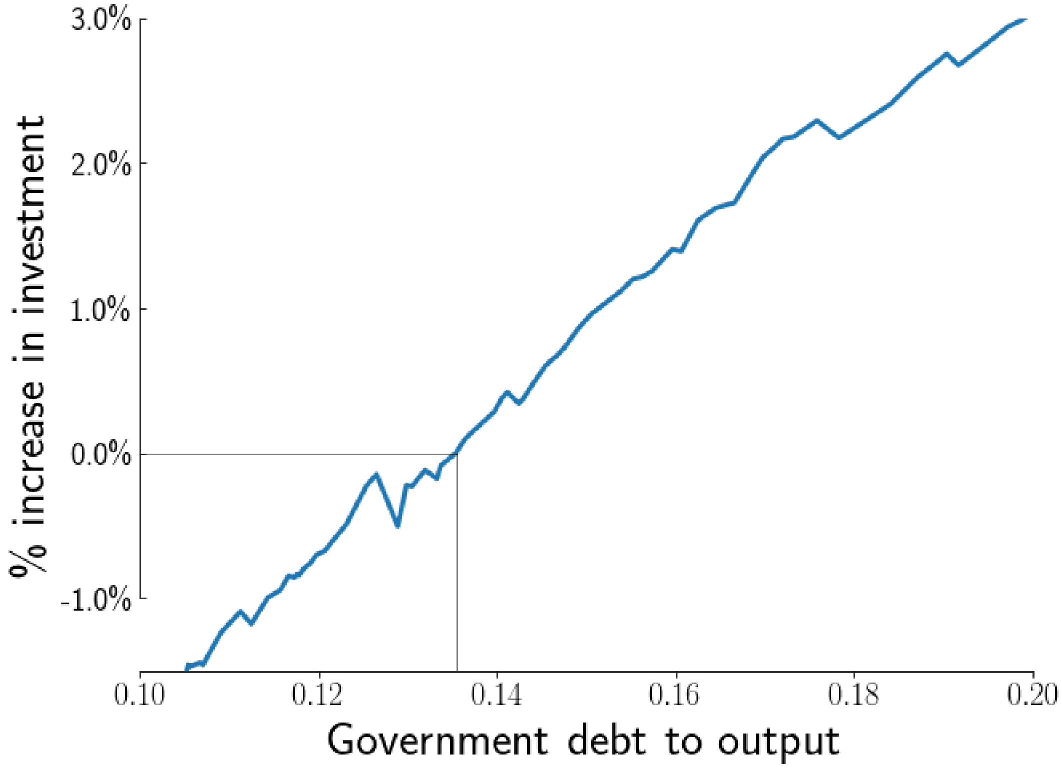


Figure 1.9: **Government borrowing and investment.** This figure presents results for the effects of government borrowing on investment in the baseline model. The baseline model excludes household demand for safe assets and empire building incentives of managers. Otherwise, parameters are as described in Table 1.3.

ments safe asset issuance. The increase in government safe asset issuance does not leave investors exactly indifferent because of the presence of binding constraints on safe asset issuance, which means that the government actually ends up increasing payments to investors.

1.6.2 Household demand for safe assets and corporate net-lending

The position of the corporate sector in the baseline model is stark. They hold all government debt, so their safe asset position must increase one-for-one with the government's borrowing. I now consider an extension to this model: households' demand for safe assets. With household demand for safe assets, increases in government debt are used in part to provide liquidity services to households, and therefore are unavailable to firms. This softens the relationship between government debt and corporate safe asset holdings. More importantly as discussed above, in an equilibrium with no household demand for safe assets, the corporate sector must be a net-lender in safe assets whenever these assets are scarce. Household demand for safe assets means this will not always be the case. Below, I show that increases in corporate borrowing can have different effects when the corporate sector becomes a large net-borrower in safe asset markets.

Households' demand for government debt limits the ability of increases in government debt to increase safe asset holdings. As rates on safe assets rise, the household sector demands more of these safe assets, and less end up in the hands of firms. Table 1.5 show the results for output and investment. A 1% increase in government borrowing now raises rates by only 10 basis points, and a 4% increase

Variable	Baseline *(scaled by output)*	Counterfactuals Increase in T/Y	
Government debt	13.54	**1%**	**4%**
Safe rate	1.53%	1.59%	1.65%
Output components		Percent increase	
Output	100.00	0.10	0.30
Investment	57.85	0.13	0.38
Consumption	41.93	0.04	0.14
Debt servicing cost	0.20	5.18	11.89
Costs of financing	0.02	-1.57	-4.39
Corporate financing			
Net safe assets	13.54	1.00	4.00
Net income	11.94	-0.12	-0.29
Payments to investors	23.41	0.09	0.24
Costly financing	0.04	-1.97	-4.86

Table 1.4: **Increases in government borrowing: baseline model.** This table presents the effects of government borrowing on investment in the baseline model. The baseline model excludes household demand for safe assets and empire building incentives of managers. Otherwise, parameters are as described in Table 1.3. I consider a 1% and 4% increase in government borrowing. The first column presents the baseline levels of variables, all normalized by output except for the rate of return on safe assets. The second and third columns present the percent change in each of these variables for these counterfactuals.

raises rates by 3 basis points. The results for corporate investment and increases in output are now more modest, as a greater amount of the increase in government ends up in the hands of households. The 1% in borrowing raises investment by a single basis point at my estimates for households' demand for safe assets. This represents the fact that it becomes extremely costly for the government to deliver safe assets to firms as a greater and greater share of their borrowing ends up being used as deposits for consumers. Whereas before the increase in government supply of safe assets increased corporate holdings by 1%, it now increases these holdings by 11%. As a consequence of the slight increase in corporate investment, households actually consume less than they did before. However, this decrease in consumption is made up for by the utility they receive from their holdings of safe assets.

1.6.3 Pledgeability of capital and the private supply of safe assets

When households hold safe assets, the corporate sector can be either a net-lender or a net-borrower in safe assets in equilibrium and a positive premium will still exist. Their position is determined by their ability to pledge their capital in order to issue safe assets and the size of the liquidity premium. Higher pledgeability of safe assets means that when the liquidity premium is high, the corporate sector becomes a large net-borrower. In essence, they become an arbitrageur, providing safe assets to households using their capital. At high levels of pledgeability, the cost-of-capital channel begins to dominate the precautionary savins channel, leading to crowding-out of investment rather than crowding-in.

Variable	Baseline (scaled by output)	Counterfactuals Increase in T/Y	
Government debt	24.47	**1%**	**4%**
Safe rate	1.53	1.54	1.56
Output components		Percent increase	
Output	100.00	0.01	0.06
Investment	57.85	0.01	0.08
Consumption	41.76	-0.00	-0.02
Debt servicing cost	0.37	1.07	6.26
Costs of financing	0.02	-0.09	-1.08
Corporate financing			
Net safe assets	13.54	0.11	0.70
Net income	27.22	0.00	0.01
Payments to investors	23.41	0.01	0.05
Costly financing	0.04	-0.16	-1.37

Table 1.5: **Increases in government borrowing: household demand.** This table presents the effects of government borrowing on investment in the model with household demand for safe assets. I do not include the empire building incentives of managers. Otherwise, parameters are as described in Table 1.3. I consider a 1% and 4% increase in government borrowing. The first column presents the baseline levels of variables, all normalized by output except for the rate of return on safe assets. The second and third columns present the percent change in each of these variables for these counterfactuals.

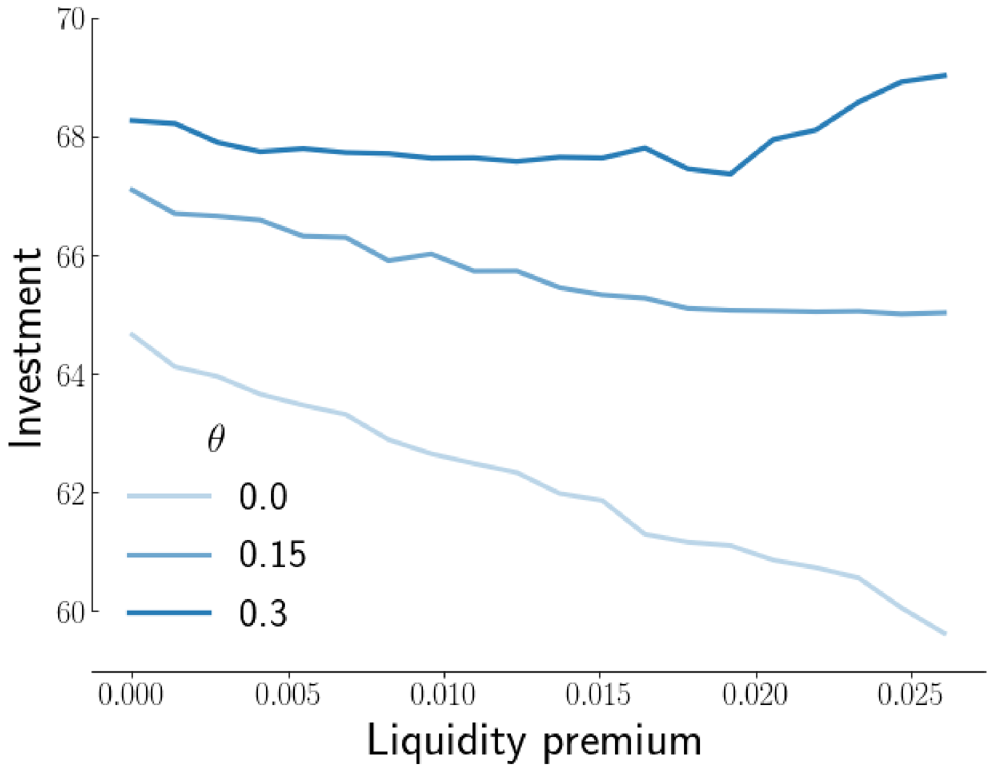


Figure 1.10: **Pledgeability, the liquidity premium, and investment.** This figure presents the relationship between liquidity premium, investment and pledgeability in the model with household holdings of safe assets. This model excludes the empire building incentives of managers. Otherwise, parameters are as described in Table 1.3.

To demonstrate the importance of pledgeability and rates for the consequences of government investment, I vary both the government supply of safe assets and the pledgeability of capital. In Figure 1.10 I show investment against the liquidity premium which results when households hold safe assets at a given level of government borrowing. The effect of government borrowing on the corporate sector is to lower the liquidity premium, moving from right to left along this graph. As pledgeability increases, the corporate sector takes on larger net-borrowing positions at a given liquidity premium. This raises their investment. Given plegeability, as the liquidity premium falls, the corporate sectors net-borrowing position increases. At low levels of pledgeability and a low liquidity premium, the corporate sector is a net-lender, and greater government borrowing acts to increase their investment. At high levels of pledgeability and a high liquidity premium, the corporate sector competes with the government in providing safe assets to households. They use capital to increase their capacity to provide safe assets to households. Increasing government borrowing limits the gains they receive from arbitraging between these two markets, and thus their investment.

1.7 Discussion

At the model estimates, government supply has quantitatively important effects on corporate investment. The sign and magnitude of these effects depend on corporations' exposure to government interest rates and household demand for these assets. The supply of these assets in my model can be understood as a net supply, including the provision of substitutes from the financial intermediaries and interventions in the market from the Federal Reserve. As such, in a broader context, varying the supply of these assets corresponds not only to the government increasing their borrowing but also to the Fed decreasing its net holdings of safe assets or to reducing reserve limits for intermediaries so that they can produce more safe assets from their existing reserves. However, for this last case, the costs of providing safe assets should include risks of bank insolvency as the financial sector provides more short-term securities from their long term assets. In the present context, these costs are unmodeled and difficult to identify. Similarly, if increased government borrowing comes with increased risk of government default the debt servicing cost will understate the aggregate cost.

It is tempting to interpret these results in a broader context and conclude conventional loose monetary policy which purchases safe assets has the perverse effect of reducing investment by driving more firms to rely on costly finance. Federal Reserve purchases of government securities without any other actions in my model would indeed be counterproductive.

However, this interpretation should come with caution since conventional monetary policy decreases the supply of government securities by buying them from banks. This action corresponds to trading one safe and liquid asset, treasuries, for an even safer, more liquid asset: reserves, which are not directly modeled in this estimation. Instead, a closer comparison for the expansion of government production of safe assets in my model would be to unconventional monetary policy. The government in my model can be understood as buying the securities that firms offer and using them to produce safe assets, similar to quantitative easing. This links my work to models of unconventional policy such as *Gertler and Karadi* (2013). Specifically, the Federal Reserve would sell their holdings of safe assets and use the proceeds to buy the costly financing of firms. Similar policies have been pursued by the European Central Bank, though the Corporate Sector Purchase Programme and the Bank of England, through their Asset Purchase Facility.

1.8 Extensions

1.8.1 Agency frictions

The final extension in my model is empire building. The inventive to empire build is large in my estimated model. To explore the effects of empire building on the return on safe assets and the liquidity premium, in Figure 1.11, I decrease ψ while holding the supply of safe assets constant. In this counterfactual, I include household demand for safe assets as well as the empire building incentives of managers.

The primary effect of empire building is to raise the liquidity premium, as empire building managers desire higher levels of cash holdings. The effect on the safe rate is large: I find that without empire building, the safe rate would be 50 basis points higher. However, empire building also decreases the wedge between the liquidity premium and expected costs of financing. This is ultimately because empire building managers desire higher levels of investment than their investors. They are therefore less likely to return funds to their investors, and more likely to retain them in safe assets. Each manager attaches an extra benefit

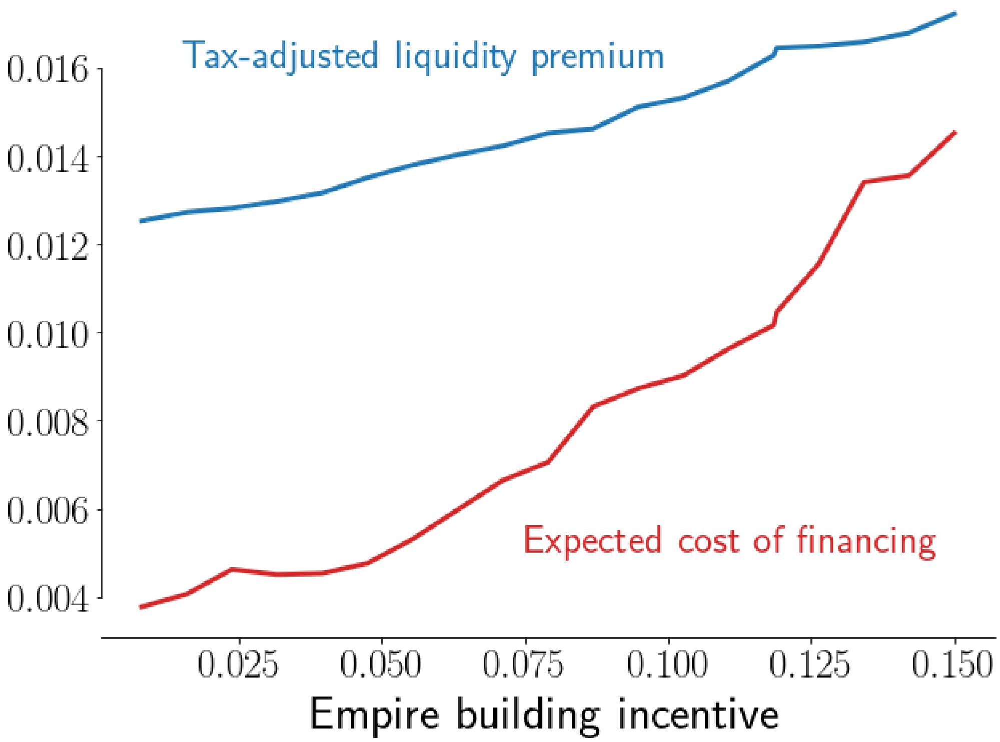


Figure 1.11: **Empire building and the liquidity premium.** This figure presents results for the effects of empire building on the liquidity premium and expected costs of financing in the baseline model. Parameters are as described in Table 1.3.

to their safe asset holdings beyond their ability to avoid financing costs in their usefulness for increasing investment in the future. As a result, as empire building increases, the return on safe assets is thus pushed below its social cost, as measured by households and other firms. These results underscore the role that corporate financing frictions have to play in the determination of liquidity premia.

1.9 Mechanism validation

The previous sections demonstrated that my estimated model produces an important equilibrium interaction between corporate finance, government borrowing and investment. However, the mechanism at the core of my model is difficult to test because it relies on segmentation between the market for firms' securities and the market for the safe assets they use for investment. In this section, I present a discussion of the plausibility of my mechanism. There are two key components of this mechanism, each of which yields a prediction about the relationship between corporate cash holding, government borrowing, and liquidity premia.

1. Corporations have a demand for the safe assets.

   Prediction: Given corporate demand, lower government supply of safe assets will be met with higher liquidity premia.

2. Supply of this asset by non-government actors is costly.

   Prediction: Given government supply, higher corporate demand for safe assets will be met with higher liquidity premia.

It is possible for either of these components of my model to not hold in the real world. First, if other types of securities are equally able to meet the precautionary needs of corporations, we should not expect to see a relationship between corporate cash holding and government borrowing. Second, if the demand for safe assets from firms can be met by other intermediaries without cost, we should not expect to see a relationship between corporate safe asset demand and liquidity premia.

A minimal demonstration of the plausibility of this mechanism therefore requires three types of changes. First, changes in supply of safe assets to the corporate sector (movements along the demand curve). Second, changes in the demand for safe assets from the corporate sector (movements along the supply curve). Finally, changes in the return on safe assets relative to the return on firms' other securities that are consistent with my model, and plausibly not due to changes in aggregate risk. For this section I use the long time series of corporate cash holdings, government debt and returns to argue that the mechanism in my model is indeed consistent with data over this time period. In particular, I argue that over this time period, decreases in government borrowing have been met with lower corporate cash holding and higher spreads between safe and unsafe returns, while increases in corporate demand for safe assets with little change in government borrowing have been met with higher spreads between safe and unsafe returns.

In bringing the mechanism of my model to the data, I face two challenges. The first is that there has been limited variation in government borrowing in the recent past. The second is distinguishing between my mechanism, which focuses on the difference between the return on firms and the return on treasuries as a result of their liquidity and exposure to idiosyncratic risk from mechanisms which focus on differences in these returns due to their exposure to aggregate risk.

To solve the first challenge, I construct a long time series of government borrowing and corporate liquid asset holdings from aggregate data. Specifically, I use corporate liquid asset holding from the Federal Reserve's Financial Accounts to construct the series on corporate liquid asset holdings, and data from FRED on federal debt held by the public to construct the series on government borrowing. Since my model is a closed economy with a unified Federal Reserve and Treasury, I net out foreign and Federal Reserve holdings of federal debt using Financial Account data.

To solve the second challenge, I focus on returns to AAA rated debt as a measure of the discount rate applied to firms' cash flows (ρ in my model). Low default rates on AAA rated debt means that the debt is unlikely to be affected by conventional risk premia. However, AAA debt is generally considered to be illiquid, and so cannot be easily employed by firms who hold it to fund investment and avoid financing costs. It is therefore an appropriate proxy for ρ in my model, which differs from the safe rate r only in that safe securities can be used as precautionary savings by firms, and not in any risk premium.

Figure 1.12 shows the time series of these three variables since 1950. In the early post-War period, both government borrowing and corporate cash holdings were high. Gradually, government borrowing fell, and corporate cash holdings fell in lock step until the 1970s. In the latter period of the 1970s, liquidity premia began to rise, consistent with safe assets becoming more scarce in the corporate sector. These rising liquidity premia would usually encourage greater issuance of safe corporate debt to meet increased demand. However, corporations were limited in their ability to meet this demand by requirements under Regulation Q which limited the ability of intermediaries to use corporate assets to create liquidity for deposit accounts and offer higher returns. We can thus plausibly think of changes in these three series as purely changes in supply: limiting the total provision of safe assets. Over the period from 1985 to 1995, on the other hand, government borrowing increased, without a corresponding increase in corporate safe asset holdings. As the supply of safe assets increased, liquidity premia fell. These two movements are consistent with the mechanism of my model.

Between 1995 and 2000, corporate sector cash holdings increased, while government borrowing decreased. During this period, in contrast to earlier periods, increasing corporate cash holding was made up primarily by increasing private supply of safe assets, and in particular supply by the corporate sector in the form of short-term debt and commercial paper. Larger levels of cash holding over this period were in turn met by higher liquidity premia, again consistent with the costs of rising corporate demand for safe assets in my model.

As emphasized above, current levels of corporate cash holdings are not unprecedented. In fact, during the 1950-1960 period, cash holdings were at fairly comparable levels. However, recent levels of cash holding have been supported largely by private supply of safe assets, especially increased provision by the corporate sector. My model emphasizes that this internal provision of safe assets is costly for firms: when the corporate sector provides safe assets internally, some firms face high expected costs of future financing. In order to compensate firms which provide safe assets, my model predicts the return on safe assets must fall relative to their cost of funds. It is thus consistent with both the behavior of interest rates, cash holdings and government borrowing prior to and post 2000.

1.10 Conclusion

The framework I present in this paper constitutes a bridge between two literatures: one considering the supply of safety and liquidity to the private sector from the government and the other considering the consequences of firms demand for assets with these attributes in a dynamic setting. The estimates I provide suggest that this bridge is quantitatively important: corporate demand for safe assets can have sizable effects on liquidity premia, and the supply of safe assets to the corporate sector plays an important role in determining aggregate investment. This paper has shown that when corporations demand safe assets for their precautionary savings and the supply of these assets is limited, the result is a combination of low rates of returns on safe assets and low investment which matches the current state of affairs in the U.S. economy. Moreover, government supply of safe assets through their borrowing has quantitatively important and counter-intuitive effects on aggregate investment. Finally, distortions to firms' demand for safe assets in this environment impact not only corporations' investment, but also the return on safe assets.

However, this bridge is by no means complete. In particular, the results of this paper suggest two natural extensions for further research. The first two concern unmodeled aspects of the net supply of safe and liquid assets to the

	$\frac{\textbf{Govt debt}}{\textbf{GDP}}$	$\frac{\textbf{Liquid assets}}{\textbf{GDP}}$	Macro variables		Returns	
			GDP growth	Inflation	T-bill	AAA-Treas
1950-1965	42.41	9.53	6.66	2.41	2.86	0.45
1970-1999	23.05	6.61	7.99	4.58	6.65	0.99
2000-2018	16.58	10.57	3.98	1.87	1.60	1.60
Subperiods:						
1990-1999	28.84	6.98	5.61	2.30	4.84	0.67
2000-2007	15.71	9.80	5.07	2.30	3.21	1.39
2008-2018	17.91	11.18	3.12	1.53	0.35	1.76

Table 1.6: **Government borrowing, corporate liquid assets and returns.** This table presents averages over different periods in the data of government borrowing, corporate liquid asset holdings, macroeconomic variables, and returns to government and corporate securities. Data is quarterly. Government debt is government debt held by the public less federal reserve holdings as reported in the flow of funds and foreign holdings. Liquid assets are non-financial corporate liquid asset holdings. GDP growth and inflation are annualized, GDP growth is in nominal terms, and inflation is constructed using the PCE price index. Returns are the secondary market 3-month treasury bill rate, while the AAA-treasury spread uses the Moody's AAA index and the return on long-term government bonds.

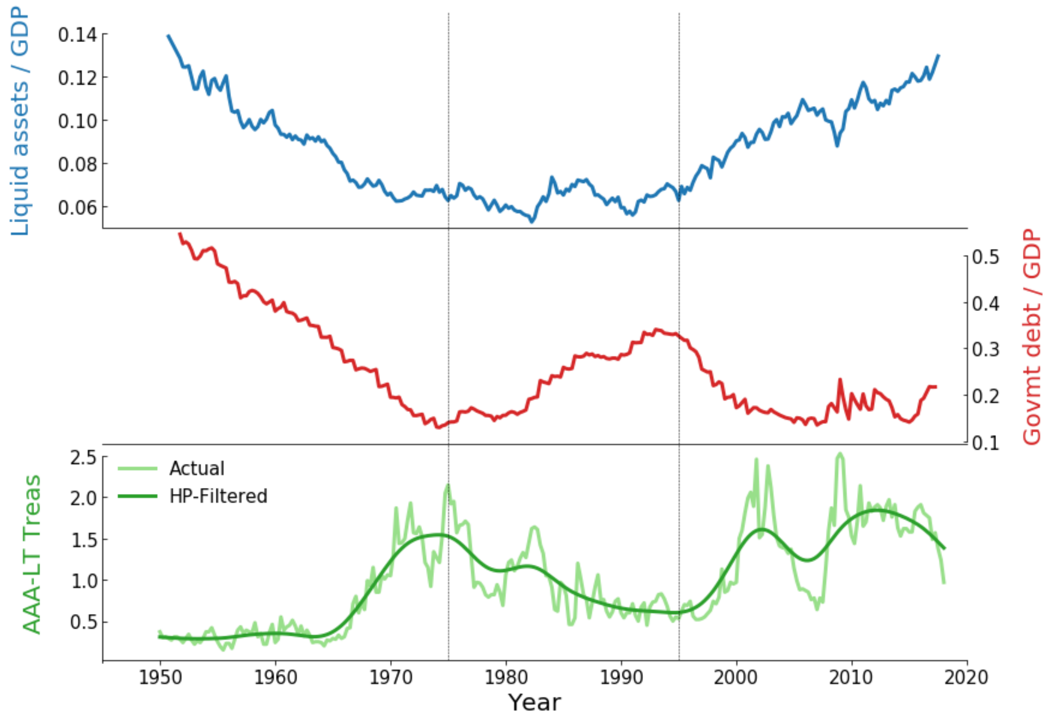


Figure 1.12: **Corporate liquid assets, government debt, and the liquidity premium over time.** This figure shows corporate liquid assets as a share of GDP, government borrowing net of foreign and Federal Reserve holdings as a share of GDP, and the spread between AAA corporate debt and long-term treasuries over time. The series on corporate liquid asset holdings is from the Federal Reserve's Financial Accounts. The series on government debt is from FRED, and series on Federal Reserve and foreign holdings of treasury debt is from the Financial Accounts. Three periods are highlighted: the first from 1950 to 1975 has falling government debt, rising liquidity premia and falling corporate cash holding. The period from 1975 to 1995 shows rising government debt, constant liquid asset holdings and falling liquidity premia. Finally, the period from 1995 to the present shows rising corporate cash holding and low government borrowing, and a rising liquidity premium.

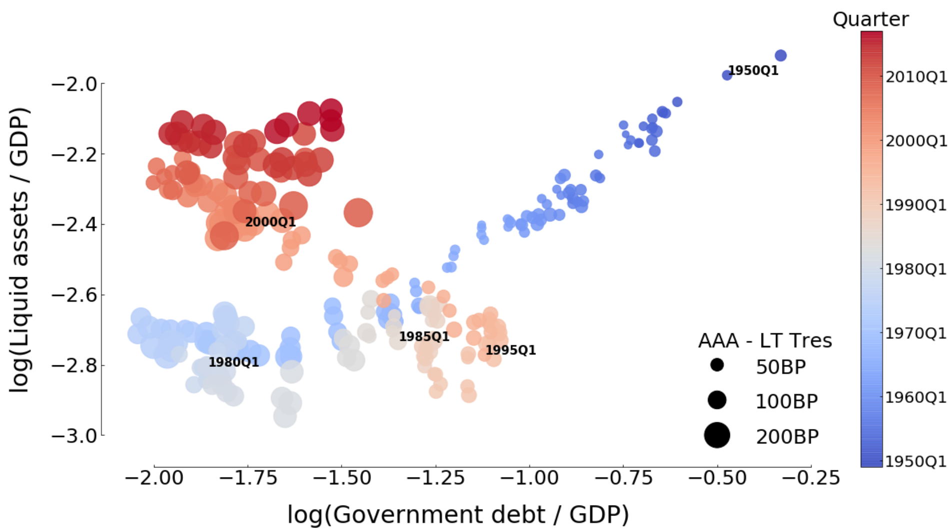


Figure 1.13: **Scatter plot of corporate safe asset holdings, government debt, and the liquidity premium.** This figure presents a scatter plot of government debt holding and corporate cash holdings. The size of points indicates the spread between AAA rated corporate debt and long-term treasuries, and the color of the points indicated the time period.

corporate sector. The first is that I have left household demand for safe assets as a reduced form. In standard models of incomplete markets, it is households' precautionary demand for these assets which determine a liquidity premium, and this premium usually increases rather than decreases investment, as firms face lower interest rates. A more micro-founded model of the interaction between the precautionary demands of households and firms may therefore be of interest, relating income shocks to households to the profitability shocks to firms. A second natural extension concerns the supply of safe assets from outside the corporate and household sectors. In my model, this supply come only from the Federal Government, but in reality intermediaries also produce these assets and the Federal Reserve both holds safe assets and influences their supply through their policy on reserves. While increases in government borrowing in my model can be thought of as analogous to unconventional monetary policy, the current model does not speak to the relationship between reserves and corporations' financial decisions. The results of my model point to an important inter-relationship between corporations' financial decisions and the supply of safe assets. Integrating these features into a model of intermediaries and monetary policy may provide new insights on the relationship between corporate finance and monetary policy.

CHAPTER II

Estimating and Testing Dynamic Corporate Finance Models

Work with Santiago Bazdresch and Toni Whited.

A large literature in finance and economics studies dynamic models of entrepreneurs, firms, and financial institutions, in which these agents, period by period, optimally make decisions about production, factor inputs, their compensation, and their financing.[1] Although these sophisticated dynamic programming problems are analytically complex and often only have approximate numerical solutions, this general research endeavor is promising. Investment, labor demand, executive compensation, and financial decisions are intrinsically dynamic problems that can only have a quantitatively satisfactory representation in a dynamic model. Moreover, dynamic models allow researchers to extract a wealth of time-series and cross-sectional predictions with which to compare model and data. This

[1] For a comprehensive review of the corporate finance literature, see *Strebulaev and Whited* (2012).

richness allows researchers to discipline dynamic models more than static models. In general, this discipline is useful because it allows the evaluation of different models' ability to match the data and, ultimately, to establish quantitatively better theoretical bases for understanding firm behavior.

Despite the growing popularity of this research agenda, little work has been done to provide benchmarks and tests for assessing how these models fit the data. In this paper, we provide some initial inroads toward filling this gap, with an emphasis on three areas. We examine the finite sample properties of the simulated minimum distance estimators that have been used to estimate the parameters of dynamic models.[2] Second, we formulate an external validity test for these models. Third, we propose an alternative set of statistical benchmarks that can be used in the estimation and evaluation of dynamic models.

Our main analysis centers around a set of Monte Carlo experiments designed to evaluate the performance of simulated minimum distance estimators in a panel setting. On an intuitive level, these estimators work by choosing parameters that set moments (or functions of moments) computed from real data as close as possible to those computed from data simulated from a model. Examining the finite-sample properties of these estimators is potentially interesting and important because the estimators are closely related to closed-form generalized method of moments (GMM) estimators. It is well known that the finite-sample properties of GMM estimators can deviate from the asymptotic properties, even when the

[2] *Hennessy and Whited* (2005) and *Cooper and Haltiwanger* (2006) are early examples. More recent examples include *Taylor* (2010), *Schroth et al.* (2014), *Warusawitharana and Whited* (2016), *Li et al.* (2016), and *van Binsbergen and Opp* (2019).

moment conditions have closed-form solutions (e.g., *Hansen et al.*, 1996; *Erickson and Whited*, 2002). In contrast, only very limited work has been done to understand the finite sample properties of simulation estimators (*Michaelides and Ng*, 2000; *Eisenhauer et al.*, 2015), largely because of the computational issues accompanying a Monte Carlo evaluation of an estimator that itself requires days of computation.

Advances in computing technology have allowed us to surmount this difficulty and find four basic results. First, all variants of the simulated minimum distance estimators that we examine produce parameter estimates that are nearly unbiased in finite samples even when the samples are substantially smaller than those typically available to corporate finance researchers. Moreover, these estimators often have extremely low root mean squared errors. Second, the standard errors that accompany these parameters produce reliable inference only in the case in which the estimator is based on an optimal, clustered weight matrix. Third, we assess various model specification tests, finding that they over-reject strongly when we use an identity weight matrix or when the sample is small. However, these tests only over-reject slightly when we consider an optimal weight matrix and a larger sample size. This last result stands in sharp contrast to the documented strong over-rejection of GMM-based specification tests in some asset pricing contexts (e.g., *Hansen et al.*, 1996). Fourth, the specification tests we consider also have excellent power to detect even small amounts of misspecification. Our result differs from the conclusion in *Arellano and Bond* (1991) that many panel GMM specification tests have poor power, but our result is in accord with the finding in *Erickson and Whited* (2012) that GMM specification tests can have excellent power to detect misspecification. We explain that these differences and similarities likely stem from the construction of the weight matrix, which, in our context, does not depend on parameter estimates.

Our second contribution is to formulate and evaluate the finite sample performance of tests to compare models and to assess the external validity of models. The model comparison tests we consider are from *Nikolov and Whited* (2014), who derive Wald tests to compare the equality of moments from different models. Our own external validity test statistics are a unique contribution of our paper. We derive tests of the null hypothesis of the equality of data and model-implied moments (or functions of moments), where these moments are not used in the estimation of the model. This type of test is useful for two reasons. First, it holds the model to a higher standard than a simple test of overidentifying restriction and thus accomplishes a purpose similar to that of an out-of-sample test. Just as an out-of-sample test assesses the ability of a statistical model to fit data not used in its estimation, our test assesses the ability of an economic model to fit economic predictions not used in its estimation. Second, such a test is useful for the simple reason that any model will fail if confronted with enough features of data that are generated by a world far more complex than the model. However, a test that can distinguish between features of the data that fit the model and those that do not can be of great use in directing researchers to develop better models.

Our third contribution is to provide guidance on the choice of which empirical predictions to use to evaluate, discipline, and test these models. Our motivation is twofold. First, we show with an example that benchmarks matter, as different benchmarks can produce economically distinct parameter estimates. Our second, broader motivation comes from the observation that different researchers make different arbitrary choices about which features of the data to consider. The result is a wealth of studies claiming that their models successfully explain the data. While the choice of empirical predictions naturally depends on the research question at hand and thus varies from application to application, there is still room for standardization of this choice. We argue that for any model there is a natural, intuitive set of statistics to be used for estimation and evaluation. Moreover, these statistics are comparable across different models. Therefore, they can be thought of as benchmarks that dynamic models should aim to match. In this sense, we provide one practical method to address the classic question in *Gallant and Tauchen* (1996) of which moments to match.

We derive these benchmarks from the model's policy functions, which characterize the solution of the model by stating the optimal response of the firm to its environment. Policy functions are thus the main objects that translate the assumptions of the model into a functional prediction about the firm's actions in different situations. Therefore, a direct, simple, and theoretically motivated way to evaluate a dynamic model is to evaluate its ability to replicate the firms' observed policies. One way to accomplish this goal is to characterize firms' policy functions empirically, and then use these characterizations as the inputs for structural model estimation and evaluation.

Of course, for any particular model, there might be a unique feature of the data (such as the mean of a variable) that could be employed to estimate the model's parameters. As such, we do not argue that policy functions are the only data features useful for estimating models. Instead, we argue that empirical policy functions (EPFs) are common benchmarks that can be used as a starting point for model evaluation.

Using EPFs as benchmarks for estimating and evaluating models confers several advantages over the common practice of using arbitrary moments. First, the moments used in the traditional estimation of these models are computed by simulating data from the policy functions, so the policy functions in principle contain at least as much information as moments. The second argument is that these quantities are often already used in other types of structural estimation (*Bajari et al.*, 2007), albeit in sharply different ways. Thus, the use of policy functions as an input to the estimation of dynamic models is not a large departure from tradition. Third, applied researchers already estimate policy functions. For example, one of the most commonly estimated regressions in corporate finance is a regression of investment on cash flow (*Fazzari et al.*, 1988). However, this regression essentially constitutes a policy function from a model in which the firm observes its cash flow and then makes its investment decision. Thus, using policy functions as benchmarks to estimate the parameters of dynamic models affords a close connection between commonly run regressions and the dynamic models that underlie these regressions.

Although our paper is clearly related to the many applied papers that have used simulation estimators to estimate the parameters of dynamic models, it is also related to a set of applied econometrics papers in corporate finance that have sought to provide guidance to empirical researchers. For example, *Petersen* (2009) deals with the computation of standard errors in panel data, *Erickson and Whited* (2012) compare the finite-sample performance of estimators that treat measurement error, and *Gormley and Matsa* (2014) consider the treatment of unobserved heterogeneity. However, these papers deal with regression-based statistical analysis, while we look at methods used to estimate the parameters of dynamic economic models.

Next, our work stands apart from two more closely related papers. The first is the estimation method proposed by *Bajari et al.* (2007). Their method uses estimated policy functions as direct inputs into an approximation of the model solution, which is subsequently used to construct moment inequalities that define the estimation. In contrast, our methods use a full model solution to generate simulated data. The empirical policy functions estimated on simulated data are then matched as closely as possible to policy functions estimated on real data. Second, our work is related to *Gala and Gomes* (2016). They focus on the estimation of the policy function of an investment model as a substitute for traditional regressions of investment on q. However, their work also contains an applied example of the idea of using policy functions as an input into indirect inference, where their application is the estimation of some parameters of their investment model.

Finally, although our methods are directly applicable to the estimation of the parameters of dynamic models, our introduction of empirical policy functions as benchmarks is also of use to the dynamic asset pricing literature, which often studies model calibrations. Even here a standardized benchmark could be of use in assessing the fit of various competing models, even though calibration offers no formal inference.

2.1 Trade-Off Model

This section outlines a class of simple dynamic capital structure models. As in any analysis of the finite sample properties of estimators, we need to choose a basic estimating equation. In the case of structural estimation, this choice is more involved than picking coefficients in a linear regression, as the estimating equation is a model itself. Thus, our goal is to pick a simple model that is as generic as possible.

The models of the firm that we consider are single-agent dynamic decision problems. In these models, the firm typically chooses optimal policies to maximize the expected discounted value of payout to current owners. Thus, the value of the equity of the firm can be described generically in terms of a Bellman equation:

$$\Pi(y, z) = \max_{y'} \left\{ e(y, y', z) + \beta \mathbb{E} \Pi(y', z') \right\}. \tag{2.1}$$

Here, y is a vector of endogenous state variables, z is a vector of stochastic exogenous state variables that follows a Markov process, $e(y, y', z)$ is the current period net cash flow accruing to shareholders, $\Pi(y, z)$ is firm equity value, $\beta \in (0, 1)$ is a discount factor, and $\mathbb{E}$ is the expectations operator with respect to the transition function for z. A prime indicates the next period, while the absence of a prime indicates the current period.

Given a functional form for $e(y, y', z)$ and distributional assumptions for z, both of which meet standard regularity conditions (e.g., *Stokey et al.*, 1989), the solution to this model exists. This solution can be expressed in terms of the value function, $\Pi(\boldsymbol{y}, \boldsymbol{z})$, and the policy function, $\boldsymbol{y}' = G(\boldsymbol{y}, \boldsymbol{z})$, which describes the firm's optimal choice of $\boldsymbol{y}'$, given the current state, $(\boldsymbol{y}, \boldsymbol{z})$. The policy function is thus given by:

$$G(\boldsymbol{y}, \boldsymbol{z}) =_{\boldsymbol{y}'} \left\{ e(\boldsymbol{y}, \boldsymbol{y}', \boldsymbol{z}) + \beta \mathbb{E} \Pi(\boldsymbol{y}', \boldsymbol{z}') \right\}. \tag{2.2}$$

Although our methods apply to the estimation of the parameters of any such model, to make our setting more concrete, we consider a special case that can be described as a streamlined version of the model in *Hennessy and Whited* (2005). We simplify this setting substantially. Otherwise, computing a Monte Carlo simulation of an estimator based on such a model would be infeasible.

In this model, the firm uses capital in a constant-returns technology to generate operating income according to zK, where K is the capital stock, and z is a profitability shock. Thus, in terms of the notation in Equation (2.1), $K \equiv \boldsymbol{y}$ and $z \equiv \boldsymbol{z}$. The use of a constant-returns technology follows *Warusawitharana and Whited* (2016) and greatly simplifies computation.

The profitability shock, z, is lognormally distributed and follows the process given by:

$$\ln(z') = \mu + \rho \ln(z) + \sigma \varepsilon', \qquad \varepsilon' \sim \mathcal{N}(0, 1). \tag{2.3}$$

Each period the firm chooses investment, I, which is defined by a standard capital stock accounting identity:

$$K' \equiv (1 - \delta) K + I, \tag{2.4}$$

in which δ is the rate of capital depreciation. We normalize the price of capital goods to one and assume that the firm faces real frictions in the form of convex investment adjustment costs. The function describing these costs is given by:

$$c(I) = I + \gamma K \frac{1}{2} \left(\frac{I}{K} \right)^2 , \tag{2.5}$$

in which the first term represents the purchase price of capital goods, and γ quantifies investment adjustment costs. In many models of this type, investing incurs costs (*Abel and Eberly*, 1994) that are independent of the amount of investment. For simplicity, we initially assume away these frictions, but we revisit the issues with fixed costs below in Section 2.5.

The firm's cash flow, $E^*(K, P, K', P', z)$, is its operating income plus its net debt issuance, $P' - P$, minus its net expenditure on investment, $c(I)$, and minus its interest payments on debt, rP:

$$E^*(K, P, K', P', z) = zK - c(I) + P' - P(1 + r), \tag{2.6}$$

in which r is the risk-free rate of interest. We assume that $r < 1/\beta - 1$ to reflect the interest tax deduction and thus the tax benefits of debt. Motivated by the dynamic contracting literature (*Rampini and Viswanathan*, 2013), we assume this debt is secured by capital, that is, we allow a fraction, ξ, of the capital to be used as collateral. Because some capital might be intangible and therefore of little worth to a lender, $0 \leq \xi \leq 1$. The collateral constraint can thus be expressed as:

$$P' \leq \xi K'. \tag{2.7}$$

This formulation of the leverage decision abstracts from debt issuance costs, but later we examine the ability of our estimation method to detect misspecification by considering the possible existence of issuance costs.

Cash flows to shareholders, $E(K, P, K', P', z)$, are defined in terms of the firm's cash flows, $E^*(K, P, K', P', z)$. A positive firm cash flow is distributed to its stockholders, while a negative cash flow implies that the firm instead obtains funds from shareholders. In this case, the firm pays a linear cost, λ. Thus, shareholder cash flows are given by:

$$\begin{aligned} E^* \geq 0 \quad &\Rightarrow \quad E = E^* \\ E^* < 0 \quad &\Rightarrow \quad E = E^*(1 + \lambda). \end{aligned} \tag{2.8}$$

Having defined cash flows, we can now state the firm's problem as a special case of Equation (2.1):

$$\Pi(K, P, z) = \max_{K', P'} \left\{ E(K, P, K', P', z) + \beta \mathbb{E} \Pi(K', P', z') \right\}, \tag{2.9}$$

subject to Equations (2.4) and (2.7). Given easily verifiable restrictions on the parameters, this model satisfies the conditions in *Stokey et al.* (1989) for the existence of a solution.

We now simplify the model by exploiting our assumption of constant returns to scale and redefining all of the quantities in the model as a fraction of the capital stock, K. This transformation eliminates capital as a state variable and greatly simplifies computation. Define the following scaled variables:

$$p \equiv \frac{P}{K}, e \equiv \frac{E}{K}, i \equiv \frac{I}{K}, \pi(p,z) \equiv \frac{\Pi(K,P,z)}{K}.$$

Then, by dividing all of the variables in Equation (2.9) by K, we obtain the following Bellman equation:

$$\pi(p,z) = \max_{p',i} \left\{ e(p,p',i,z) + \beta \mathbb{E} \pi(p',z')(1-\delta+i) \right\} \tag{2.10}$$

and the constraints become:

$$e(p,p',i,z) = z(1-\tau) - i - \frac{\gamma i^2}{2} - p(1+r(1-\tau)) + p'(1-\delta+i), \tag{2.11}$$

$$p \leq \xi. \tag{2.12}$$

2.1.1 Optimal policies

Although much less elaborate than the model in *Hennessy and Whited* (2005), our simple model conveys much of the same intuition. To illustrate, we examine the optimality conditions for investment and leverage. To obtain the first-order condition for optimal investment, we differentiate Equation (2.10) with respect to i:

$$(1 + \mathbb{I}_e \lambda)(1 + \gamma i - p') = \beta \mathbb{E} \pi \left(p', z'\right), \tag{2.13}$$

in which $\mathbb{I}_e$ is an indicator function that is one if the firm is issuing equity. Naturally, this first-order condition appears similar to that from a neoclassical q model. If the firm is not issuing equity, then the marginal cost of investment is $(1 + \gamma i - p')$, but in those states of the world in which the firm is issuing equity, this marginal cost rises by a factor of $(1 + \lambda)$. At an optimum, the marginal cost of investment less the proceeds from any debt issues must equal the right-hand side of Equation (2.13), which is the expected future equity value per unit of capital. Because of our constant returns to scale assumption, this quantity is equal to the marginal value of capital or marginal q.

We obtain the first-order condition for debt by differentiating Equation (2.10) with respect to p', as follows:

$$1 = -\beta\mathbb{E}\left(\pi_p(p', z')\right). \tag{2.14}$$

Next, we use the envelope condition to eliminate $\pi_p(p', z')$ from the problem. Let η be the Lagrange multiplier associated with the collateral constraint in Equation (2.12). Substituting in the envelope condition, $-\pi_p(p, z) = (1 + r)(1 + \mathbb{I}_e\lambda) + \eta$, and rearranging gives:

$$1 = \beta\mathbb{E}\left((1 + r)(1 + \mathbb{I}_e\lambda') + \eta'\right). \tag{2.15}$$

Because of the assumption $r < 1/\beta - 1$, in the absence of financial frictions in the form of equity issuance costs, the obvious optimal policy of the firm is to borrow up to the collateral constraint. However, if the firm expects to be issuing equity in the next period, then Equation (2.15) will not hold at this corner solution. Instead, as is standard in dynamic investment models, debt capacity has value because it confers financial flexibility.

We now elaborate on this discussion by plotting the actual model policy functions in Panels A–C of Figure 2.1. Each panel depicts next-period net debt/capital, investment/capital, and net distributions/capital as a function of the profitability shock, and each panel is drawn for a different level of current debt/assets, in particular, the 10th, 50th, and 90th percentiles of simulated debt to assets. Of course, the shape of the policy functions depends on the parameters, so these functions are based on the parameter estimates from the moment estimation described below.

Several features of the policy functions shown in Figure 2.1 are noteworthy. First, they are clearly nonlinear. For example, when the firm is currently at a medium level of net debt-to-capital, distributions are unresponsive to the profitability shock if it is low, but they rise sharply with the shock if it is high. Second, while investment is always increasing in the profitability shock, the response is muted relative to the responses of debt and distributions. Quadratic investment adjustment costs lie behind this pattern, as they give the firm an incentive to smooth investment over time. Third, next-period net debt-to-capital increases with the profitability shock when current debt is low, but it decreases with the profitability shock when current debt is medium or high. This difference is due to the relative strengths of income and substitution effects. When debt is low and the firm has a great deal of free debt capacity, a substitution effect dominates. That is, when the firm receives a positive profitability shock, it optimally wants to invest in productive capital instead of debt capacity, so it funds its investment with debt, and both rise with the shock, z. However, when debt is at a medium or high level, an income effect dominates, so the firm optimally wants to invest in both capital and debt capacity, and we see a concurrent rise in investment and a fall in debt.

Our empirical policy function estimation benchmarks are based on estimates of these model policy functions instead of the actual policy functions themselves. Matching an exact function is ill-defined in a statistical sense, as indirect inference requires matching two sets of statistics: estimates from actual data with identical estimates from simulated data. It is this task to which we turn next.

2.2 Benchmarks and Estimation

2.2.1 Empirical policy functions

An empirical policy function is an estimate of the relationship between the current state of the firm and the policies the firm chooses in that state. One challenge posed by this estimation is the issue that in many models, some state and choice variables are unobservable. In such cases, it is often convenient to work with state and choice variables that are functions of the original variables. We therefore propose transforming the original policy function into one whose arguments are observable functions of the original arguments. Specifically, we define the transformed state and control variables as:

$$x \equiv x(y, z) \tag{2.16}$$

$$w \equiv w(y'). \tag{2.17}$$

The dimensions of $\boldsymbol{x}$ and $\boldsymbol{w}$ are M and P, respectively. Note that these dimensions can differ from the dimensions of $(\boldsymbol{y}, \boldsymbol{z})$ and $\boldsymbol{y}'$. With these definitions, the policy function can be written as:

$$\boldsymbol{w} = H(\boldsymbol{x}). \tag{2.18}$$

For example, in the model in Section 2.1, z and p are the state variables, and i and p' are the control variables. The variables p, p', and i are obviously observable, and in the case of our simple constant returns model, z is the ratio of operating profits to capital. So $\boldsymbol{w} = \{i, p'\}$, and $\boldsymbol{x} = \{p, z\}$. In Section 2.5, we consider a decreasing returns-to-scale model in which we need to perform a nontrivial transformation.

With this notation in hand, we can explain the estimation of the key features of $\boldsymbol{w} = H(\boldsymbol{x})$. Linear regression is clearly inadequate for this task, as the constraints and nonconvexities in many dynamic models imply highly nonlinear policy functions, such as those in Figure 2.1. A natural alternative is any flexible semiparametric regression technique, as long as it can be characterized by a finite parameter vector. To describe the policy-function estimation step, we let $\boldsymbol{v}_{it} \equiv (\boldsymbol{w}_{it}, \boldsymbol{x}_{it})$, $i = 1, \ldots, N$, $t = 1, \ldots, T$, be a sample of observations on the state and control variables, where i indexes individual firms/plants/people, and t indexes time. For each control variable, we consider a semiparametric regression of the form:

$$\boldsymbol{w}_{it}^{n} = H^{n}(\boldsymbol{x}_{it}) + u_{it}^{n}, \tag{2.19}$$

in which the superscript n indicates the n^{th} element of the policy vector $\boldsymbol{w}_{it}$, and u_{it}^{n} is the regression disturbance, whose expectation, conditional on $\boldsymbol{x}_{it}$, is zero. This assumption is without loss of generality, as we do not need to find an interpretable causal relation between $\boldsymbol{w}_{it}$ and $\boldsymbol{x}_{it}$. Instead, estimation of the policy functions is motivated by a revealed-preference argument that the choices we observe in the data must be optimal choices, so the goal of the estimation is to uncover this endogenous, optimal relation between states and choices.

Because the policy function, $H(\boldsymbol{x}_{it})$, is of unknown form, to capture this nonlinearity we estimate Equation (2.19) using series approximating functions, which we denote as $h_j(\boldsymbol{x}_{it})$, $j = 1, \ldots, J$. We assume these approximate $H(\boldsymbol{x}_{it})$ in the following sense. As $J \to \infty$, the expected mean squared difference between $H(\boldsymbol{x}_{it})$ and a linear combination of the functions $h_j(\boldsymbol{x}_{it})$ approaches zero, that is:

$$\lim_{J\to\infty} E\left(\sum_{j=1}^{J} b_j h_j(\boldsymbol{x}_{it}) - H(\boldsymbol{x}_{it})\right)^2 = 0. \tag{2.20}$$

Several different series functions, such as power series or trigonometric series, can satisfy Equation (2.20), and we discuss the choice of the approximating function below.

2.2.2 Indirect inference

Once the above benchmarks are calculated, we use them to estimate a model through the indirect inference procedure in, for example, *Smith* (1993) and *Gourieroux et al.* (1993). We now outline the procedure and then explain how it applies to our policy function benchmarks.

Recall that $\boldsymbol{v}_{it}$ is our vector of data observations. Let $\boldsymbol{v}^s_{it}$ be a simulated vector from simulation s, $s = 1, \ldots, S$, where S is the number of times the model is simulated. The simulated data vector, $v_{it}^{s}(\theta)$, depends on a vector of structural parameters, θ. In our context, the structural parameters include the cost of equity issuance, λ, and the quadratic investment adjustment cost, γ. Next, we define the estimating equations as:

$$g(v_{it}, \theta) = \frac{1}{nT} \sum_{i=1}^{n} \sum_{t=1}^{T} \left[m(v_{it}) - S^{-1} \sum_{s=1}^{S} m\left(v_{it}^{s}(\theta)\right) \right], \tag{2.21}$$

in which $m(\cdot)$ is a vector of functions, whose dimension is at least as large as the dimension of the structural parameter vector, θ. For example, in the special case of a simulated moments estimator (*Lee and Ingram*, 1991), $m(\cdot)$ is a vector of moments, but the indirect inference procedure is more general than a simulated moments estimator, so $m(\cdot)$ can also be a vector of functions of moments.[3] Hereafter, we refer to the vector $m(\cdot)$ generically as a benchmark. The objective of the estimation is to get this vector as close to zero as possible, so we introduce the term model error to describe the term in square brackets in Equation (2.21).

The indirect inference estimator, θ is the solution to the minimization of:

$$\hat{\theta} = \arg\min_{\theta} g(v_{it}, \theta)' \hat{W}_{nT} g(v_{it}, \theta), \tag{2.22}$$

in which $\hat{W}_{nT}$ is a positive definite matrix that converges in probability to a deter-

[3]Indirect inference also encompasses likelihood-based methods, which have not featured as prominently in problems of estimating the parameters of dynamic models, so we do not cover these methods here.

ministic positive definite matrix W as $n \rightarrow \infty$.[4]

Finally, we explain how a simulated moments estimator and our use of empirical policy function benchmarks fit into this framework. In the case of a simulated moments estimation, the benchmark is simply a vector of moments. The case of our EPF benchmarks requires more explanation. First, we note that our implementation of indirect inference is closely related to the original motivation in *Gourieroux et al.* (1993) for using this technique. They note that on an intuitive level, it might be desirable to estimate θ via maximum likelihood. However, in the class of computational dynamic models we consider, this strategy is unavailable, as the model solution does not provide an expression for the likelihood. Indirect inference fills this gap by using an auxiliary model, which should ideally capture important features of the data, even if it does not completely summarize the data in the same way that a likelihood function does. Because the empirical policy function is a characterization of the solution of the model, it is a highly suitable auxiliary model.

Because the auxiliary model is the empirical policy function given by Equation (2.20), the benchmark function $m(\boldsymbol{v}_{it}, \theta)$ is an estimate of the parameter vector b in Equation (2.20). In both the real and simulated data, because we use ordinary least squares (OLS) to estimate b, $m(\cdot)$ is a vector of functions of moments, in particular, the means, variances, and covariances of the data. The simulated data depend on the structural parameter vector, θ, so the estimates of the auxiliary parameters in

[4]While it is beyond the scope of this applied paper to state the asymptotic properties of these estimators, it is worth noting that, as is typical in panel settings, the asymptotic properties hold as n goes to infinity, with T held constant.

the simulated data, $b(\theta)$, naturally depend on the underlying structural parameters. The final goal is then to estimate θ by minimizing the distance between the parameter vector of the auxiliary model, b, estimated with a real data set and the same parameter vector estimated with data simulated from a model.

We next discuss the identification of the parameter vector, θ. Global identification requires a one-to-one mapping between the model parameters, θ, and a same-dimension subset of the parameters of the auxiliary model, b. Local identification of the parameters in any indirect inference estimation requires that the gradient of the auxiliary model with respect to the parameters, $\partial m \left(\boldsymbol{v}_{it}^{s} (\theta) \right) / \partial \theta$, have full rank. Intuitively, this condition indicates that for an element of the parameter vector, θ to be identified, some subset of the elements of $m(\cdot)$ must change when that particular element of θ moves. For example, identification of the depreciation rate, δ relies on the positive relation in the model between average investment and the depreciation rate. Although in the short run, investment is driven by productivity shocks, in the long run, the firm invests enough to replace depreciated capital, so high depreciation rates are associated with high average investment, and vice versa. In the EPF-based estimation, the intercept of the investment policy function serves the same purpose as the average depreciation rate.

Also important for identification and inference is the precision of the estimation of the auxiliary parameter vector, b, as the parameter vector θ is a function of b and thus, as shown in the expressions in the Appendix for the variance of θ, inherits its sampling variation. The consideration of precision brings up the important issue of the trade-off between using a close approximation to the true policy function and using up degrees of freedom in the data. Although it appears intuitive that a close approximation should provide sharper parameter identification, a better-fitting estimation of the policy function need not deliver better finite sample properties of an indirect inference estimator. The reason is sampling variation from the policy function estimation stage. For example, if one is estimating a model with a sharply discontinuous policy function, one needs a very flexible semiparametric estimator to capture the policy function shape. However, when such an estimator does deliver a good fit, it typically requires the estimation of so many auxiliary parameters that it ends up being high variance. This issue can compromise parameter identification because when the auxiliary parameters are estimated imprecisely, the amount of identifying information they provide is small.

It is beyond the scope and computational constraints of this paper to explore in detail the trade-off between sample size and the flexibility of the approximating function in Equation (2.20). Therefore, for simplicity, we consider a simple power series as our set of $h_j(\cdot)$ functions, with terms that are linear and quadratic in our state variables, as well as all cross products. As a robustness check, we also consider a higher order polynomial approximation.

Before continuing to explain inference and testing in this framework, it is worth digressing to explain the differences between our use of empirical policy functions in structural estimation and the method put forth by *Bajari et al.* (2007) (BBL, hereafter). The BBL estimator is a two-step method that does not require a full model solution. The first step constitutes semi-parametric estimation of empirical policy functions, as well as transitions probabilities for all stochastic state variables (z in our notation). These estimates are substituted directly into the model and are used to forward simulate value functions. The second step is the actual estimation of the structural parameters, which are chosen so that the observed policies are optimal relative to a set of perturbations of the value function.

This method has the distinct advantage of not requiring the time-consuming step of solving the model at every iteration of the econometric hill-descending routine. However, it does confer some disadvantages. First, the forward simulation step imposes a linear relation between the policy and value functions and thus introduces small sample bias, as value functions are generally nonlinear transformations of policy functions. For example, in a standard corporate finance setting, adjustment costs and equity issuance costs imply that leverage and investment do not enter linearly into the flow payoff of the firm. Our use of indirect inference sidesteps this issue because our policy function estimates are not introduced directly into the model solution. Second, BBL estimation requires that all state variables must be observed, as must all states to which a firm can transition with positive probability. This requirement is necessary for the forward simulation of the value functions, yet it is unlikely to be satisfied in many corporate finance models, in which the underlying states are not observed (e.g., *Hennessy and Whited*, 2005, 2007). Even when they are, such as in our constant-returns model, all of the state transitions may not be observable. For example, in the presence of model features such as default or equity issuance, the states that lead to either action can be reached from most other states with such low probability that, given typical sample sizes in Compustat, the state transitions may not be observed. The BBL estimator would struggle to detect the effect of these low probability events. In contrast, because policy functions reflect the existence of low-probability events even in states when they do not occur, the effect of these events can be seen in the comparison of model-implied and empirical policy functions. For example, a high cost of equity issuance affects the height and shape of the policy for optimal leverage over a wide range of states, not just the states in which equity issuance occurs.

2.2.3 Inference and tests

Much of our examination of the finite sample properties of these estimators centers around the performance of the test statistics that accompany indirect inferences. As such, we now sketch the basic distributional properties of these estimators and then derive our external validity specification test, which is a new addition to this literature.

First, we tackle the question of the weight matrix. While any positive definite matrix, W, is a potentially valid choice, we focus on two typical choices: an identity matrix and the optimal weight matrix, which in a panel setting with large n and fixed T is the inverse of the clustered covariance matrix of the vector of functions, $m(\cdot)$. We denote this optimal weight matrix as $\hat{\Omega}^{-1}$ and calculate it using the influence function technique from *Erickson and Whited* (2002).

An influence function for an estimator is a function of the data whose mean has the same asymptotic distribution as the estimator. Thus, on an intuitive level, covarying the influence functions of two estimators produces their asymptotic covariance. Recall that the vector $m\left(v_{it}\right)$ contains moments (in the case of a simulated moments estimator) or functions of moments (in the case of indirect inference with EPF benchmarks). It follows that we can compute the clustered covariance matrix, $\hat{\Omega}$, by stacking the influence functions for the elements of $m\left(v_{it}\right)$ and simply taking a clustered covariance as follows:

$$\hat{\Omega} = \frac{1}{nT}\sum_{i=1}^{n}\left(\sum_{t=1}^{T}\psi_{m(v_{it})}\right)\left(\sum_{t=1}^{T}\psi_{m(v_{it})}\right)', \tag{2.23}$$

in which $\psi_{m(v_{it})}$ is the vector of influence functions for the elements in $m(v_{it})$. For example, in the case in which $m(v_{it})$ is the vector of empirical policy function coefficients, b, the influence functions $\psi_{m(v_{it})}$ are just standard OLS influence functions. Importantly, the expression given by Equation (2.23) does not depend on any model parameters, so the parameter vector never enters the weight matrix, as it does in many applications of GMM.

It is worth noting that other methods for calculating the covariance matrix $\hat{\Omega}$ are either cumbersome or potentially incorrect. For example, although estimation of $\hat{\Omega}$ as part of a large joint estimation of the vector $m(v_{it})$ is asymptotically equivalent to our influence function approach (*Taylor*, 2010), this type of exercise can be cumbersome if the dimension of $m(v_{it})$ is large. Another possibility is to use a bootstrap. However, unless the resampling distribution is the same as the distribution of the data, this procedure is invalid, as the covariance matrix, $\hat{\Omega}$, is not an asymptotically pivotal statistic.

We leave the formulae for the standard indirect-inference test statistics to the Appendix, but we do sketch two tests. The first is the test from *Nikolov and Whited* (2014) of the null hypothesis that the simulated vector $m(\boldsymbol{v}_{it}, \theta_k)$ for a model k equals the vector $m(\boldsymbol{v}_{it}, \theta_j)$ for a different model j. A standard Wald test for this null hypothesis takes the form

$$\frac{nTS}{1+S}\left(m(\boldsymbol{v}_{it}, \theta_k) - m(\boldsymbol{v}_{it}, \theta_j)\right)' \left(\text{avar}\left(m(\boldsymbol{v}_{it}, \theta_k) - m(\boldsymbol{v}_{it}, \theta_j)\right)\right)^{-1} \left(m(\boldsymbol{v}_{it}, \theta_k) - m(\boldsymbol{v}_{it}, \theta_j)\right),$$

in which avar $\left(m(\boldsymbol{v}_{it}, \theta_k) - m(\boldsymbol{v}_{it}, \theta_j)\right)$ is the asymptotic variance of the difference between the two moment vectors. As in the case of the estimation of the weight matrix given by Equation (2.23), we calculate this variance by covarying the influence function for $m(\boldsymbol{v}_{it}, \theta_k) - m(\boldsymbol{v}_{it}, \theta_j)$ with itself. Of course, this test can be performed for individual elements of $m(\cdot)$, subsets of elements, or for the entire vector. See *Nikolov and Whited* (2014) for details.

Second, we develop a Wald test for model errors that are not contained in the vector in Equation (2.21) used for estimation. Specifically, suppose we have a vector of benchmarks, $m^{*}(\cdot)$, that are not used to estimate the parameter θ. We want to test the null hypothesis that

$$g^{*}\left(\boldsymbol{v}_{it}, \theta\right) = E\left(m^{*}\left(\boldsymbol{v}_{it}\right) - S^{-1}\sum_{s=1}^{S} m^{*}\left(\boldsymbol{v}_{it}^{s}\left(\theta\right)\right)\right) = 0. \tag{2.24}$$

This hypothesis constitutes a test of the external validity of the model, as it assesses the model's ability to explain patterns in the data that are not used to estimate its parameters. Under the null hypothesis that the model is correctly specified, this vector should equal zero. Because $g^*(\boldsymbol{v}_{it}, \theta)$ is a function of the parameter vector θ, we can use a standard Wald test of the null in Equation (2.24). The hurdle is calculating the asymptotic variance of $g^*(x_i, b)$ because it is a function of two quantities that are estimated separately: the data vector, $g^*(\boldsymbol{v})$, and the parameter vector, θ.

Again, we use the influence function technique from *Erickson and Whited* (2002). The influence function for $g^*(\boldsymbol{v}_{it}, \theta)$ can be calculated using the delta method, as follows. Let the influence function for observation it for θ be given by ϕ_θ, and let the influence function for $m^*(\boldsymbol{v}_{it})$ be ϕ_m^*. Then the influence function for $g^*(\boldsymbol{v}_{it}, \theta)$ is given by:

$$\phi_g^* = \phi_m^* - \left(S^{-1} \sum_{s=1}^{S} \left(\partial m^* \left(\boldsymbol{v}_{it}^s(\theta) \right) / \partial \theta \right) \right) \phi_\theta.$$

The variance of $g^*(\boldsymbol{v}_{it}, \theta)$ can then be obtained by covarying the influence function ϕ_g^* with itself, as follows:

$$\text{avar}(g^*(\boldsymbol{v}_{it}, \theta)) = E\left[\phi_g^* \phi_g^{*\prime} \right],$$

where the computation of this expectation proceeds as in Equation (2.23). The square-roots of the diagonal elements of avar($g^*(\boldsymbol{v}_{it}, \theta)$) can serve as standard errors in the construction of t-statistics of the null hypothesis that individual model errors in the vector $g^*(\boldsymbol{v}_{it}, \theta)$ equal zero. Finally, the Wald test for the joint null hypothesis that all elements of the vector $g^*(v_{it}, \theta) = 0$ can be constructed as

$$g^*(v_{it}, \theta)' (\text{avar}(g^*(v_{it}, \theta))^{-1} g^*(v_{it}, \theta), \tag{2.25}$$

which has degrees of freedom equal to the dimension of $g^*(v_{it}, \theta)$.

2.3 Estimation

2.3.1 Data

We draw our sample of firms from the Compustat database for the 1971 to 2015 period. We screen the sample as follows. The firm must have a CRSP share code of 10 or 11. We then drop all firms with fewer than two years of data or that belong to the financial (SIC code 6) or regulated (SIC code 49) sectors. We also drop quasi-governmental firms in SIC 9 and the U.S. Postal Service. Finally, we delete all observations in which any of the variables we use are missing, in which total assets are less than 10 million real 1982 dollars, or in which either sales or book assets grow by more than 200%. Even though we winsorize all variables at the 1% level, this last screen is nonetheless useful for minimizing the impact of outliers on our estimation. We are left with a sample of 111,902 firm/year observations.

We define the following variables to be used in the rest of the analysis. The numerator of book leverage is (DLC + DLTT − CHE) plus the capitalized value of leases, as in *Li et al.* (2016), and the denominator is total assets (AT). Profitability is OIBDP/AT, investment is CAPX/AT, and net payout is (CDIV + PDIV + PRSTK − SSTK)/AT. These data variables correspond to the variables p, z, i, and e in the model. Note that because the model variables p and e can be either positive or negative, they correspond to leverage net of cash and payout net of issuances. Finally, for reference, we also calculate the market-to-book ratio, which takes the form (AT + CSHO × PRCC_F − CEQ − TXDB)/AT.

The firms in Compustat are heterogeneous, yet the models described and exemplified above are typically models in which firms are ex ante homogenous. Thus, we demean each state and control variable at the firm level. This step is also important because we are concerned mainly with the dynamics of the different variables, as opposed to any cross-sectional variation. Nonetheless, we want the policy functions to be able to reconcile the average levels of the control variables in the model with the average levels in the data. Because removing firm fixed effects implies that all variables have a zero mean, we therefore add the mean over the entire sample back into each variable.

Table 2.1 presents summary statistics for the state and control variables in the model. Because we demean all variables at the firm level, the standard deviations and percentile ranges presented in Table 2.1 reflect within-firm variation, which is at most what a model of an individual firm can be expected to explain. In this regard, the large ranges seen for the policy and state variables are of interest. For example, the firm at the 10th percentile of net leverage has negative net leverage, that is, it is actually holding more cash than debt. In contrast, the firm at the 90th percentile has net leverage of over 30%. The ranges for our other policy variables are similarly wide. In particular, the 10th and 90th percentiles of investment are consistent with the presence of some lumpiness in investment, with at least 10% of the firm-year observations exhibiting investment bursts that are nearly twice the median rate of investment. Finally, note that the standard deviation of the market-to-book ratio is much larger than the standard deviations of our state and policy variables. As much of this variation likely reflects measurement error (*Erickson and Whited*, 2012), we do not use this variable in our structural estimations.

2.3.2 Estimation results

We now compare the results from estimating the trade-off model using two different types of estimation benchmarks: traditional moments and the series estimates of the empirical policy functions. Our intent is not to provide new economic insights, as the model we are estimating is only a simplified version of models that have been studied extensively (*Hennessy and Whited*, 2005; *DeAngelo et al.*, 2011). Instead, our intent is to illustrate what one can learn from the differences in parameter estimates that different benchmarks produce. It is worth emphasizing that one should expect different parameter estimates when using different benchmarks, as models, which are simple by nature, can never reconcile all of the features of data that are generated by a complex world.

For the two estimation benchmarks we consider, we need to estimate seven parameters: δ, the depreciation rate of capital, λ, the equity issuance cost parameter, ξ, the collateral parameter, and γ, the adjustment cost parameter, as well as μ, ρ, and σ, the mean, serial correlation, and standard deviation of the driving process for $\ln(z)$.

For our first, moments-based estimation, we need at least seven moments to estimate these seven parameters. We choose the means and variances of the four variables in our model: investment, leverage, net equity payout, and operating profits. This choice produces an overidentified model by one degree of freedom.

For our second, EPF-based estimation, we use a second-order polynomial approximation to the policy functions. Specifically, we regress the three policy variables—net leverage, net distributions to shareholders, and investment—on second-order polynomials in the two lagged state variables—net leverage and operating profits. Thus, each regression contains six parameters: an intercept, the two coefficients on the linear terms, the two coefficients on the quadratic terms, and the coefficient on the interaction term. With three empirical policy functions, we end up with an $m(\cdot)$ vector that contains 18 elements, which overidentifies the model by 11 degrees of freedom. In both the moments-based and the EPF-based estimation, the weight matrix for measuring the distance between the simulated and data moments is the inverse of the clustered covariance matrix of either the moments or the OLS policy function coefficients.

Panel A of Table 2.2 presents the parameter estimates from the two estimations. Several general patterns emerge. First, with the exception of the equity issuance cost parameter, λ, all of the coefficients are statistically significantly different from one another across the two estimations, and many pairs of coefficients are also economically different. For example, the collateral parameter, ξ, is 50% higher in the EPF-based estimation, and the shock variance, σ, is almost 30% higher in the EPF-based estimation. These sharp differences are to be expected, as our stylized model is much simpler than the typical model used in the literature.

One result in particular highlights the usefulness of the two different benchmarks for identifying parameters. The large standard error on the estimate of the equity issuance cost, λ, in the moments-based estimation means that few of the moments change significantly with λ. Indeed, only the mean and variance of net distributions change with this parameter, and the effects are small. In general, poor parameter identification results in larger standard errors. In turn, larger standard errors imply that parameter values far from the point estimates produce largely the same set of estimated benchmarks as the actual point estimates themselves.

In Panel A of Table 2.2, we also present results from two specification tests: the standard test of overidentifying restrictions and the external validity test given by Equation (2.25). In the case of the moments-based estimator, the moments used for the external validity test are the empirical policy function coefficients, and in the case of the EPF-based estimator, the moments used for the external validity test are the moments used in the moments-based estimator. Both tests show that the model is strongly rejected. Again, this result is to be expected, as we are dealing with an oversimplified and thus naturally misspecified model. This result is also important, as it foreshadows the result from our Monte Carlo exercises that these two specification tests have excellent power to detect even small amounts of model misspecification.

In Panel B of Table 2.2, we compare the model-implied simulated moments from the moments-based and EPF-based estimations. The first column contains the data moments used in the traditional moments-based estimation. The second and third columns contain the simulated moments from the traditional moments-based estimation and the *t*-statistics for the difference between the data and simulated moments—that is, the *t*-statistic for the model error. The next two columns contain analogous estimates and test statistics for our EPF-based estimation, so these two columns represent an external validity test of the model in the EPF-based estimation.

In Panel B of Table 2.2, we find large *t*-statistics on nearly all of the moment conditions. These large figures stem from two sources. The first is the highly stylized nature of this particular model. Second, because the *t*-statistics are proportional to the square root of the sample size, a large sample size of over 100,000 implies precisely estimated moments. Next, we usually find smaller *t*-statistics on the external validity moment conditions for the EPF-based estimation than on the moment conditions that are actually used for the moments-based estimation. Intuitively, one would expect external validity tests to reject more strongly, so this result at first glance seems odd. However, the result can be explained by the observation that the estimated parameters and the simulated moments inherit the sampling variability of the benchmarks used to estimate them, whether the benchmarks are moments or estimates of empirical policy functions. Because regression coefficients are typically estimated with less precision than means in an i.i.d. cross section, the simulated moments from the EPF-based estimation have more sampling variability and consequently are associated with lower *t*-statistics.[5]

[5] We have also done a symmetric analysis with the coefficients of the estimated policy functions. Because the results are largely similar, we omit them.

2.4 Monte Carlo Simulations

Although indirect inference estimators are asymptotically consistent and can be efficient within a class of minimum distance estimators, little is known about their finite sample properties, which need not mirror their asymptotic properties. This section describes a set of Monte Carlo experiments that assess the finite sample performance of the indirect inference estimators that we have discussed and used so far. We design these experiments as follows. Each Monte Carlo is based on 1,000 simulated data sets,[6] in which the data are simulated from the actual (not estimated) policy functions that characterize the solution to the model in Section 2.1. We consider two sample sizes for our simulated data. The first has a length of 8 and a cross-sectional width of 9,375, for a total size of 75,000. These dimensions are slightly smaller than those of our actual data. We also consider a small sample size, with a length of 8 and a cross-sectional width of 125, with a total size of 1,000.

We create our simulated samples as follows. First, we choose values for four key parameters: the depreciation rate, δ, the cost of equity issuance, λ, the collateral parameter, ξ, and the convex investment adjustment cost parameter, γ. To make the Monte Carlo simulations relevant to our application, we set these parameters equal to the estimates from the EPF-based estimation in Table 2.2. Because estimations with more parameters take more time, to keep the Monte Carlo tractable, we treat the parameters that govern the process for z (μ, σ, and ρ) as known, again setting them to the estimates from the EPF-based estimation in Table 2.2. We then solve

[6] Because one estimation of a model takes several hours, larger numbers of Monte Carlo trials, which are typical in many simulation studies, are infeasible.

the model to obtain the policy functions and simulate 1,000 different data sets from the policy functions. Most of our analysis is based on simulations in which we estimate the same model that generated the data, so the null hypothesis underlying these experiments is that the model is true. Later we examine the performance of the estimators when the model used to simulate the data differs from the model used for estimation.

We consider two weight matrices: the optimal clustered weight matrix and an identity weight matrix, which is popular in the macroeconomics and asset pricing literatures that focus on the calibration of models. For each of these weight matrices, we then estimate the model using both traditional moments and empirical policy functions as benchmarks.

From an ex ante perspective, the choice of weight matrix is not obvious, as neither weight matrix necessarily puts the most weight on features of the data that might be of the most economic interest in any particular application. For example, although the optimal weight matrix minimizes overall model error by (roughly) putting the most weight on the most precisely estimated moments, these particular moments need not be the most relevant to the economic questions addressed by the model. The use of identity weight matrices confers a different disadvantage, as identity weight matrices have the unfortunate property that they mechanically put the most weight on the moment that is largest in absolute value. Similarly, minimizing the percent difference between the moments mechanically puts the most weight on the smallest moment in absolute value. It is hard to imagine an economic objective that coincides with either of these mechanical objectives. This perspective lies in contrast to the advice given in *Cochrane* (2005) regarding the use of an identity matrix in tests of asset pricing models. However, this advice makes sense in the context of minimizing pricing errors because the returns on different portfolios are typically all of the same order of magnitude. In contrast, moments used in a corporate finance simulated moments exercise can be of very different magnitudes, as can the regression coefficients that define an empirical policy function, so an identity matrix can end up mechanically emphasizing uninteresting moments. In the end, because there is no obvious ex ante choice, the consideration of the finite sample properties of these two weight matrices is of particular interest.

2.4.1 Baseline results

Table 2.3 shows the results from our first Monte Carlo simulation, where we set the sample size to 75,000. For each parameter we estimate, and for each method we use, we report the mean bias, the root mean squared error (RMSE), and the probability of rejecting a nominal 5% test of the null hypothesis that the parameter equals its true value. Bias and RMSE are both expressed as a percentage of the true parameter.

Three notable results stand out. First, both the moments-based and EPF-based estimators produce largely unbiased parameter estimates, regardless of the weight matrix we use. Second, except for the case of the equity issuance cost, λ, all estimators have extremely low RMSEs. Even the slightly higher RMSEs for λ are not large. For example, the RMSE for the moments-based estimator with the identity weight matrix is only 3.14% of the true parameter value of 0.235. Third, using a clustered weight matrix produces estimators with lower bias and RMSE for both the moments-based and EPF-based estimators.

These results are interesting in that they are the only extant evidence on the finite sample performance of the sorts of simulation estimators used in corporate finance. And the evidence is encouraging. If the model is correctly specified, as it is here, then the estimates from these simulation methods have both low finite-sample bias and variance. Intuitively, this good performance stems from two sources. First, the parameter estimates inherit the sampling variation of the moments and OLS regression coefficients used in the estimation, and these simple benchmark statistics are themselves precisely estimated in finite samples. Second, the mappings from the moments to the parameters are in most cases steep, with the one exception again being the estimators for λ. Equation (B.1) in the Appendix shows that this weak mapping should be evident in the parameter standard error, which, for λ, exceeds the parameter value itself on average (not reported).

The evidence on the finite sample performance of the t-tests associated with each of these parameters is somewhat less encouraging. First, only in a few instances do we find that the actual rejection rates of these tests approach the nominal 5% values. Second, for the parameter λ, these tests almost never produce a rejection, again because of the large standard errors associated with this parameter. Third, the tests associated with the identity weight matrices tend to reject the null much more often than the tests associated with the clustered weight matrix. For example, for the EPF-based estimator of the collateral parameter, ξ, the t-test rejection rate is 0.019 when we use the optimal weight matrix, but the rejection rate rises to 0.359 when we use an identity weight matrix. We conjecture that the often higher rejection rates for the tests associated with the identity weight matrix are due to the inevitable inaccuracy in the numerical gradients used to calculate the parameter standard errors. Inspection of the indirect inference variance formula given by Equation (B.1) in the Appendix reveals that small errors in the gradient can be compounded to reduce the estimator variance. In contrast, the estimator variance expression in Equation (B.2) in the Appendix is less likely to suffer from this problem, as it derives from the optimal weight matrix

Next we turn to the results in Table 2.4 from a similar Monte Carlo simulation in which the sample size is set at 1,000. In this case, we again find that the estimates of all of the parameters are nearly unbiased, and that the estimators that use the optimal weight matrix outperform those that use the identity weight matrix. However, the substantially smaller sample size results in much higher RMSEs.

From comparing Tables 2.3 and 2.4, we can conclude that the indirect inference estimators used in the estimation of dynamic models produce highly accurate parameter estimates when the model is correctly specified. We can also conclude that inference about the parameter estimates is much less accurate, especially in small samples, and especially in the case of a diagonal weight matrix. The high rates of test rejection imply that the *t*-statistics associated with the parameter estimates in Table 2.2 need to surpass critical values higher than the usual 1.96 threshold for a nominal 5% test.

Table 2.5 presents additional results from the two simulations, specifically, the performance of various specification tests associated with the moments-based and EPF-based estimators. We examine three tests, all of which are given in the Appendix. The first is the standard test of the overidentifying restrictions of the model, which is given by Equation (B.4) in the case of the diagonal weight matrix or Equation (B.5) in the case of the optimal weight matrix. The second is the external validity test given by Equation (2.25). As in the data analysis in Section 2.3, for the moments-based estimator, the external validity moments are the empirical policy function coefficients, and for the EPF-based estimator, the external validity moments are the moments used in the moments-based estimator. The third test is a t-test of the null hypothesis that an individual element of the benchmark vector $g(\boldsymbol{v}_{it}, \theta)$ equals zero. For brevity, instead of reporting rejection rates for each element of $g(\boldsymbol{v}_{it}, \theta)$, we report the minimal, median, and maximal rejection rates across all of the moments (or empirical policy function coefficients) used in the estimation.

The results in Table 2.5 show that the performance of all of these test statistics is much better when the estimation uses an optimal weight matrix. For both the large and small sample size, and for both the moments-based estimator and the EPF-based estimators, the external validity test and the overidentification test over-reject strongly when the estimation employs an identity weight matrix. This result is intuitive because estimations that use an identity weight matrix essentially put the most weight on benchmarks (moments or policy function coefficients) that are largest in absolute value. This objective clearly fails to coincide with the sensible objective of these tests, which is to detect overall model error, in which, roughly speaking, precisely estimated benchmarks are given more weight than imprecisely estimated benchmarks. Thus, we naturally observe large rejection rates when the weight matrix is an identity matrix.

In contrast, when we look at the estimators that use the clustered weight matrix, the actual size of most of the specification tests is within ten percentage points of the 5% nominal size. The one notable exception is the external validity test in the case of the moments-based estimator. This result makes intuitive sense. The intercept and slope coefficients from the empirical policy functions implicitly contain all of the information in the means and variances of the policy variables. However, they also contain information about covariances, which the moments-based estimator does not use. Thus, it is no surprise that the moments-based estimator cannot match the policy coefficients but that the converse holds—that is, the EPF-based estimation can match the moments.

Table 2.5 also shows the closeness of the nominal and actual sizes of most of the t-tests for the null hypotheses that the elements of $g(v_{it}, \theta)$ equal zero. This relatively good performance is evident even for the estimators that use an identity weight matrix.

Figures 2.2 and 2.3 add texture to the results in Table 2.5 by examining the distributions of three specification test statistics: the test of overidentifying restriction, the external validity test, and the test of overidentifying restrictions evaluated at the true parameters. Figure 2.2 shows the results from the simulation with the large sample size of 75,000. On the y-axis of each plot is the percentile over all Monte Carlo trials of each chi-squared statistic. On the x-axis is the theoretical percentile of that statistic, which has an asymptotic chi-squared distribution. If the Monte Carlo distribution of the chi-squared statistic equals its theoretical distribution, then the simulated and theoretical percentiles should plot along the 45-degree line. If the tests over-reject (under-reject), then the simulated and theoretical percentiles should plot below (above) the 45-degree line.

Panel A of Figure 2.2 considers the moments-based estimator. In the case of both the optimal weight matrix and the identity weight matrix, if we evaluate the model at the true parameter vector, the overidentification test statistic has a chi-squared distribution, as it should. This result is intuitive in that this Monte Carlo experiment isolates sampling variation. In the estimation with an optimal weight matrix, the test of overidentifying restrictions for the model evaluated at the estimated parameters is close to its theoretical distribution. However, the external validity test deviates sharply. This deviation is driven by a large fraction of extremely large test statistics, with 50% of the simulated statistics lying near the 100th percentile of the theoretical chi-squared distribution. In the estimation with an identity weight matrix, both the overidentification test and the external validity tests exhibit deviations from the 45-degree line, with both tests over-rejecting strongly.

Panel B presents the results for the EPF-based estimator. As expected, given the results in Table 2.5, all of the tests associated with the estimator that uses the optimal weight matrix plot near the 45-degree line. However, for the identity weight matrix, we again find a large fraction of the tests statistics near the one-hundredth percentile of the theoretical distribution.

Figure 2.3 presents analogous results for the simulation with a small sample size of 1,000. While these results largely mirror those in Figure 2.2, there is one important difference. Even when the model is evaluated at the true parameters, the actual percentile of the overidentification test statistic fails to mirror the theoretical percentile, and this pattern is more pronounced for the EPF-based estimator. Intuitively, sampling variation in the actual estimation of the data moments is more important with a small sample size. Moreover, estimating empirical policy functions requires more data than estimating moments, so the extra sampling variation adds noise to the specification test statistics.

In conclusion, the good performance of many of these tests appears unusual, given the well-documented tendency of tests associated with GMM estimators to over-reject in finite samples (*Hansen et al.*, 1996; *Shanken and Zhou*, 2007). We attribute the good performances of these estimators to two factors. The first is the large sample size, which is not a feature of many time-series asset pricing or macroeconomics applications. The second and more important factor is the weight matrix. Because the data and parameters are additively separable in Equation (2.21), it is possible to estimate the optimal weight matrix without knowledge of the parameter vector. This separability property is also a feature of a small number of GMM applications, including asset pricing applications based on minimizing pricing errors and the estimators in *Erickson and Whited* (2002). Interestingly, these latter estimators also have good finite sample properties.

2.4.2 Test power

In all of the simulations discussed above, the model we estimate is the same as the one that generates the data. In other words, we have examined the properties of the simulation estimators we consider under the maintained hypothesis that the model is correct. However, models are by nature misspecified. Therefore, we next examine whether the specification tests that accompany simulation estimators have power to detect misspecification.

In order to assess the power of different benchmarks to detect model misspecification, we perform a second set of Monte Carlo simulations in which we simulate data sets from a misspecified model but then estimate the model in Section 2.1. The misspecified model adds a cost of debt issuance to the model in Section 2.1, so if $p' - p > 0$ and $p' > 0$, then the firm must pay an issuance cost equal to $c \min(p' - p, p')$. To calculate a power curve for each of the tests we consider, we let c take eight evenly spaced values between 0.0025 and 0.04, performing a separate Monte Carlo simulation for each value. For each of these simulations, we calculate the power of three tests: the standard overidentification test, the external validity test, and the test from *Nikolov and Whited* (2014) that an element of $g(\boldsymbol{v}_{it}, \theta)$ from the correctly specified model ($c = 0$) equals the corresponding element from the misspecified model ($c > 0$). For brevity, instead of reporting rejection rates for each element of $g(\boldsymbol{v}_{it}, \theta)$, for these latter tests we report the maximum, median, and minimum test rejection rates.

Figure 2.4 presents the results for the EPF-based estimator for the large sample size of 75,000. Strikingly, the test of overidentifying restrictions has excellent power to detect even small amounts of misspecification. The power of the test shoots up to 1 even when the issuance cost is at the lowest level we consider, 0.0025. Although the external validity test does not exhibit such striking behavior, it nonetheless has good power to detect misspecification, with the rejection rates of 0.7 and 0.9 for issuance costs of 0.02 and 0.04. Finally, the t-tests for the individual elements of $g(v_{it}, \theta)$ also have good power, with the median and maximum rejection rates spiking to 1 even for small issuance costs up to 0.02. Even the minimum rejection rate eventually reaches 1 when the issuance cost is 0.04.

Figure 2.5 presents analogous results for the moments-based estimator for the large sample size of 75,000. Here, we observe somewhat lower power for the overidentification test and for the moment t-tests. Mirroring the results in Table 2.5, the external validity test over-rejects strongly even under the null, so the strong over-rejection away from the null is not surprising.

2.5 Robustness

Monte Carlo simulations have the obvious drawback that they pertain only to a specific parameter constellation for a specific model. To address this issue, we consider several extensions to our basic setup. In particular, we consider using additional moments in our moments-based estimation, an alternative transformation of the state variables in the EPF-based estimation, and a richer specification of the baseline polynomial approximation to the empirical policy function. Finally, we consider two alternate models: one adds fixed costs of capital adjustment to the basic constant-returns model in Section 2.1, and the other augments this baseline mode by allowing for decreasing returns to scale.

First, we explore the result from Table 2.5 of the poor performance of the external validity test of the moments-based estimator. Our intuition for this result is that the moments-based estimation does not contain any of the covariances that define the empirical policy function estimates, so the parameters from the moments-based estimation struggle to replicate the empirical policy function coefficients. The question naturally arises whether adding covariance terms to the moments-based estimation can improve the performance of the external validity test. To address the question, we add three covariances to the moment list: $\text{cov}(i, p)$, $\text{cov}(i, d)$, and $\text{cov}(p, d)$. This exercise also addresses the result from Tables 2.3 and 2.4 of the inferior performance of the moments-based estimator relative to the EPF-based estimator. Our intuition for this last result is that the lack of covariance moments in the moments-based estimation implies less identifying information to allow for precise parameter estimation.

In the first column of Table 2.6, we report the results of a Monte Carlo simulation of this augmented moments-based estimator. Here, we have gathered the parameter recovery and test size results into one table. All results are from estimators with a clustered weight matrix and a sample size of 75,000. Interestingly, for each parameter, the RMSE for this parameter lies between those for the moments-based and EPF-based estimators reported in Table 2.3. This result confirms our intuition concerning the identifying information in the extra moments. We also find that although the external validity test again over-rejects, the rejection rate is not as high as the 0.843 rate reported in Table 2.5. We conclude that adding these extra moments goes part of the way toward improving the performance of this test. However, because we are not adding all of the extra moments that define the empirical policy function estimates, this improvement is incomplete relative to the rejection rate of 0.079 for the EPF-based external validity test reported in Table 2.5.

Second, we consider using a more flexible approximation to the policy function. As discussed above, the issue at hand is whether using a closer-fitting approximation to the policy function improves finite sample performance. On the one hand, a better fit ought to be able to better capture the dynamic interactions between the policy variables and thus be better able to identify the economic model parameters. On the other hand, closer-fitting approximations imply more auxiliary parameters to estimate and are thus likely to be higher variance, which in turn compromises identification of the economic model parameters.

Due to computational constraints, we can consider only a simple extension of our quadratic approximation of the empirical policy functions, specifically, the addition of third-order terms to the polynomial expansion in Equation (2.20). The results from this Monte Carlo simulation are in the second column of Table 2.6. The bias and RMSE figures for all parameters are slightly smaller than those in Table 2.3 from the EPF-based estimator with a clustered weight matrix and a second-order approximation to the policy function. Moreover, the sizes of both the t-tests and specification tests are closer to the nominal 5% value than the corresponding sizes in Tables 2.3 and 2.5. These results imply that for this simple extension, the improved accuracy of the policy function approximation improves finite sample performance.

Third, we explore the robustness of the EPF-based estimator to an alternative reparameterization of the policy and state variables. This issue is of interest for models in which the primitive state variables are unobservable and in which one must work with observable transformations of these unobservable variables. Although this issue is not relevant for our simple constant-returns model, we nonetheless consider a state variable transformation that has been widely used in the corporate finance literature. Specifically, instead of considering profitability and net debt (z and p), we express the empirical policy functions in terms of profitability and net worth: z and $\xi(1-\delta)+z-p$ (*Cooley and Quadrini*, 2001; *Hennessy and Whited*, 2007; *Li et al.*, 2016). This transformation is of particular interest because model parameters appear in the expression for net wealth, just as a parameter appears in the transformation that we describe for a decreasing returns model below. The results from using this alternative transformation are in the third column of Table 2.6, where we find that the results are nearly identical to those from Table 2.3.

Next, we consider the possibility that the policy function might have sharp discontinuities. In particular, we augment our model from Section 2.1 to allow for the presence of fixed costs of capital adjustment that take the form of $\chi\mathcal{I}(i \neq 0)$. This model feature creates a sharp discontinuity in the policy function that relates investment, i, to the profit shock, z. The optimal investment policy is zero below a threshold for z, with a jump to a higher level of investment when z surpasses the threshold. Considering policy functions with discontinuities is of interest for two reasons. First, many models that have been studied in the literature contain similar nonconvexities (e.g., *Cooper and Haltiwanger*, 2006). Second, and more importantly, the presence of a discontinuity might hinder parameter identification if the empirical approximation to the policy function does not capture the effects of the discontinuity.

To explore this possibility, we start with our baseline model from Section 2.1 and calibrate the fixed-cost parameter χ at 0.025, which puts the jump in the policy function at the mean of z and sets the height of the jump at just over the depreciation rate. This setting implies that many large investment bursts associated with the policy function discontinuity occur in the simulated data, so the discontinuity is empirically relevant. We then perform a Monte Carlo simulation of two EPF-based estimators. Both use the optimal clustered weight matrix, but one uses a second-order approximation to the policy function, while the other uses a third-order approximation.

The results are in Table 2.7, where we report statistics for the four parameters in Table 2.3, as well as for the fixed-cost parameter, χ. For the second-order EPF-based estimator, we find near-zero bias and low RMSEs for all parameters, including χ. For the third-order EPF-based estimator, we find even smaller bias and RMSE figures for all parameters, including the bias and RMSE for χ.

The low bias and RMSEs for both of these EPF-based estimators at first appear counterintuitive, as neither a second- nor a third-order polynomial can typically capture a sharp discontinuity. However, nonconvexities in the optimization problem affect many other features of the policy function besides the obvious kink. For example, fixed investment adjustment costs affect the level of leverage and the response of investment to profitability. As long as these other features of the policy function are sufficient for parameter identification, then a tight-fitting policy function approximation need not be necessary. This finding reinforces the intuition in *Gourieroux et al.* (1993) that the auxiliary model for indirect inference (the EPF approximation in our case) does not need to be a perfectly accurate description of the true distribution of the data. Instead, the auxiliary model simply needs to capture enough features of the data to identify the economic model parameters.

Finally, we consider an alternative model that augments the model from Section 2.1 by allowing for decreasing returns to scale. Specifically, we consider a production function that takes the form $zK^{\alpha}, \alpha < 1$. In this case, one cannot reduce the dimension of the state space by dividing all variables by K, so the state variable z is an unobservable shock. Therefore, to estimate this alternative model using the EPF-based estimator, we need to work with observable transformations of the state and control variables. For consistency with our earlier results, we use the natural transformation $\boldsymbol{w} = \{I/K, P'/K'\}$ and $\boldsymbol{x} = \{P/K, zK^{\alpha}/K\}$. Finally, we simplify the process governing z by setting the mean of the log process, μ, to zero. This specification is standard in the literature (e.g., *Gomes*, 2001; *Hennessy and Whited*, 2005).

Using this model in our Monte Carlo simulations is interesting for two reasons. First, the dimension of the state space is larger, and it is worth investigating whether the dimension of the state space matters for estimator performance. Second, models based on decreasing returns technology are much more widely used in the literature than models based on constant returns technology. Indeed, they are a workhorse in the macroeconomics and corporate finance literatures (e.g., *Gomes*, 2001; *Hennessy and Whited*, 2005), so a Monte Carlo based on this class of models is of broad interest.

In order to calibrate the Monte Carlo simulations, we need a baseline model parameterization, which we obtain by estimating the model using our second-order EPF-based estimator. For brevity, we do not report the full estimation results, but Table 2.8 lists the parameters, all of which are significantly different from zero in our estimation. Table 2.8 also contains the results from two Monte Carlo simulations, where we consider a moments-based estimator and a second-order EPF-based estimator, both of which use a clustered optimal weight matrix. For these Monte Carlos, we only estimate four of the model parameters, treating α, σ and ρ as given. In addition, computational constraints limit us to considering only 100 trials.

Even when we use the more elaborate decreasing returns model, Table 2.8 shows that the performance of both estimators is nearly identical to the performance documented in Table 2.3 for the constant returns model. In particular, the large RMSE for the moments-based estimator of the issuance cost parameter, λ, and the external validity test over-rejection for the moments estimator are qualitatively similar across the two tables. This similarity arises because mapping from moments or policy function coefficients to the underlying structural parameters is similar in these two classes of models. For example, average leverage (or the intercept in the debt policy function) maps strongly into the collateral parameter, ξ, in both models.

2.6 Conclusion

This paper contributes in three ways to the methods that help us understand the interface between models and data. First, we assess the finite sample properties of popular simulation estimators in a setting relevant to researchers who use micro data to evaluate dynamic models. The results are mostly positive. The estimators produce unbiased coefficient estimates, and when we use an optimal weight matrix for the estimation of the model parameters, the specification tests associated with the estimator and the t-tests associated with the parameter estimates are close to correctly sized. Most importantly, the specification tests associated with the simulation estimators we consider have excellent power to detect misspecification. Given the paucity of work on the finite sample properties of simulation estimators, these results provide important guidance to applied researchers interested in using these estimators.

Second, we introduce a specification test that holds dynamic models to a high standard by assessing their ability to reconcile features of the data not used in their estimation. We find that this test can over-reject for a simple moments-based estimator but that it is close to correctly sized in the case of our EPF-based estimator. In this case, it also has excellent power.

Third, we introduce a set of statistical benchmarks to use for the quantitative evaluation of dynamic models. The benchmarks are empirical policy functions—that is, the empirical counterparts of the policy functions from these models. We argue that these benchmarks are intuitive, robust, and theoretically motivated. We then demonstrate how to use these benchmarks as a basis for the estimation of model parameters using indirect inference.

The biggest advantage of using empirical policy functions as a basis for the estimation of dynamic models is discipline. In particular, the use of policy functions alleviates the common concern with using data moments that moments can be cherry-picked to steer the estimation results a certain way. Another advantage is that policy functions characterize the solutions to all dynamic models, so using them as benchmarks for evaluation makes sense from an economic perspective. The combination of these two advantages implies that estimators based on empirical policy functions can be used to compare models, as long as the models describe the same policies.

Model comparison has been a neglected feature of the evaluation of dynamic models. Although many studies (e.g., *Whited*, 1992; *Kadiyali et al.*, 2001; *Nikolov and Whited*, 2014) compare nested models, few compare nonnested models that describe similar policy variables. We therefore view using empirical policy function benchmarks to compare both nested and nonnested models as a natural extension of the research we have presented here.

	Mean	SD	10%	Median	90%
Net book leverage	0.189	0.169	-0.009	0.190	0.383
Operating income/assets	0.142	0.090	0.044	0.141	0.243
Market-to-book ratio	1.587	0.700	0.954	1.523	2.252
Investment/assets	0.077	0.057	0.026	0.071	0.133
Net distributions/assets	0.001	0.076	-0.040	0.003	0.060
Observations	111,902				

Table 2.1: **Summary statistics: State and control variables.** This table provides summary statistics for the state and control variables in this paper. The sample is drawn from Compustat, covering an unbalanced panel of 111,902 firm/year observations from 1971 to 2015. All variables have been demeaned at the firm level, with the overall sample mean added back in, so standard deviations and percentile ranges reflect within-firm variation. Precise variable definitions are given in Section 2.3.1.

Panel A: Parameters

Parameter	Moments-based	EPF-based
μ	−2.2067	−2.0455
	(0.0236)	(0.0019)
ρ	0.8349	0.8200
	(0.0003)	(0.0013)
σ	0.3594	0.4497
	(0.0211)	(0.0012)
δ	0.0449	0.0665
	(0.0011)	(0.0001)
γ	29.9661	21.5488
	(2.6340)	(0.2225)
ξ	0.3816	0.6181
	(0.0038)	(0.0043)
λ	0.1829	0.2350
	(1.2196)	(0.0282)
Overidentifying χ^2 *p*-value (d.f.)	0.000 (1)	0.000 (11)
External validity χ^2 *p*-value (d.f.)	0.000 (18)	0.000 (8)

Panel B: Moments

	Data	Moments-based		EPF-based	
		Simulated	*t*-statistic	Simulated	*t*-statistic
Mean leverage	0.1886	0.1774	6.5603	0.1984	−2.8716
Variance leverage	0.0285	0.0225	33.6700	0.1110	−68.6243
Mean investment	0.0768	0.0600	60.6440	0.0809	−6.0456
Variance investment	0.0033	0.0002	67.1409	0.0007	41.2507
Mean distributions	0.0012	0.0124	−107.1251	0.0020	−1.0780
Variance distributions	0.0058	0.0026	86.1149	0.0010	45.5955
Mean profits	0.1421	0.1325	285.1138	0.1689	−24.3985
Variance profits	0.0081	0.0070	22.3168	0.0170	−38.3895

Table 2.2: **Estimations of trade-off model with different benchmarks.** Panel A contains parameter estimates from a trade-off model using two different benchmarks: traditional moments and empirical policy functions (EPFs). Indirect inference is performed by minimizing the (inverse covariance matrix weighted) distance between the simulated values of each set of benchmarks and the corresponding values found in Compustat. Clustered standard errors are in parentheses under the parameter estimates, and degrees of freedom are in parentheses next to the specification test statistic *p*-values. μ is the (log) mean of the productivity process, and ρ and σ are the serial correlation and residual standard deviation of this process. δ is the depreciation rate of capital, γ is the investment quadratic adjustment cost, ξ is the collateral value of capital, and λ is the linear equity issuance cost. In Panel B, the first column presents the data estimates used in the traditional moments-based estimation. The second and third columns contain the simulated moments from the traditional moments-based estimation, along with the *t*-statistics for the difference between the actual and simulated moments. The next two pairs of columns contain analogous results for the two EPF-based estimations.

Parameter	Moments-based Identity	Moments-based Clustered	EPF-based Identity	EPF-based Clustered
δ (depreciation rate)				
Average % bias	0.123	-0.006	-0.021	-0.001
RMSE %	0.608	0.047	0.059	0.010
$\Pr(t)$	0.605	0.367	0.309	0.348
λ (equity issuance cost)				
Average % bias	0.598	-0.165	1.793	-0.047
RMSE %	3.141	1.477	2.662	0.875
$\Pr(t)$	0.001	0.002	0.001	0.003
ξ (collateral parameter)				
Average % bias	-0.189	-0.299	-0.308	0.035
RMSE %	0.790	0.659	1.997	0.110
$\Pr(t)$	0.117	0.277	0.359	0.019
γ (investment adjustment cost)				
Average % bias	-0.239	0.027	0.052	0.007
RMSE %	1.273	0.106	0.127	0.022
$\Pr(t)$	0.313	0.135	0.115	0.100

Table 2.3: **Monte Carlo comparison of simulation estimators: Large sample size.** Indicated expectations and probabilities are estimates based on 1,000 Monte Carlo samples of size 75,000. The samples are generated from the model in Section 2.1. We consider two different benchmarks: traditional moments and empirical policy functions. Both estimators use a clustered weight matrix. For each parameter, we report three statistics. Bias is expressed as a fraction of the true coefficient value. RMSE indicates root mean squared error and is also expressed as a fraction of the true coefficient. $\Pr(t)$ is the fraction of the time we observe a nominal 5% rejection of the null hypothesis that a parameter equals its true value using a t-test.

Parameter		Moments-based Identity	Moments-based Clustered	EPF-based Identity	EPF-based Clustered
δ (depreciation rate)					
	Average % bias	0.848	0.183	0.055	-0.005
	RMSE %	1.685	0.360	0.230	0.099
	$\Pr(t)$	0.891	0.487	0.344	0.501
λ (equity issuance cost)					
	Average % bias	-0.851	0.779	-2.715	0.504
	RMSE %	6.414	3.623	6.878	3.046
	$\Pr(t)$	0.019	0.000	0.001	0.001
ξ (collateral parameter)					
	Average % bias	-1.841	-0.027	-3.065	-0.060
	RMSE %	4.220	2.843	5.917	1.867
	$\Pr(t)$	0.087	0.042	0.317	0.191
γ (investment adjustment cost)					
	Average % bias	-1.719	-0.381	-0.093	0.023
	RMSE %	3.443	0.761	0.482	0.208
	$\Pr(t)$	0.834	0.203	0.159	0.180

Table 2.4: **Monte Carlo comparison of simulation estimators: Small sample size.** Indicated expectations and probabilities are estimates based on 1,000 Monte Carlo samples of size 1,000. See Table 2.3 for definitions.

	Moments-based		EPF-based	
	Identity	Clustered	Identity	Clustered
Sample size = 75,000				
Overidentification test rejection rate	0.558	0.048	0.825	0.083
External validity test rejection rate	0.985	0.843	0.668	0.079
Moment *t*-statistics:				
maximum rejection rate	0.317	0.022	0.354	0.024
median rejection rate	0.132	0.012	0.056	0.010
minimum rejection rate	0.000	0.005	0.000	0.005
Sample size = 1,000				
Overidentification test rejection rate	0.470	0.081	0.719	0.116
External validity test rejection rate	0.973	0.713	0.607	0.417
Moment *t*-statistics:				
maximum rejection rate	0.288	0.049	0.397	0.047
median rejection rate	0.066	0.026	0.116	0.000
minimum rejection rate	0.000	0.014	0.000	0.000

Table 2.5: **Monte Carlo comparison of specification tests.** Indicated expectations and probabilities are estimates based on 1,000 Monte Carlo samples of sizes 75,000 and 1,000. The samples are generated from the model in Section 2.1. The moments-based estimator minimizes the distance between simulated and data moments. The EPF-based estimator minimizes the distance between policy functions estimated from simulated data and those estimated from real data. We report the fraction of trials that produce a nominal 5% rejection of three additional tests. The first is the test of the model overidentifying restrictions. The second is our external validity test, which has two varieties. For the EPF-based estimator, it is a chi-squared test of the null hypothesis that the moments equal their true values. For the moments-based estimator, it is a chi-squared test of the null hypothesis that the policy function slopes equal their true values. The third is a *t*-test on individual moment conditions. For these tests, we report the highest, median, and lowest rejection rates.

Parameter	Extra covariance moments	High-order EPF-based	Transformed EPF-based
δ (depreciation rate)			
Average % bias	-0.002	0.001	0.000
RMSE %	0.029	0.004	0.007
Pr(t)	0.288	0.188	0.275
λ (equity issuance cost)			
Average % bias	0.068	-0.014	-0.200
RMSE %	1.210	0.429	0.857
Pr(t)	0.001	0.007	0.001
ξ (collateral parameter)			
Average % bias	-0.009	-0.012	0.012
RMSE %	0.240	0.044	0.101
Pr(t)	0.030	0.019	0.017
γ (investment adjustment cost)			
Average % bias	0.016	0.001	0.004
RMSE %	0.067	0.007	0.017
Pr(t)	0.101	0.055	0.077
Overidentification test rejection rate	0.071	0.090	0.097
External validity test rejection rate	0.710	0.081	0.086
Moment t-statistics:			
maximum rejection rate	0.028	0.015	0.030
median rejection rate	0.014	0.009	0.006
minimum rejection rate	0.011	0.004	0.005

Table 2.6: **Monte Carlo comparison of simulation estimators: Covariance moments, high order EPFs, and transformed EPFs.** Indicated expectations and probabilities are estimates based on 1,000 Monte Carlo samples of size 75,000. The samples are generated from the model in Section 2.1. We consider three model extensions. For the first, we add extra covariance moments to the moments-based estimator. For the second, we consider a third-order polynomial approximation to the empirical policy function. For the third, we consider an alternative transformation of the state variables in the EPF-based estimator. All estimators use a clustered weight matrix. Bias and RMSE are expressed as fractions of the true coefficient. See Tables 2.3 and 2.5 for definitions.

Parameter	Second-order EPF-based	Third-order EPF-based
δ (depreciation rate)		
Average % bias	-0.003	-0.000
RMSE %	0.009	0.003
$\Pr(t)$	0.025	0.057
λ (equity issuance cost)		
Average % bias	-0.144	0.063
RMSE %	1.111	0.566
$\Pr(t)$	0.011	0.083
ξ (collateral parameter)		
Average % bias	-0.006	-0.000
RMSE %	0.008	0.005
$\Pr(t)$	0.064	0.033
γ (investment adjustment cost)		
Average % bias	-0.061	-0.000
RMSE %	0.089	0.007
$\Pr(t)$	0.030	0.030
θ (fixed adjustment cost)		
Average % bias	0.116	0.004
RMSE %	0.180	0.008
$\Pr(t)$	0.032	0.040
Overidentification test rejection rate	0.049	0.107
External validity test rejection rate	0.016	0.043
Moment t-statistics:		
maximum rejection rate	0.011	0.017
median rejection rate	0.005	0.005
minimum rejection rate	0.001	0.000

Table 2.7: **Monte Carlo comparison of simulation estimators: Model with fixed adjustment costs.** Indicated expectations and probabilities are estimates based on 1,000 Monte Carlo samples of size 75,000. The samples are generated from the model in Section 2.1, with one addition. We allow for the presence of fixed costs of capital adjustment that take the form of $\chi\mathcal{I}(i \neq 0)$. We consider two different benchmarks: a second-order approximation to the empirical policy function and a third-order approximation. Both estimators use a clustered weight matrix. Bias and RMSE are expressed as fractions of the true coefficient. See Tables 2.3 and 2.5 for definitions.

Parameter		Moments-based	EPF-based
δ (depreciation rate)			
	Average % bias	-0.048	0.004
	RMSE %	0.076	0.025
	$\Pr(t)$	0.010	0.060
λ (equity issuance cost)			
	Average % bias	-2.448	-0.745
	RMSE %	3.275	1.492
	$\Pr(t)$	0.000	0.020
ξ (collateral parameter)			
	Average % bias	-0.012	-0.005
	RMSE %	0.036	0.019
	$\Pr(t)$	0.120	0.050
γ (adjustment cost)			
	Average % bias	1.293	-0.081
	RMSE %	1.768	0.594
	$\Pr(t)$	0.010	0.040
	Overidentification test rejection rate	0.210	0.080
	External validity test rejection rate	0.910	0.170
	Moment t-statistics:		
	maximum rejection rate	0.310	0.040
	median rejection rate	0.065	0.015
	minimum rejection rate	0.010	0.000

Table 2.8: **Monte Carlo comparison of simulation estimators: Decreasing returns to scale model.** Indicated expectations and probabilities are estimates based on 1,000 Monte Carlo samples of size 75,000. The samples are generated from the model in Section 2.1, with two modifications. We allow for decreasing returns to scale, with the profit function curvature given by α. We also omit investment adjustment costs. We consider two different benchmarks: traditional moments and empirical policy functions. Both estimators use a clustered weight matrix. Bias and RMSE are expressed as fractions of the true coefficient. See the captions to Tables 2.3 and 2.5 for definitions.

True estimated parameter values: $\delta = 0.144$, $\xi = 0.521$, $\gamma = 2.173$, and $\lambda = 0.014$.

True fixed parameter values: $\alpha = 0.528$, $\rho = 0.297$, and $\sigma = 0.489$.

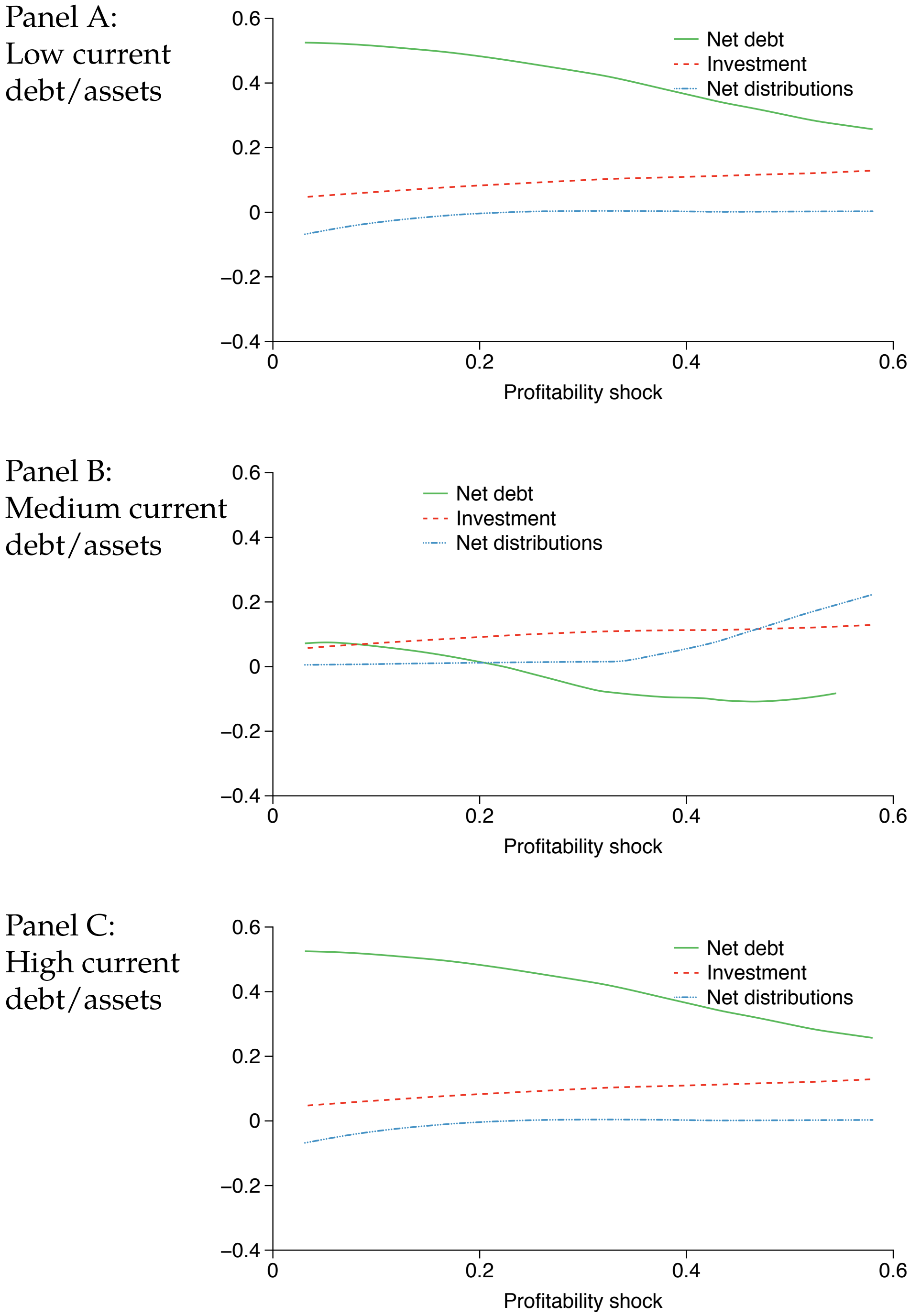
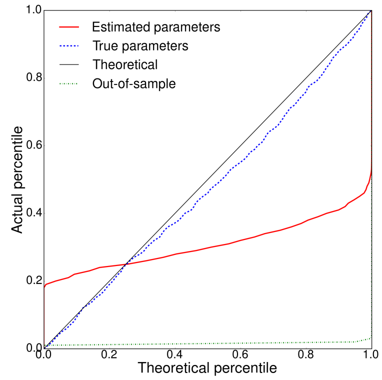


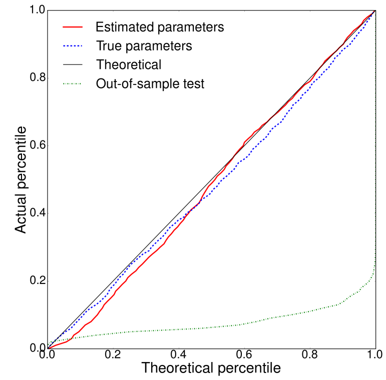
Figure 2.1: **Theoretical policy functions.** This figure plots optimal next-period net debt/capital, investment/capital, and net distributions/capital as a function of the profitability shock. Each panel is drawn for a different level of current debt/assets: low, medium, and high.

Panel A:
Moments-based
estimation

Identity weight matrix

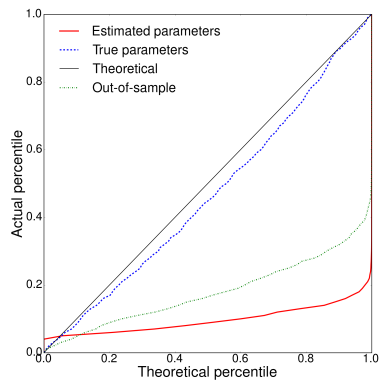


Optimal weight matrix



Panel B:
EPF-based
estimation

Identity weight matrix



Optimal weight matrix

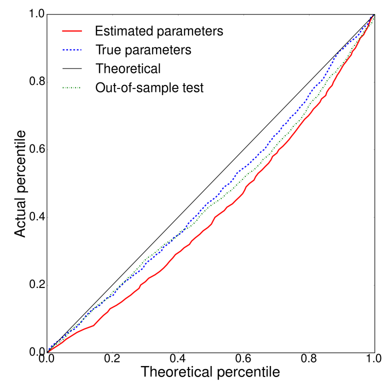


Figure 2.2: **Distribution of chi-squared test statistics: Large sample size.** Indicated probabilities are estimates based on 1,000 Monte Carlo samples of size 75,000. The samples are generated from the model in Section 2.1, and estimation uses both an identity and a clustered weight matrix. On the y-axis of each plot is the percentile over all Monte Carlo trials of each chi-squared statistic. On the x-axis is the theoretical percentile of that statistic. If the Monte Carlo distribution of the chi-squared statistic equals its theoretical distribution, then the simulated and theoretical percentiles should plot along the 45-degree line. We show three statistics. The first is a test of overidentifying restrictions when the model is evaluated at the true parameter vector. The second is the standard test of overidentifying restrictions using the estimated parameter vector, which we refer to as the minimizing parameters. The third has two varieties. For the moments-based estimator, it is a chi-squared test of the null hypothesis that the policy function slopes equal their true values. For the EPF-based estimator, it is a chi-squared test of the null hypothesis that the moments equal their true values.

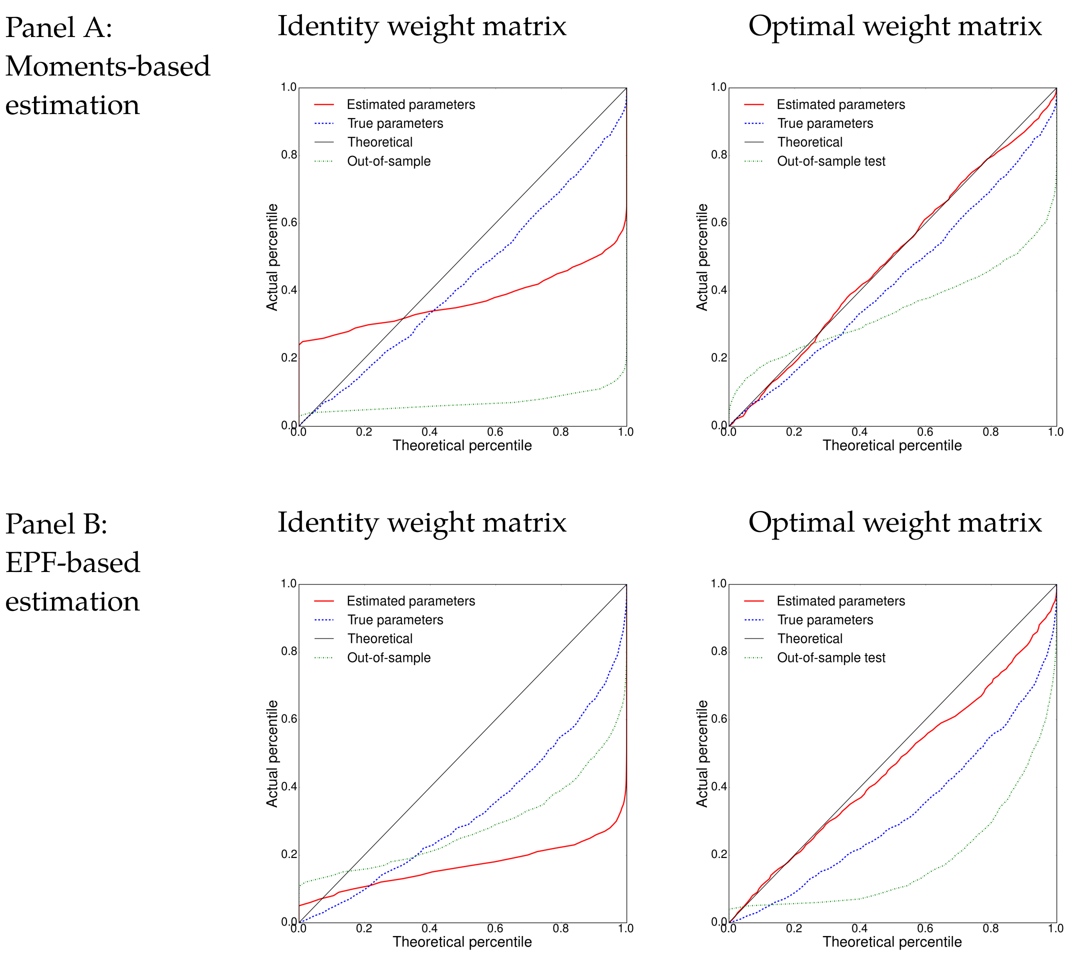
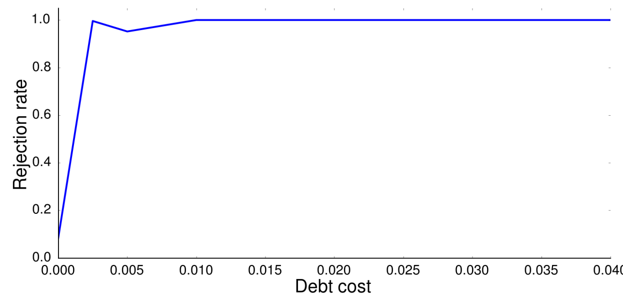
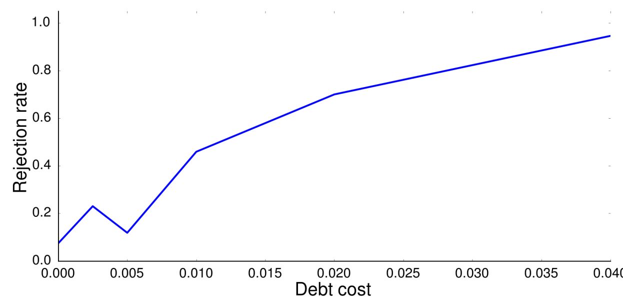


Figure 2.3: **Distribution of chi-squared test statistics: Small sample size.** Indicated probabilities are estimates based on 1,000 Monte Carlo samples of size 1,000. The samples are generated from the model in Section 2.1, and estimation uses both and identity and a clustered weight matrix. On the y-axis of each plot is the percentile over all Monte Carlo trials of each chi-squared statistic. On the x-axis is the theoretical percentile of that statistic. If the Monte Carlo distribution of the chi-squared statistic equals its theoretical distribution, then the simulated and theoretical percentiles should plot along the 45-degree line. We show three statistics. The first is a test of overidentifying restrictions when the model is evaluated at the true parameter vector. The second is the standard test of overidentifying restrictions using the estimated parameter vector, which we refer to as the minimizing parameters. The third has two varieties. For the moments-based estimator, it is a chi-squared test of the null hypothesis that the policy function slopes equal their true values. For the EPF-based estimator, it is a chi-squared test of the null hypothesis that the moments equal their true values.

Panel A:
Overidentification test



Panel B:
External validity test



Panel C:
Individual policy function slope test

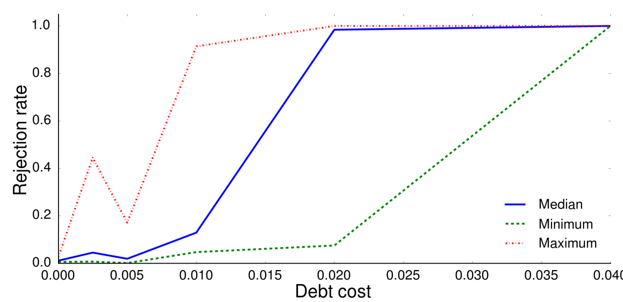
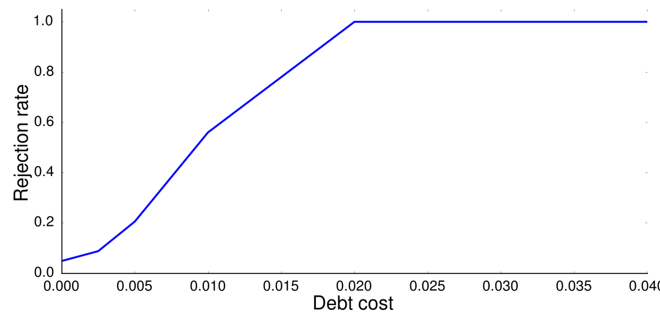
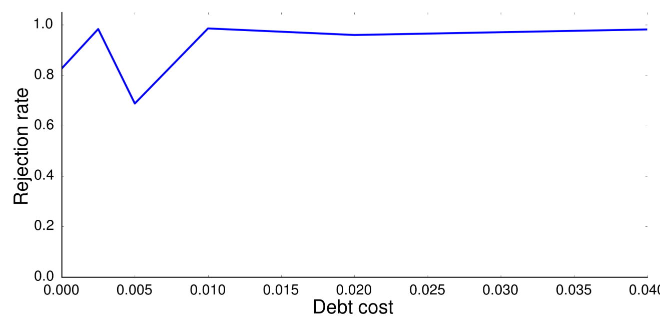


Figure 2.4: **Specification test power in the EPF-based estimators.** Indicated probabilities are estimates based on 1,000 Monte Carlo samples of size 75,000. The samples are generated from the model in Section 2.1, with a proportional cost of debt issuance, c. On the x-axis of each panel is the parameter c. On the y-axis is the rejection rate for the relevant test. All estimations use empirical policy functions as benchmarks. Panel A shows the actual size of a nominal 5% test of the model overidentifying restrictions, where the data are generated for a model in which $c > 0$, but the model is estimated as if $c = 0$. Panel B shows the actual size of a nominal 5% test of an external validity test whose null is that the moments (which are not used in the estimation) equal their true values. Panel C shows the power of the test from *Nikolov and Whited* (2014) that a policy-function slope from a model estimated with $c > 0$ equals the same policy-function slope from a model in which c is restricted to zero. We report the maximum, median, and minimum rejection rates across our set of policy function slopes.

Panel A:
Overidentification test



Panel B:
External validity test



Panel C:
Individual moment test

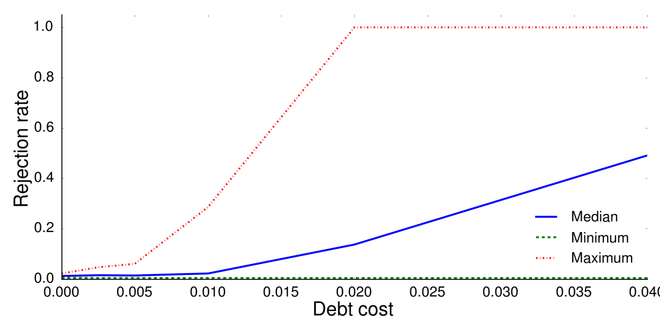


Figure 2.5: **Specification test power in the moments-based estimators.** Indicated probabilities are estimates based on 1,000 Monte Carlo samples of size 75,000. The samples are generated from the model in Section 2.1, with a proportional cost of debt issuance, c. On the x-axis of each panel is the parameter c. On the y-axis is the rejection rate for the relevant test. All estimations use moments as benchmarks. Panel A shows the actual size of a nominal 5% test of the model overidentifying restrictions, where the data are generated for a model in which $c > 0$, but the model is estimated as if $c = 0$. Panel B shows the actual size of a nominal 5% test of an external validity test whose null is that the moments (which are not used in the estimation) equal their true values. Panel C shows the power of the test from *Nikolov and Whited* (2014) that a moment from a model estimated with $c > 0$ equals the same moment from a model in which c is restricted to zero. We report the maximum, median, and minimum rejection rates across our set of moments.

CHAPTER III

Corporate Taxation, Investment, and the Return on Safe Assets

3.1 Introduction

Since at least *Modigliani and Miller* (1958), economists in corporate finance have been interested in the effect of taxes on corporate financing and investment. While corporate finance has long recognized that taxes on financial flows such as interest income and dividends potentially affect corporate capital structure, rising corporate savings have renewed interest in how taxes influence corporate savings behavior. But, despite the context of persistently low interest rates offered by government debt since 2000, little attention has been paid to how these changes in taxes might influence interest rates.

This paper examines how taxes on corporations jointly affect their real decisions and the returns on different types of assets. I apply the equilibrium model of *Kahn* (2019). The model features a segmented market for safe debt securities, which households receive convenience utility from holding. Both the government and firms can issue these debt securities, but despite their risk-neutral preferences firms' ability to issue debt in response to differences in the expected after-tax return on debt and equity is limited by a precautionary motive to preserve debt capacity. As a result, expected after-tax returns on debt and equity differ in equilibrium, as a function both of the demand from consumers for debt and the limited ability of corporations to arbitrage returns between debt and equity. In this context, taxes have two effects. The first is to alter the trade-offs between debt and equity that consumers and firms face. The second is to alter the supply of debt directly by changing the government's revenue, and therefore their issuance of debt.

The results show sizable effects of tax changes on both returns and corporations' real decisions. I consider two types of tax changes: increases in the dividend tax and reductions in the tax on interest income. When the government uses the increased revenues from taxing income to back new issuance of safe debt, I find that increasing the dividend tax can lead to positive effects on consumption and investment while increasing interest rates. However, when tax revenue is used to reduce lump-sum taxes on households, the interest rate increases only slightly while driving consumption and investment down. Decreasing the taxation of interest income while decreasing debt, on the other hand, has no effect on after-tax interest rates but increases consumption. The results suggest that both the size of government debt and the method of taxation used to back the government's issuance of this debt are important determinants of the macroeconomic effects of fiscal policy on firms' financing and investment. Having presented these baseline results, I then turn to how market segmentation from firms and consumers affects equilibrium outcomes, first by varying the costs of financial shortfalls firms face and second by varying households' demand for safe assets. Finally, I discuss the importance of limited pledgeability in my results.

In the main, this paper is a straightforward extension of my work in *Kahn* (2019). In that paper, I emphasized that when firms have a precautionary demand for safe assets, increases in government borrowing can lead to increases in investment through decreasing the costs of firms' precautionary savings. However, that paper was silent on what limits the size of government debt. Here, I impose additional discipline on the problem by requiring that increases in the government's steady state debt be met by increasing distortionary taxes on firms to repay this debt. This paper therefore speaks to the relationship between government taxation, interest rates and investment in models of incomplete financial markets. In a wide range of models which have followed *Aiyagari* (1994), government taxation plays a similar dual role as I emphasize here: first, providing a savings technology to the private sector, and second, altering the decisions of firms. However, these models have focused on the precautionary demand for debt securities from households, whereas my model focuses on the precautionary demand from firms.

A closer point of comparison is *Holmström and Tirole* (2011), which like my paper emphasizes the needs of firms for the liquidity services which government debt provides. In their model, as in my work in *Kahn* (2019), the government provides these liquidity services through lump sum taxes levied on consumers. Dead-weight losses of taxation incurred in repaying the government's debt constitutes the only cost to larger government borrowing in their model. However, the source of this dead-weight loss is left unmodeled. By integrating realistic taxation explicitly into a model of firms' liquidity demand, I am able to deliver more explicit policy prescriptions not only for the amount of debt the government should provide to the corporate sector, but also for the method of taxation it should use to back this debt.

In addition to the contributions above *Kahn* (2019), this paper contributes to a literature on the consequences of government taxation of firms for investment and corporate financing. Though the entirety of this literature is too extensive to review, *Graham* (2003) provides a detailed overview from a corporate finance perspective. In particular, I examine the effects of taxes on dividends and interest income on equilibrium rates of return on safe assets.

My first contribution is to the literature on taxation of firms' equity. The literature on taxation of firms' equity has generally split into two camps: a "new view" and an "old view", both of which are reviewed by *Sinn* (1990). Under the new view, as in *King* (1977), *Auerbach* (1983) and *Bradford* (1981), taxation of dividends and capital gains has little effect on firm investment since firms fund their investment out of retained earnings. Under the old view, as in *Harberger* (1962), *Feldstein* (1970) and *Poterba and Summers* (1983), the marginal source of funds is new equity, and taxation of dividends and capital gains has a direct effect on investment and firm value.

Heterogeneity in firms' financial positions means that, as in *Gourio and Miao* (2010), my model presents a mix of views, where corporate financing decisions are endogenously determined by their investment needs. My paper expands on their work along two dimensions: first, I examine a model where firms have a precautionary demand for debt capacity, and second, I consider dividend taxes in the context of segmented markets for debt and equity. In the presence of both these frictions, changes in the dividend tax will affect both returns and real corporate decisions. In equilibrium, these frictions then lead to both quantitatively and qualitatively different predictions for the effect of dividend taxes on consumption than appear in *Gourio and Miao* (2010). In particular, I find that low but positive values of dividend taxation can increase consumption while decreasing interest rates, but only so long as the increased revenue from taxation is used to back new debt issuance. This result emphasizes the importance of considering how the government changes its other tax behavior along with the increase in the dividend tax, an area that has received relatively less attention.

A related literature focuses on the tax advantage given to debt through interest income tax deductibility, and cost of cash holding induced by the tax on interest income. The closest relative to my paper in this vein is *Li et al.* (2016), who specify a dynamic contracting problem with limits to corporations' pledgeability and where issuance of debt securities is tax deductible. In contrast, my model features a limited set of securities that corporations can issue and hold where the returns between different assets are determined by their relative supply. As with their paper I find that the tax on interest income has little effect on corporate decisions. The logic for the near irrelevance of taxes on interest income in my paper is simple: a reduction in taxes on interest income increases the effective return to private agents from holding debt, and so increases demand for debt. But when the government issues new debt using their higher tax revenue, the increased demand is met with supply. The result, at least in my baseline equilibrium, is a wash: taxation of interest income has no effect on investment or financing behavior, only on pre-tax returns.

Finally, this paper focuses on the role of firms' precautionary savings in the relationship between taxation, rates of return and investment. This links my paper to a set of papers in corporate finance which examine the role of taxes in high cash holdings and corporate savings since 2000. In particular, *Faulkender et al.* (2017) examines changes in the effective tax rate on corporate cash holdings due to their benefit in avoiding repatriation taxes, while *Armenter and Hnatkovska* (2011) and *Chen et al.* (2017) emphasize changes to the dividend tax. I extend these studies by examining the consequences of these distortions for aggregate investment and interest rates. While I find a limited role for taxes on interest income, I find a pronounced role for taxes on dividends. In particular, at my model estimates, declines in taxes on dividends lead to a decrease in the equilibrium interest rate, a decrease in investment and a decrease in consumption. The results I present are therefore consistent with the literature which links increases in corporate savings since 2000 to decreases in the taxation of dividends, and provides a further link between decreases in the taxation of dividends and low rates of return on safe assets over this period.

3.2 An equilibrium model of corporate taxation and rates of return

I now present my model of corporations' financial decisions, investment and rates of return in an equilibrium characterized by segmentation in the market for safe debt. The model is presented more formally in *Kahn* (2019). My goal here is to be brief and give the intuition behind the model clearly. I first present the financing and investment problem of firms, and then discuss household demand for safe assets, which I model in reduced form. The final agent in the model is the government, which takes taxes from firms and households and uses this revenue to back their issuance of safe debt to the private sector. In equilibrium, returns must be set so that the safe debt holding of the household and of firms is either backed by the pledgeable portion of corporate capital or by future government surpluses. Having presented this equilibrium, I then turn to discussing firms' optimal financial decisions, and then proceed to the tax policy counterfactuals which motivate this paper.

3.2.1 Firms

The focus of this paper is on taxes on the corporate sector. As such, I establish a relatively rich model of corporate financing and investment, while leaving the household sector in a reduced form. There is a continuum of firms, each of which is ex-ante homogeneous, but all of which differ in their history of idiosyncratic productivity shocks. Firms face a variety of taxes, including dividend taxes (τ_d), taxes on interest income (τ_i), and taxes on corporate profits, (τ_c). Limited pledgeability means that firms cannot fully arbitrage differences in expected after-tax returns on debt and equity these tax rates induce, while the idiosyncratic risk of their physical capital and costs of equity issuance mean that they prefer to preserve their debt capacity, and are thus even more hesitant to adjust capital structure.

For simplicity, I will discuss the problem of an individual firm and then turn to the distribution of firms. Each firm's profitability, z_t, follows an auto-regressive process:

$$\log z_{t+1} = \chi \log z_t + \epsilon_{t+1}$$

where $\epsilon_{t+1} \sim (0, \sigma)$ is an idiosyncratic shock to their profitability. Subject to this idiosyncratic shock, firms produce output using capital and a decreasing returns to scale production function $\pi(z_t, k_t)$. Firms choose capital for tomorrow, k_{t+1} today, before their profitability shock is observed. Capital depreciates gradually, and is subject to adjustment costs, so that the full cost of investment $I_{t+1} = k_{t+1} - (1-\delta)k_t$ is:

$$I_t + \phi(k_t, I_t) = I_t + \phi_0 1_{|I_t|>0} k_t + \frac{\phi_1}{2}\left(\frac{I_t}{k_t}\right)^2$$

where ϕ_0 is a fixed adjustment cost and ϕ_1 is a quadratic adjustment cost on capital.

3.2.1.1 Financing and value

Firms have access to two securities markets to finance their investment. The first is an equity market, with a risk-neutral required return, ρ. The second is a safe debt market, which has a pre-tax required return r. The firm takes these returns as given, but in equilibrium they will be determined by the supply and demand for each asset from firms, households and the government. The tax treatment of debt and equity matter for corporations decisions: equity is subject to dividend taxation, while the safe debt holdings of the firm are taxed, and interest paid on safe debt issued by the firm is tax deductible.

Firms' financing is subject to two forms of financial frictions. First, limits on safe debt issuance due to pledgeability, and second, costs of equity issuance. For the purposes of the model, I assume all cash is held in safe assets, and all debt issued by the firm is safe, so that the net safe asset holding can be either positive (more cash than safe debt) or negative (more safe debt than cash). Safe debt issuance is limited by the pledgeability of capital:

$$-a_{t+1} \leq \theta k_{t+1}$$

Limited pledgeability implies that the firm will not be able to issue infinite debt in order to meet demand from households. Optimal capital structure is also determined by costs of issuing equity. Like net debt, equity flows can be positive (which I will assume represents payments of dividends) or negative (equity issuance). The cost of issuance has fixed and variable components, λ_0 and λ_1. Specifically, to issue e dollars of equity costs the firm:

$$\Lambda(e) = \frac{\lambda_0 + \lambda_1 e}{1 - \lambda_1}$$

dollars of internal funds. As a result of these financing costs, firms will never issue equity and pay dividends in the same period.

The cash flow identity of the firm reflects the fact that any financing above revenues this period must be obtained from issuing debt or equity. These funds are then used for investment, purchases of safe debt, dividends, or payments of adjustment and equity issuance costs:

$$(1-\tau_c)\pi_t + \delta\tau_c k_t + a_t = I_t + \left(\frac{1}{1+(1-\tau_i)r}\right)a_{t+1} + e_t - \Lambda(e_t) + \phi(k_t, I_t) \qquad (3.1)$$

This identity reflects the taxation of corporate income at a rate τ_c, as well as the tax exemptions afforded to depreciation expenditures.

Both income and financial flows are subject to taxes. For simplicity, I model the rate of taxation on safe debt as linear so that interest income is subject to the same tax rate as the rate at which interest expense is tax deductible, τ_i. This tax deductibility may differ from the rate at which corporate income is taxed, τ_c, to separate taxes on financial flows from those on profits accruing to physical capital. Finally, I treat dividends as being taxed at a rate τ_d, implicitly assuming that all payments to equity holders are in the form of dividends instead of repurchases.

The firm acts to maximize the value of its equity, taking the returns on safe debt and equity as given. The after-tax return on debt is $(1-\tau_i)r$, while I abstract from capital gains taxes so that the after-tax and pre-tax required return on equity are simply ρ. Therefore, the firm solves:

$$
\begin{aligned}
V(z,k,a) = \max_{e,I,a',k'} \quad & (1-\tau_d 1_{e>0})\, e + \frac{\mathrm{E}\left[V(z',k',a')|z\right]}{1+\rho} \qquad (3.2)\\
\text{such that} \quad & (1-\tau_c)\pi_t + \delta\tau_c k_t + a_t = I_t + \left(\frac{1}{1+(1-\tau_i)r}\right) a_{t+1} + e_t - \Lambda(e_t) + \phi(k_t, I_t)\\
& k' = (1-\delta)k + I\\
& -a' \le \theta k'
\end{aligned}
$$

This problem has no closed form solution, and so I solve it using value function iteration. In addition to the value function, this process yields a policy function $[k', a'] = g(s)$ where $s = [z, k, a]$.

3.2.1.2 Distribution of firms

For a given set of taxes and rates of return on safe debt and equity, I examine a steady-state distribution of firms. The solution to (3.2) yields a policy function which transforms states $s = [z, k, a]$ to choice variables, $[k', a', e] = g(s)$. Given returns on debt and equity, the cross-sectional distribution of firms over their state, $\Upsilon(s)$ must satisfy:

$$\Upsilon(s) = \int 1_{[k',a'] \in g(s)} P(z'|z)\ d\Upsilon(s)$$

This yields aggregate quantities:

1. Total payouts: $E = \int e(s)\ d\Upsilon(s)$.

2. Total corporate cash holding: $A = \int a(s)\ d\Upsilon(s)$.

3. Investment: $I = \int I(s)\ d\Upsilon(s)$.

4. Output: $Y = \int \pi(k, z)\ d\Upsilon(s)$.

5. Adjustment costs: $\Phi = \int \phi(k'(s) - (1-\delta)k(s), k(s))\ d\Upsilon(s)$.

3.2.2 Households

The household sector chooses between equity and debt securities to maximize their utility. I assume that the household receives utility from their bond holdings beyond their value in transferring income from today to tomorrow. As a result, the required rates of return on equity and debt will differ due to the different returns on these assets. The spread between these required returns will depend on the relative supply of both assets in equilibrium.

For simplicity, I model the sector using an infinitely lived, representative household, who maximizes their lifetime utility of consumption, C_t and debt securities, D_t, by choosing their debt holdings D_t and holdings of equity in each firm s_i. Following , I assume that households receive utility from the convenience of holdings of debt securities, D_t such that their utility is $U(CD^{\omega})$. The household maximizes lifetime utility:

$$\sum_{t=0}^{\infty} \beta^t U(C_t D_{t+1}^{\omega})$$

In maximizing this utility, the household takes the returns on debt and equity securities as given, and chooses their asset holdings and consumption. Households receive income from their holdings of firms' equity, corporate and government debt securities, and are subject to lump sum taxes $\bar{\tau} Y$. In steady state, their budget constraint is:

$$C = \int (1 - \tau_d) e(s) 1_{e(s)>0} - (1 + \lambda) e(s) 1_{e(s)<0} + (1 - \tau_i) r D - \bar{\tau} Y$$

As a result of households' preference for debt securities, debt will command a lower return than equity in equilibrium. For households to hold an equity asset in a steady state equilibrium, the asset must command an after-tax return, ρ equal to their discount rate. On the other hand, households are willing to hold debt securities so long as the required after tax return is:

$$(1 - \tau_i) r = \frac{1}{\beta} - 1 - \omega \frac{C}{D} = \rho - \omega \frac{C}{D}$$

Crucially, for households to be willing to hold a greater amount of debt securities households, the return on debt must rise. Note that in the absence of convenience utility, for both debt and equity to be held by consumers in equilibrium it must be that $\rho = (1 - \tau_i) r$, eliminating the after-tax liquidity premium. With convenience utility, the return on debt must always fall below the return on the firm in equilibrium. In a market where debt securities could be freely issued backed by equity, corporations would thus issue an infinite amount of debt to households drive this return difference to zero. However, as above the corporate sector is limited in their issuance of safe debt by pledgeability, and actually wishes to preserve debt capacity themselves for precautionary purposes.

3.2.3 Government

There are two sources of safe debt securities in the model: corporations and the government. While the corporate sector issues safe debt securities by pledging their capital, the government issues debt by pledging their future tax revenue. Implicitly, I assume that the government can pledge the entirety of their future surpluses, as a result of their unique ability to tax and enforce contracts. As a result, higher taxes allows the government to issue greater debt securities backed by higher surpluses, which households and corporations can use to meet their demand for debt securities.

Government debt, B, is a claim to future surpluses. The government has three sources of income: taxes levied on corporations, $\tau(s)$, taxes on households' interest income, $\tau_i rD$, and other taxes, $\bar{\tau}Y$, which I assume are levied on households in a lump-sum fashion. The total tax bill is thus:

$$S = r\tau_i D + \int \tau(s) d\Upsilon(s) + \bar{\tau}Y$$

Because the focus of this paper is on taxes on corporations, I will assume that $\bar{\tau}$ is fixed. This keeps the lump sum behavior of the government in proportion to output, preventing scale effects in the size of the government relative to other sectors.

To ensure that the government the transversality condition holds with positive steady-state government borrowing, the present value of the government's future surpluses, discounted at the safe rate, must be equal to the market value of government debt B:

$$B = \frac{S}{r}$$

This can be thought of as a condition which ensures that debt held by corporations and households is fully backed by future tax revenue. Simply put, each period the government issues claims to their surpluses next period. When holders of government bonds approach the government for repayment, the government pays out of its tax revenue next period, or by borrowing from another group of private agents. This borrowing is sustainable so long as the value of debt issued by the government represents the present discounted value of its surpluses, discounted at a rate which represents the use of these surpluses in meeting liquidity demand. The interest rate, r, on government debt is determined in equilibrium by the supply and demand for debt securities in the segmented market in which they trade. Note that this implies that, all else equal, an increase in tax revenues, for instance by increasing $\bar{\tau}$, will decrease returns on debt.

3.3 Equilibrium

For the purposes of this paper, it suffices to state the equilibrium in this economy as follows:

1. Given the returns on debt and equity, the steady state distribution of firms is consistent with the policy rules that solve the firm's problem as well as the laws of motion for capital and productivity.
2. Households are indifferent between a marginal dollar of debt and consump-

tion: $\rho = \frac{1}{\beta} - 1$

3. Households are indifferent between a marginal dollar of debt and equity: $(1 - \tau_i)r = \rho - \frac{D}{C}$

4. All debt issued by firms and the government must be held by households: $D + A = B$.

5. The goods market clears: $Y = C + I + \Phi + \bar{\tau}Y$.

6. Government debt is backed by tax revenue: $B = \frac{S}{r}$.

Substituting the goods market clearing condition into the household's budget constraint, we arrive at a straightforward description of consumption:

$$C = \int e(s) - ra(s)d\Upsilon(s)$$

This condition simply reflects the fact that all production is pursued by firms, and lump sum taxes appear in the government's balance sheet. Household consumption is then simply net flows from firms. Higher cash holdings reduce these flows, all else equal, since they represent lower net claims on the part of households.

3.3.0.1 Firm policies under taxation

I turn to examining the first-order conditions of firms for debt issuance and capital investment. For simplicity, I examine the case where there are no fixed-costs of equity issuance and no adjustment costs on capital. Firms' choice of debt issuance is determined by the benefits of a dollar of marginal funds today versus tomorrow, the relative returns on debt and equity, tax treatments of both assets, and the ability of the firm to issue debt. The first-order conditions reflect these incentives:

$$1-\tau_d+(\lambda_1+\tau_d)1_{e>0}-\gamma_{b\leq\theta k}=\frac{1+(1-\tau_c)r}{1+\rho}(1-\tau_d+(\lambda+\tau_d)\,\mathrm{P}\,(e'<0)))$$

where $\gamma>0$ is a multiplier on the firms' collateral constraint.

Firms in the model can be in one of three positions: *financially constrained*, issuing equity while unable to issue further debt, *limited in arbitrage*, paying dividends while unable to issue further debt, or *indifferent*, paying dividends while not constrained in debt. For firms who are financially indifferent, the cost of a marginal dollar of internal funds today is directly offset by the benefit of a dollar tomorrow:

$$\frac{\rho-(1-\tau_c)r}{1+r}=\left(\frac{\lambda_1+\tau_d}{1-\tau_d}\right)\mathrm{P}\,(e'<0) \tag{3.3}$$

For all other firms, the pledgeability constraint is binding. Firms who are financially constrained use equity to meet their investment needs, while firms who are arbitraging use capital to increase the dividends they pay, effectively buying back a high return security using a low return security. Note that taxes on interest income raise firms' after-tax cost of holding safe assets, while dividend taxes increase precautionary needs by making financial shortfalls relatively more costly.

Firms' investment policy depends on which of these three positions they find themselves in. To make this point concretely, I examine the decision of the firm with respect to the marginal product of capital, transformed to reflect the relative after-tax liquidity benefit of capital:

$$\tilde{R}_K = \left(\frac{1-\tau_d + (\lambda+\tau_d)1_{e'<0}}{1-\tau_d + (\lambda_{\tau d})\,\mathrm{P}\,(e'<0)}\right)\alpha z' k'^{\alpha-1}$$

Firms who are indifferent between debt and equity invest at a rate:

$$(1-\tau_i)r + (1-\tau_c)\delta = \mathrm{E}\left[\tilde{R}_K\right]$$

For firms who are financially constrained, the first-order condition for investment is:

$$(1-\theta)\rho + \theta(1-\tau_i)r + (1-\tau_c)\delta + \frac{(\lambda+\tau_d)(1-\mathrm{P}\,(e'>0)\,(1-\theta)(1+\rho)}{1-\tau_d+(\lambda+\tau_d)P(e'>0)} = \mathrm{E}\left[\tilde{R}_K\right]$$

Finally, for firms who are limited in arbitrage:

$$(1-\theta)\rho + \theta(1-\tau_i)r + (1-\tau_c)\delta - \frac{(\lambda+\tau_d)\,\mathrm{P}\,(e'>0)\,(1-\theta)(1+\rho)}{1-\tau_d+(\lambda+\tau_d)P(e'>0)} = \mathrm{E}\left[\tilde{R}_K\right]$$

Three things are important to note. First, examining a firm who faces the same probability of becoming financially constrained tomorrow, firms who are indifferent between debt and equity invest more than other firms. Second, the effect of dividend taxes: as dividend taxes increase, it drives the cost of capital of firms who are financially constrained down, while the cost of capital of firms who are arbitraging increases. This result is intuitive. For arbitrageurs, the marginal source of funds is dividends. As taxes on dividends increase, the attractiveness of dividends today decreases, and investment increases. For financially constrained firms, the marginal source of funds is equity issuance. As taxes on dividends increase, the value of dividends tomorrow falls. The firm thus invests less in capital.

These first-order conditions present an illustrative example of how dividend and interest income taxation affect firms' decisions. The presence of heterogeneity means it matters which state firms find themselves in. This decision endogenously links financing and investment decisions, and complicates analysis based solely on these first-order conditions. Additionally, in the full model I employ I also include fixed and quadratic adjustment costs on capital and fixed costs of equity issuance. More importantly for my story, the equilibrium of the model presents a limited supply of debt securities to the household sector, which means that general equilibrium effects from the production of safe assets using taxes are important for understanding the effect of taxation on equilibrium outcomes. As such, I now turn to the parameterization of the model, and calculation of counterfactual equilibria.

3.4 Effect of taxes in the baseline parameterization

In the context of this equilibrium model, I consider changes to the tax treatment of dividends and interest income, as well as changes to the corporate tax rate and tax on capital gains. To match the magnitude of tax cuts, I consider a limited set of counterfactuals. In particular, I consider setting dividend taxes to their pre-2003 levels of 0.25 and eliminating the taxation of interest income. I employ the parameter estimates from *Kahn* (2019). These estimates are most appropriate for considering the effects of tax changes on short-term cash holding and safe debt. Below I discuss the effects of higher levels of pledgeability, which may represent a

Parameter	Value
Production parameters	
Returns to scale, α	0.773
Depreciation rate, δ	0.148
Standard deviation of profitability, σ	0.172
Persistence of profitability, χ	0.8367
Fixed adjustment cost, γ_0	0.015
Quadratic adjustment cost, γ_1	0.846
Financing parameters	
Household discount factor, β	0.172
Fixed equity issuance cost, λ_0	0.994
Linear equity issuance cost, λ_1	0.086
Pledgeability of capital, θ	0.001
Household preference for safe assets, ω	0.011
Return on safe assets, r	0.015

Table 3.1: **Parameter estimates from *Kahn* (2019).** Parameters are taken from the estimation performed in *Kahn* (2019). Note that I exclude the empire building parameter in this paper from my parameterization.

larger class of securities for which there is segmented demand.

In the baseline counterfactuals I show in Table 3.2, I consider the case where corporate taxes are changed but the share of lump-sum taxes are held constant. The first column shows baseline results from the counterfactual. I display returns on safe debt, equity and capital, and also percent changes in output, consumption and investment. To indicate the effect of changing taxes on equilibrium capital structure, I also show the ratio of household safe asset holdings to consumption (D/C) and of corporate leverage ($-A/V$). Since the baseline parameterization is from an environment where cash holdings are greater than short-term debt, corporate leverage is initially negative.

The second column shows the effects of eliminating the taxation of interest income. Eliminating this taxation does not effect either pre-tax rates of return or corporate decisions on investment and financing. However, consumption rises and the rate of return on safe assets falls. The intution for this result is simple. So long as the return on safe assets falls to exactly offset the decrease in the tax rate, corporations and households will remain indifferent between old and new after-tax returns, so the equilibrium can be sustained. But what about the supply of safe assets? Rewriting the market clearing condition for safe debt, we find:

$$(1-\tau_i)r(D+A) = \tau_D E + \tau_c(Y-\delta I) + \bar{\tau} Y$$

The decline in government tax revenues from interest income is therefore matched by an increase in the safe rate, representing larger costs of interest payments made by the government. However, the decline in the return on safe assets lowers the cost of the provision of liquidity for firms, which is born by households because they provide the tax revenues which allow for safe debt provision to firms. As such, consumption rises when the return on safe assets falls. Figure 3.2 shows the results for different ranges of taxes on interest income, over which the effects are uniform.

The effects of dividend taxation are more complex. As reviewed above, the effect of dividend taxes on firms' financing is to reduce their reliance on equity financing, and encourage them to save more. If the government kept the present

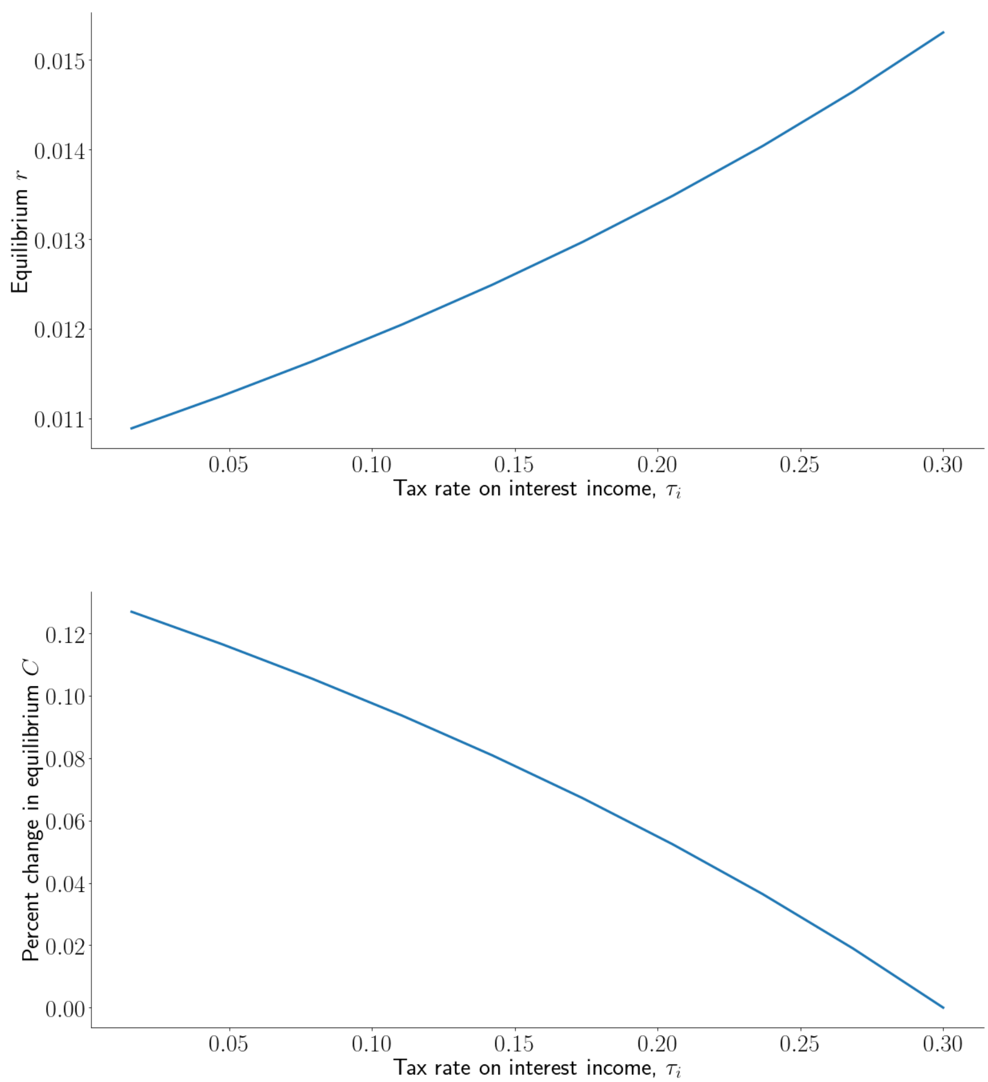


Figure 3.2: **Effect of taxes on interest income on equilibrium.** This figure shows the effect of alternative interest income taxes on consumption and the equilibrium interest rate on safe assets.

value of its total debt constant, then all else equal this would lower safe asset returns. However, the government in the baseline counterfactual uses the revenue from dividend taxes to issue more safe securities, which reduces the cost of precautionary savings. The increase in the dividend tax rate thus represents a transfer from firms which *ex-post* pay out dividends which *ex-post* are forced to issue equity. As a result, the rate of return on safe assets rises.

Figure 3.4 presents more detail on the effects of dividend taxes on equilibrium rates of return and consumption. The equilibrium interest rate increases constantly over the range of dividend taxes. This reflects decreasing precautionary demand as firms are increasingly avoiding costs of equity issuance. However, the path for consumption is not so straightforward. At low levels of dividend taxes, safe assets are in scarce supply, while firms are often financially constrained. As the dividend tax rate increases, transfers are made from firms who *ex-ante* pay high dividends to firms who are in need of safe assets. As dividend taxes increase beyond the rate of 20%, they begin to reduce the investment of financially constrained firms and consumption yet again decreases.

To clarify the importance of the supply of debt securities in these counterfactuals, in Table 3.3 I consider an alternative counterfactual where the government keeps the present value of lump-sum taxes instead of the amount of lump sum taxes. That is, the government holds constant:

$$\bar{g}Y = \frac{\tau}{r}Y = D + A - \frac{\int \tau(s)\ d\Upsilon(s)}{r}$$

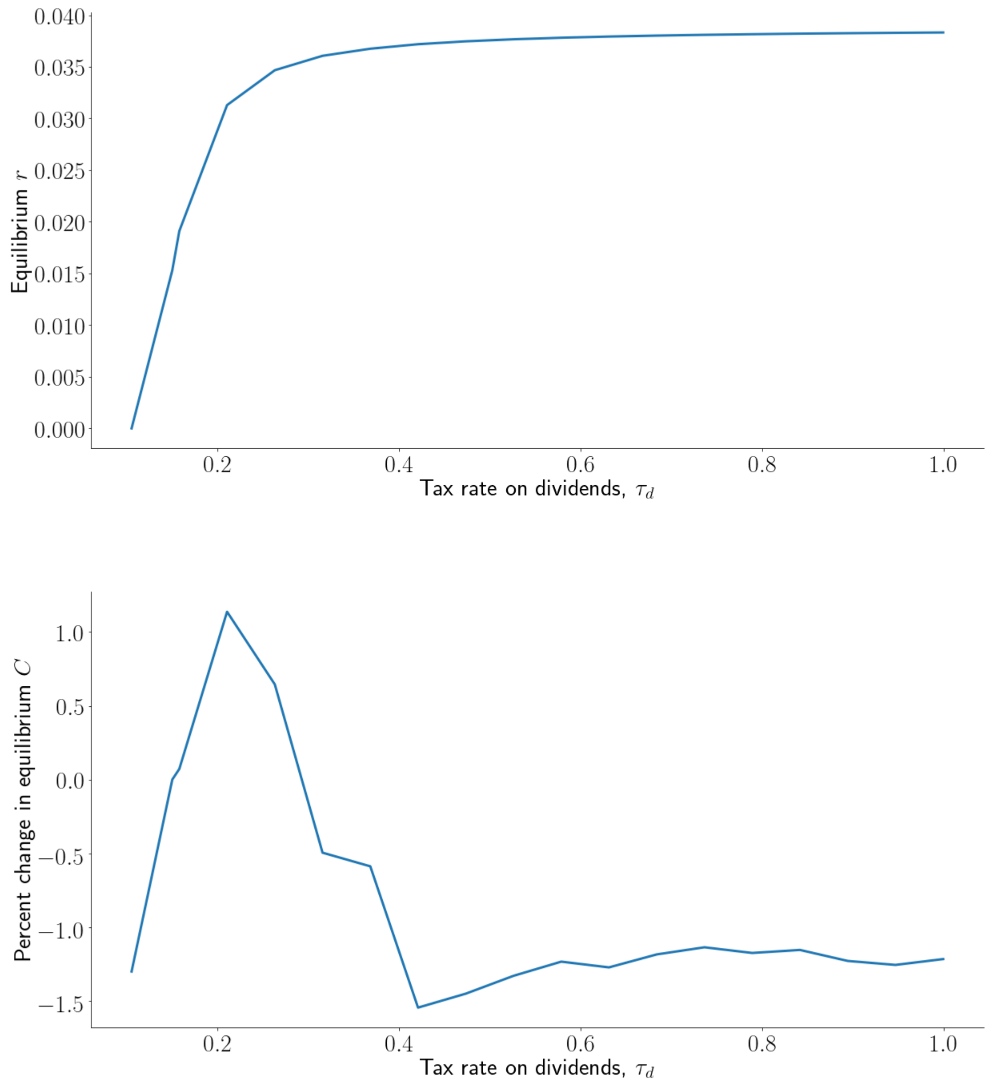


Figure 3.4: **Effect of dividend taxes on equilibrium.** This figure shows the effect of alternative dividend taxes on consumption and the equilibrium interest rate on safe assets.

	Baseline	$\tau_i = 0$	$\tau_d = 0.2$
		Pre-tax rates of return	
Debt	0.015	0.011	0.035
Equity	0.027	0.027	0.027
Capital	0.288	0.288	0.285
		Percent change in output component	
Output	0	0	4.440
Consumption	0	0.198	1.039
Investment	0	0	5.721
		Financial ratios	
Debt holdings / Consumption	0.656	0.656	3.874
Corporate leverage	-0.035	-0.035	-0.093

Table 3.2: **Counterfactual tax policies, constant share of lump sum taxes in output.** This table displays the impact of alternative tax policies on dividends and interest income on equilibrium prices and quantities in the model. In these counterfactuals, lump sum taxes are held constant as a share of output. Pre-tax rates of return are the pre-tax rate of return on debt, the discount rate of households and the average return on capital for firms. Output, consumption and investment are expressed as percent changes from the baseline tax environment. Financial ratios are aggregates.

Increases in the interest rate are now offset by increases in lump-sum taxes on households. This provides a middle ground between holding total debt constant (present value of all future surpluses) and holding surpluses from lump-sum taxes constant as above. We can equivalently imagine G as an outside supply of safe debt that is not affected by changes in government surpluses.

This equilibrium produces dramatically different results for the effects of changes in firm taxation on the rates of return and corporate decisions. Now, when taxes on interest income falls, there is a much smaller decrease in the supply of government debt. As a result, after-tax interest rates fall, and corporate investment, output and consumption rise. Similarly, when dividend taxes rise there is now a smaller offsetting increase in debt, so that the increase in interest rates is much smaller. In this case, as was emphasized above, output, investment and consumption all fall as corporations are less able to meet their precautionary demand while cash balances become costlier to households. These dramatically different results are precisely due to the government's decisions on fiscal policy, and emphasize that under market segmentation both the incentive effect of taxes and the way that tax changes are funded matter for equilibrium outcomes. I now turn to the question of how much segmentation from firms and households contributes to the effects of tax changes.

3.5 Asset market segmentation and the effects of taxation

Financial markets in my model are segmented by two forces. The first is firms' demand for safe debt securities for precautionary purposes. The second is

	Baseline	$\tau_i = 0$	$\tau_d = 0.2$
	Pre-tax rates of return		
Debt	0.015	0.015	0.018
Equity	0.027	0.027	0.027
Capital	0.288	0.287	0.288
	Percent change in output component		
Output	0	1.196	-0.605
Consumption	0	0.838	-0.650
Investment	0	1.536	-0.639
	Financial ratios		
Debt holdings / Consumption	0.656	0.886	0.730
Corporate leverage	-0.035	-0.042	-0.040

Table 3.3: **Counterfactual tax policies, constant present value of lump sum taxes.** This table displays the impact of alternative tax policies on dividends and interest income on equilibrium prices and quantities in the model. In these counterfactuals, the present value of lump sum taxes is held constant. Pre-tax rates of return are the pre-tax rate of return on debt, the discount rate of households and the average return on capital for firms. Output, consumption and investment are expressed as percent changes from the baseline tax environment. Financial ratios are aggregates.

households' demand for safe debt securities. But it is unclear which friction plays the greater role in the general equilibrium effects I describe above. To clarify, Table 3.4 examines the effects of the dividend tax counterfactual above with alternative parameters. The second two columns show the effects when equity issuance costs are set to zero. In this case, firms still have a precautionary demand for holding cash, but only because of the dividend tax. The second two columns show the results when ω is set to a significantly higher level of 0.2. The first two columns repeat the results in Table 3.2 for comparison.

The results in this table illustrate that costs of equity issuance play a limited role in determining equilibrium outcomes, while households' preference for safe assets plays a more significant one. Eliminating the cost of financial shortfalls has a limited effect on the equilibrium. While the percentage decrease in consumption is smaller without issuance costs, this is mostly due to the direct effects of eliminating financial shortfall costs on consumption. Changes in leverage are similar in both cases. On the other hand, changing households' preference for safe debt has a large effect on equilibrium outcomes. With $\omega = 0.2$, the household has a strong preference for holding liquid assets. A greater share of the newly created debt from dividend tax revenue increases thus is held by the household. As a result, increases in output, consumption and investment are all smaller under these preferences, as are changes in firm leverage.

This should not be read as saying that firm's precautionary demand does not contribute to the equilibrium I find. In the next section, I discuss the effects of altering the pledgeability of capital. In this case, I find that firms' demand plays

	Estimates		No issuance cost		$\omega = 0.2$	
	Baseline	$\tau_d = 0.2$	Baseline	$\tau_d = 0.2$	Baseline	$\tau_d = 0.2$
			Pre-tax rates of return			
Debt	0.015	0.035	0.015	0.035	0.015	0.024
Equity	0.027	0.027	0.027	0.027	0.027	0.027
Capital	0.288	0.285	0.288	0.285	0.288	0.286
			Percent change in output component			
Output	0	4.440	0	4.400	0	1.934
Consumption	0	1.039	0	0.645	0	0.783
Investment	0	5.721	0	5.884	0	2.504
			Financial ratios			
Debt holdings / Consumption	0.656	3.874	0.656	3.733	6.080	9.963
Corporate leverage	-0.035	-0.093	-0.022	-0.084	-0.035	-0.049

Table 3.4: **Counterfactual dividend tax under alternative market segmentation.** This table displays the impact of taxes on interest income on equilibrium prices and quantities when issuance costs (λ_0, λ_1) are set to zero, and when household's preference parameter for safe assets, ω, is set to 0.2. In these counterfactuals, the present value of lump sum taxes is held constant. Pre-tax rates of return are the pre-tax rate of return on debt, the discount rate of households and the average return on capital for firms. Output, consumption and investment are expressed as percent changes from the baseline tax environment. Financial ratios are aggregates.

an important role in the relationship between taxation, investment and rates of return.

3.6 Pledgeability and the effects of taxation

In this section, I consider the role of pledgeability in determining the relationship between corporate taxation, investment and returns. Here, I return to the case where the government keeps the present value of lump sum taxes constant. This limits the effects of taxes on interest rates. I consider two alternative scenarios for pledgeability $\theta = 0.3$ and $\theta = 0.7$. These scenarios match estimates for pledgeability in conventional models of corporate leverage, where the scope of securities

	$\theta = \hat{\theta}$		$\theta = 0.3$		$\theta = 0.7$	
	Baseline	$\tau_i = 0$	Baseline	$\tau_i = 0$	Baseline	$\tau_i = 0$
			Pre-tax rates of return			
Debt	0.015	0.015	0.015	0.015	0.015	0.015
Equity	0.027	0.027	0.027	0.027	0.027	0.027
Capital	0.288	0.287	0.283	0.283	0.279	0.281
			Percent change in output component			
Output	0	1.196	0	0.271	0	-2.711
Consumption	0	0.838	0	-1.069	0	-4.258
Investment	0	1.536	0	0.304	0	-3.617
			Financial ratios			
Debt holdings / Consumption	0.656	0.886	0.656	0.900	0.656	0.899
Corporate leverage	-0.035	-0.042	0.229	0.223	0.551	0.535

Table 3.5: **Counterfactual effect of a interest income tax decrease for different levels of pledgeability.** This table displays the impact of taxes on interest income on equilibrium prices and quantities when pledgeability is varied. In these counterfactuals, the present value of lump sum taxes is held constant. Pre-tax rates of return are the pre-tax rate of return on debt, the discount rate of households and the average return on capital for firms. Output, consumption and investment are expressed as percent changes from the baseline tax environment. Financial ratios are aggregates.

considered is significantly broader than short-term, highly rated debt.

The results for changing the tax on interest income in Table 3.5 are illustrative. With higher pledgeability, the corporate sector switches from demanding safe debt to supplying it. With medium pledgeability, though more firms are borrowers, there is still little capacity preservation. As such, firms still have significant precautionary demand. As before, decreasing the tax on interest income increases the after-tax return on debt, which the government, keeping the present value of lump-sum taxes on consumers constant, does not fully act to offset by issuing more safe debt. The result is a decline in the price of safe-debt capacity, which as with cash-holdings are a liquidity reserve for the firm. However, firms are now issuing safe debt to households. As a result, when after-tax returns on debt rise,

	$\theta = \hat{\theta}$		$\theta = 0.3$		$\theta = 0.7$	
	Baseline	$\tau_d = 0.2$	Baseline	$\tau_d = 0.2$	Baseline	$\tau_d = 0.2$
			Pre-tax rates of return			
Debt	0.015	0.018	0.015	0.018	0.015	0.017
Equity	0.027	0.027	0.027	0.027	0.027	0.027
Capital	0.288	0.288	0.283	0.283	0.279	0.281
			Percent change in output component			
Output	0	-0.605	0	-0.258	0	-2.962
Consumption	0	-0.650	0	0.063	0	-1.146
Investment	0	-0.639	0	-0.296	0	-3.804
			Financial ratios			
Debt holdings / Consumption	0.656	0.730	0.656	0.728	0.656	0.710
Corporate leverage	-0.035	-0.040	0.229	0.227	0.551	0.538

Table 3.6: **Counterfactual effect of a dividend tax increase for different levels of pledgeability.** This table displays the impact of an increase in the dividend tax on equilibrium prices and quantities when pledgeability is varied. In these counterfactuals, the present value of lump sum taxes is held constant. Pre-tax rates of return are the pre-tax rate of return on debt, the discount rate of households and the average return on capital for firms. Output, consumption and investment are expressed as percent changes from the baseline tax environment. Financial ratios are aggregates.

household consumption falls.

When firms have particularly high pledgeability, their precautionary demand decreases dramatically. The final columns in Table 3.5 show the results for $\theta = 0.7$. At this level of pledgeability, firms preserve large amounts of debt capacity. As a result, many firms are arbitrageurs, instead of indifferent between safe debt and dividends. When the after-tax returns on debt decrease, the gains from this arbitrage fall, so firms reduce their investment. The negative effect of this decline in investment on consumption is then compounded by the increase in after-tax returns on debt.

Similarly, the results for dividends in Table 3.6 follow a pattern based on changes in precautionary demand due to pledgeability. When the dividend tax rises for medium pledgeability, the effects on output and investment are qualitatively similar to the effect in the case of low pledgeability, but the sign on consumption is flipped because firms are now net-borrowers from households in safe debt. However, the effect for high pledgeability is quantitatively more dramatic. The reason is a difference in the importance of arbitrageurs, whose investment tends to be driven up by increases in the dividend tax.

These results emphasize the importance of firms' precautionary demand in determining the equilibrium response of the model economy to changes in tax rates. Taken together, the two preceeding sections have shown that both the precautionary demand of firms and the convenience benefits of households' holdings of safe debt play a key role in the results I find.

3.7 Conclusion

This paper shows that when asset markets are segmented, both by the demand from households and from firms for safe and liquid debt, taxation of firms' financial flows has important effects both on corporations' decisions and on returns. The sign and magnitude of these effects depend on the extent of market segmentation, and on limits to firms' ability to arbitrage between the two asset markets. Importantly, the taxation of dividends can simultaneously increase the return on safe assets and increase investment. This effect occurs because taxing dividends and using the proceeds to fund new safe debt issuance transfers resources from firms who are ex-post not financially constrained to firms who have an ex-ante need for safe assets. However, the benefits to dividend taxation are limited, since at high levels of dividend taxation, incentives for firms to invest are curbed. The results suggest a strong role for fiscal policy in altering interest rates by jointly affecting the demand for safe securities from firms and the ability of the government to issue safe securities.

Moreover, I show effects differ depending on how the government decides to employ tax revenue: by decreasing taxes on other sectors or by increasing their steady state deficit. These results suggest a holistic approach to analyzing the effects of taxes on corporations' financial decisions, one that takes into account both the incentive structures taxes imply and their effects on the supply and demand for segmented assets. A broader view of the interaction between fiscal policy and corporate finance may provide a promising avenue for future research.

APPENDICES

APPENDIX A

Chapter I supporting material

A.1 Construction of data variables

A.1.1 Corporate cash holdings in the Financial Accounts of the U.S.

One potential concern with the use of Financial Accounts data is how representative they are of Compustat cash holdings. In particular, Financial Accounts data may differ from Compustat in two ways: the Financial Accounts exclude certain securities holdings such as cross-holdings of corporate debt, and the Financial Accounts exclude financial assets of foreign subsidiaries. In this section, I show that at least for Compustat cash and short-term investments, the Financial Accounts are likely to be representative of the breakdown of holdings across securities.

To address the first concern, classes of securities holdings omitted from the Financial Accounts, I examine the Census' Quarterly Financial Report data. This

QFR data underlies the calculations of holdings of safe assets in the Financial Accounts, but it differs from the Financial Accounts in that the QFR tracks all marketable securities listed as current, including a category labelled "other short-term investments" which is excluded from the Financial Accounts.[1] The QFR data shows that around 85% of total current financial assets are represented by the categories in Financial Account data. Moreover, the share of assets not accounted for in the Financial Account has been declining over time as cash and short-term investments have risen.

QFR data shows that current, domestic holdings of marketable securities not accounted for in the financial account data are likely small. However, the QFR still excludes holdings of these assets through foreign subsidiaries. It is possible that these overseas holdings differ substantially from the assets included in the QFR. To address this concern, in Figure A.1, I show details of cash and short-term asset holdings from the 10-K filings of the largest holders of financial assets for whom this data was available. Again, the majority of these holdings are in securities included in the Federal Reserve's database, and in particular government debt, deposits and money market mutual funds. Moreover, the more comprehensive analysis of 10-K statements in *Duchin et al.* (2017) suggests that these large cash holders hold more corporate debt than is the norm. Analyzing the whole of corporations holdings' of financial assets, both their cash and short-term investments and their long-term securities holdings, they find that corporate securities only

[1]Unfortunately, QFR data only gives a detailed breakdown of holdings for firms in the manufacturing industry, so if firms outside of the manufacturing industry differ substantially from other firms in the Compustat sample, these results may be unreliable.

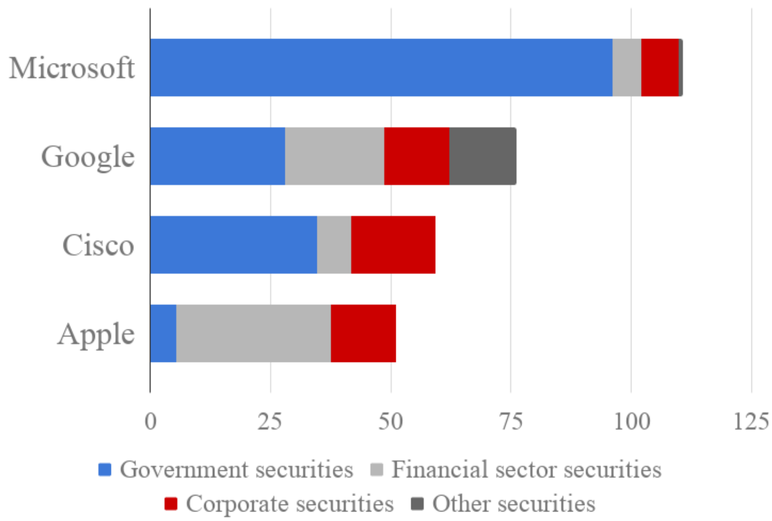


Figure A.1: **Cash and short-term investments of select U.S. firms.** This chart shows the makeup firms' cash and short-term investments for the largest holders in Compustat for which data was available. Data has been collected from 2017 10-K statements. Government securities include treasury debt, GSE and agency backed debt, and municipal securities. Corporate securities include corporate debt, direct equity holdings and mutual funds shares. Financial sector securities include commercial paper, money market mutual fund shares, deposits and savings accounts. Other private securities include asset-backed securities and other uncategorized securities.

make up 10% of the total. Therefore of the current portion of firms' financial assets, firm cross-holdings of debt are likely to be small.

A.2 Computation

A.2.1 Solution of the firm's dynamic problem

I use finite-grid value function approximation to solve the firm's dynamic problem. This requires a finite grid for capital, the productivity process, and safe asset holdings. To create a grid for the productivity process I use the method in *Tauchen* (1986). I include 21 points in the productivity grid, bounded by three standard deviations of the productivity process in either direction.

The grid for capital is set so that the firm will never choose capital outside of the grid. Specifically, I choose a grid for capital bounded by:

$$k_{\text{min}} = \left(\frac{(1-\tau_c)\alpha \underline{z}}{\rho+\delta}\right)^{\frac{1}{1-\alpha}}, \qquad k_{\text{max}} = \left(\frac{(1-\tau_c)\alpha \bar{z}}{\rho+\delta}\right)^{\frac{1}{1-\alpha}}$$

where $\underline{z}$ is the lowest value in the grid of the productivity process and $\bar{z}$ is the highest value. In between these two points, I include 31 values of capital over which I evaluate the value function. The firm is allowed to choose four points between every point on this grid, and linear interpolation is used to evaluate the value function between these points. Similarly, for safe asset holdings, I choose 61 points, with $b_{\text{min}} < 0 < b_{\text{max}}$. I set the grid so that it does not bind in a steady state, and equally space net holdings along the grid.

The firm's value function iteration is evaluated in parallel, as is their expectation of the value function tomorrow. I use Howard improvement to reduce the time it takes for the value function to converge. Howard improvement updates the expectation of the value function holding the policy function fixed at the current guess. For my model, this significantly reduces the amount of iterations required to reach convergence. Solving the model takes around two seconds on my workstation. The code used to solve this model is based on code made publicly available in *Bazdresch et al.* (2018).

A.2.2 Steady state distribution and market clearing

To solve for the steady state of the model, I use the finite grid representation of the state variables. Specifically, I use a vector $\hat{\Upsilon}$ over my finite grid to approximate the continuous steady state distribution $\Upsilon(s)$. The size of this vector is 39,711× 1 with one entry for every a, k and z combination in my finite grid. The law of motion for this grid is a Markov chain induced by the productivity process and firms' policy functions, $\Pi_{39{,}711\times 39{,}711}$. This transition matrix is large, but it is also sparse since $\Pi_{i,j}$ only has positive entries when a_i and k_i are optimal policies for a firm with state z_j, k_j, a_j.:

$$\Pi_{i,j} = 1_{[a_i,k_i]\in p(z_j,k_j,a_j)} P(a_i|a_j)$$

Therefore, I only need store i, j, and $\Pi_{i,j}$ in memory when $\Pi_{i,j} > 0$. Without this sparse representation, the transition matrix would be too large for my workstation to store in memory.

Since firms are allowed to choose points between the grid points on which I evaluate the value function, I use the same interpolation routine to determine the transition matrix for firm's states as for the value function. If the interpolation weight on state j is w_j for the firm's optimal policy given state j, then entry $\Pi_{i,j}$

will be:

$$\Pi_{i,j} = w_j P(a_i|a_j)$$

The steady state distribution can then be solved by initializing a distribution over states $\hat{\Upsilon}_0$, and iterating over this distribution:

$$\hat{\Upsilon}_{t+1} = \Pi\hat{\Upsilon}_t$$

until $||\hat{\Upsilon}_{t+1} - \hat{\Upsilon}_t||$ is below some tolerance, in my case 1e-6. The matrix multiplication is conducted using the sparse representation of Π. Again, each update of the distribution is conducted in parallel.

To solve for market clearing in the safe asset market I use bisection. I use the same technique to solve for the effects of changing taxes while holding transfers to households constant. I vary r to find the level of interest rates consistent with either these constant transfers or constant government borrowing. I choose initial guesses $r_{\text{high}} = 1/\beta - 1 - 1e - 6$ and $r_{\text{low}} = 0$. The lower bound is arbitrary, since there is nothing which prevents interest rates on safe assets from being negative in this model. I set the tolerance for bisection to 1×10^{-5}. I find that varying this tolerance has little effect on the results.

A.3 Details of estimation

A.3.1 Market clearing in the GMM estimation

Estimating a general equilibrium model requires enforcing the market clearing condition in the liquid asset market:

$$\mathcal{M}(\eta, r_a, T) = T - D(\eta, r_a, T) + \int a \ d\Upsilon(s \ |\eta, r_a)$$

where η denotes all estimated parameters except T, $\Upsilon(s|\eta, r_a)$ is the distributions of firms resulting from solving managers' problem given η and r_a, and $D(\eta, r_a)$ is consumers' demand for liquid assets.

This market clearing condition acts as a constraint which determines the return on liquid funds, r_a. The full GMM program, enforcing the market clearing condition and with moment condition $g(\eta, T, r_a) = \mathrm{E}[m(\eta, T, r_a) - m_{i,t}] = 0$ can then be written as the constrained GMM problem:

$$\begin{aligned} \min_{\eta, T} \quad & g(\eta, T, r_a)' W g(\eta, T, r_a) \\ \text{such that} \quad & \mathcal{M}(\eta, r_a, T) = 0 \end{aligned} \tag{A.1}$$

Solving (A.1) is computationally difficult, since at every evaluation the market clearing condition, $\mathcal{M}(\eta, r_a, T)$ has to be solved through bisection. Instead, I exploit the fact that, given a set of parameters describing firm and consumer demand for liquid assets, the mapping from this interest rate to the outside supply of liquidity is one to one. In other words, there exists an invertable function, $r_a = \mathcal{R}_\eta(T)$, such that $\mathcal{M}(\eta, \mathcal{R}_\eta(T), T) = 0$.

The full estimation program with moment condition program is then equivalent to the program:

$$\min_{\eta, r_a} \quad g(\eta, T, r_a)' W g(\eta, T, r_a) \tag{A.2}$$
$$\text{such that} \quad T = \mathcal{R}_\eta^{-1}(r_a)$$

This simplifies the estimation of the model dramatically, since it is not necessary to use bisection to clear the liquid asset market at every step. Since these problems are equivalent, I solve (A.2), and use the market clearing condition to determine $\hat{T}$.

Since the problems are not only asymptotically equivalent but also computationally equivalent, the $\hat{T}$ produced by solving these two problems on the same data will be exactly the same. Given the $\hat{T}$ from (A.2), it is then possible to calculate the standard errors for the program while enforcing the market clearing condition to construct standard errors for (A.1). This substitution has little effect on the standard errors for other parameters, but provides discipline to the general equilibrium component of the model in $\hat{T}$.

APPENDIX B

Chapter II supporting material

This Appendix sketches the standard test statistics that we use. The covariance matrix for the parameter vector, θ, is given by:

$$\frac{1}{nT}\left(1+\frac{1}{S}\right)(G'\hat{W}G)^{-1}G'\hat{W}\hat{\Omega}\hat{W}G(G'\hat{W}G)^{-1}, \tag{B.1}$$

in which $G \equiv \partial g(\boldsymbol{v}_{it}, \theta)/\partial\theta$. This expression is a standard generalized method of moments (GMM) parameter variance formula with a correction for simulation error, which is given by $\left(1+\frac{1}{S}\right)$. As is standard, when $\hat{W} = \hat{\Omega}^{-1}$, Equation (B.1) reduces to:

$$\frac{1}{nT}\left(1+\frac{1}{S}\right)(G'\hat{\Omega}^{-1}G)^{-1}. \tag{B.2}$$

Second, the variance of the vector $g(\boldsymbol{v}_{it}, \theta)$ is given by:

$$\operatorname{var}(g(\boldsymbol{v}_{it}, \theta)) = \frac{1}{nT}\left(1+\frac{1}{S}\right)(I - G(G'WG)^{-1}G'W)\hat{\Omega}(I - G(G'WG)^{-1}G'W). \tag{B.3}$$

Third, the test of overidentifying restrictions when one uses an arbitrary weight matrix, W, is given by:

$$\frac{nTS}{1+S} g(\boldsymbol{v}_{it}, \theta)' \text{var}(g(\boldsymbol{v}_{it}, \theta))^{+} g(\boldsymbol{v}_{it}, \theta), \tag{B.4}$$

in which + indicates a pseudo-inverse. In the case in which W is the optimal weight matrix, this test takes the familiar form

$$\frac{nTS}{1+S} g(\boldsymbol{v}_{it}, \theta)' \hat{\Omega}^{-1} g(\boldsymbol{v}_{it}, \theta) \tag{B.5}$$

The last two tests have degrees of freedom equal to the dimension of $g(\boldsymbol{v}_{it}, \theta)$ minus the dimension of θ.

BIBLIOGRAPHY

BIBLIOGRAPHY

Abel, A., and J. Eberly (1994), A Unified Model of Investment under Uncertainty, *American Economic Review*, *84*(5), 1369–84.

Aiyagari, S. R. (1994), Uninsured Idiosyncratic Risk and Aggregate Saving, *The Quarterly Journal of Economics*, *109*(3), 659–684.

Arellano, M., and S. Bond (1991), Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations, *Review of Economic Studies*, *58*(2), 277–297.

Armenter, R., and V. Hnatkovska (2011), The macroeconomics of firms' savings, *Working Paper 12-1*, Federal Reserve Bank of Philadelphia.

Auerbach, A. J. (1983), Taxation, Corporate Financial Policy and the Cost of Capital, *Journal of Economic Literature*, *21*(3), 905–940.

Ayturk, Y. (2017), The effects of government borrowing on corporate financing: Evidence from Europe, *Finance Research Letters*, *20*, 96 – 103, doi:https://doi.org/10.1016/j.frl.2016.09.018.

Azar, J. A., J.-F. Kagy, and M. C. Schmalz (2016), Can Changes in the Cost of Carry Explain the Dynamics of Corporate "Cash" Holdings?, *The Review of Financial Studies*, *29*(8), 2194–2240, doi:10.1093/rfs/hhw021.

Bajari, P., C. L. Benkard, and J. Levin (2007), Estimating Dynamic Models of Imperfect Competition, *Econometrica*, *75*(5), 1331–1370.

Barkai, S. (2016), Declining Capital and Labor Shares, *Tech. Rep. 2*, University of Chicago, Stigler Center for the Study of the Economy and the State.

Barro, R. J. (1974), Are Government Bonds Net Wealth?, *Journal of Political Economy*, *82*(6), 1095–1117.

Bazdresch, S., R. J. Kahn, and T. M. Whited (2018), Estimating and Testing Dynamic Corporate Finance Models, *The Review of Financial Studies*, *31*(1), 322–361, doi:10.1093/rfs/hhx080.

Blanchard, O. J. (2019), Public Debt and Low Interest Rates, *Working Paper 25621*, National Bureau of Economic Research, doi:10.3386/w25621.

Bolton, P., H. Chen, and N. Wang (2011), A Unified Theory of Tobin's q, Corporate Investment, Financing, and Risk Management, *The Journal of Finance*, *66*(5), 1545–1578, doi:10.1111/j.1540-6261.2011.01681.x.

Bradford, D. F. (1981), The incidence and allocation effects of a tax on corporate distributions, *Journal of Public Economics*, *15*(1), 1–22, doi:10.1016/0047-2727(81)90049-9.

Caballero, R., and E. Farhi (2018), The Safety Trap, *The Review of Economic Studies*, *85*(1), 223–274, doi:10.1093/restud/rdx013.

Caballero, R. J., T. Hoshi, and A. K. Kashyap (2008), Zombie Lending and Depressed Restructuring in Japan, *American Economic Review*, *98*(5), 1943–1977.

Caballero, R. J., E. Farhi, and P.-O. Gourinchas (2017), The Safe Assets Shortage Conundrum, *Journal of Economic Perspectives*, *31*(3), 29–46, doi:10.1257/jep.31.3.29.

Chemla, G., and C. A. Hennessy (2016), Government as borrower of first resort, *Journal of Monetary Economics*, *84*, 1–16, doi:10.1016/j.jmoneco.2016.09.001.

Chen, P., L. Karabarbounis, and B. Neiman (2017), The global rise of corporate saving, *Journal of Monetary Economics*, *89*, 1–19.

Cochrane, J. H. (2005), *Asset Pricing: Revised Edition*, revised edition ed., Princeton University Press, Princeton, N.J.

Cooley, T. F., and V. Quadrini (2001), Financial Markets and Firm Dynamics, *American Economic Review*, *91*(5), 1286–1310, doi:10.1257/aer.91.5.1286.

Cooper, R. W., and J. C. Haltiwanger (2006), On the Nature of Capital Adjustment Costs, *The Review of Economic Studies*, *73*(3), 611–633, doi:10.1111/j.1467-937X.2006.00389.x.

DeAngelo, H., L. DeAngelo, and T. Whited (2011), Capital structure dynamics and transitory debt, *Journal of Financial Economics*, *99*(2), 235–261.

Duchin, R., T. Gilbert, J. Harford, and C. Hrdlicka (2017), Precautionary Savings with Risky Assets: When Cash Is Not Cash, *The Journal of Finance*, *72*(2), 793–852, doi:10.1111/jofi.12490.

Easterbrook, F. H. (1984), Two Agency-Cost Explanations of Dividends, *American Economic Review*, *74*(4), 650–59.

Eisenhauer, P., J. J. Heckman, and S. Mosso (2015), Estimation Of Dynamic Discrete Choice Models By Maximum Likelihood And The Simulated Method Of Moments, *International Economic Review*, *56*, 331–357.

Erickson, T., and T. Whited (2002), Two-step GMM estimation of the errors-in-variables model using high-order moments, *Econometric Theory*, *18*(03), 776–799.

Erickson, T., and T. M. Whited (2012), Treating Measurement Error in Tobin's q, *Review of Financial Studies*, *25*(4), 1286–1329.

Faulkender, M. W., K. W. Hankins, and M. A. Petersen (2017), Understanding the Rise in Corporate Cash: Precautionary Savings or Foreign Taxes, *Working Paper 23799*, National Bureau of Economic Research, doi:10.3386/w23799.

Fazzari, S. M., R. G. Hubbard, B. C. Petersen, A. S. Blinder, and J. M. Poterba (1988), Financing Constraints and Corporate Investment, *Brookings Papers on Economic Activity*, *1988*(1), 141–206, doi:10.2307/2534426.

Feldstein, M. S. (1970), Corporate Taxation and Dividend Behaviour, *Review of Economic Studies*, *37*(1), 57–72.

Friedman, B. M. (1978), Crowding Out Or Crowding In? The Economic Consequences of Financing Government Deficits, *Working Paper 284*, National Bureau of Economic Research, doi:10.3386/w0284.

Gala, V., and J. F. Gomes (2016), Investment without Q.

Gallant, A. R., and G. Tauchen (1996), Which Moments to Match?, *Econometric Theory*, *12*(4), 657–681.

Gamba, A., and A. Triantis (2008), The Value of Financial Flexibility, *The Journal of Finance*, *63*(5), 2263–2296, doi:10.1111/j.1540-6261.2008.01397.x.

Gertler, M., and P. Karadi (2013), QE 1 vs. 2 vs. 3. . . : A Framework for Analyzing Large-Scale Asset Purchases as a Monetary Policy Tool, *International Journal of Central Banking*, *9*(1), 5–53.

Gomes, J. F. (2001), Financing Investment, *American Economic Review*, *91*(5), 1263–1285, doi:10.1257/aer.91.5.1263.

Gomme, P., B. Ravikumar, and P. Rupert (2015), Secular Stagnation and Returns on Capital, *Economic Synopses*, (19), doi:10.20955/es.2018.5.

Gormley, T. A., and D. A. Matsa (2014), Common Errors: How to (and Not to) Control for Unobserved Heterogeneity, *The Review of Financial Studies*, *27*(2), 617–661, doi:10.1093/rfs/hht047.

Gorton, G., and G. Pennacchi (1990), Financial Intermediaries and Liquidity Creation, *The Journal of Finance*, *45*(1), 49–71.

Gorton, G. B., and G. Ordoñez (2013), The Supply and Demand for Safe Assets, *NBER Working Papers 18732*, National Bureau of Economic Research, Inc.

Gourieroux, C., A. Monfort, and E. Renault (1993), Indirect Inference, *Journal of Applied Econometrics*, *8*, S85–S118.

Gourio, F., and J. Miao (2010), Firm Heterogeneity and the Long-run Effects of Dividend Tax Reform, *American Economic Journal: Macroeconomics*, *2*(1), 131–168.

Graham, J., M. T. Leary, and M. R. Roberts (2014), How Does Government Borrowing Affect Corporate Financing and Investment?, *NBER Working Papers 20581*, National Bureau of Economic Research, Inc.

Graham, J. R. (2003), Taxes and Corporate Finance: A Review, *The Review of Financial Studies*, *16*(4), 1075–1129.

Graham, J. R., and M. T. Leary (2017), The Evolution of Corporate Cash, *NBER Working Papers 23767*, National Bureau of Economic Research, Inc.

Greenwood, R., S. Hanson, and J. C. Stein (2010), A Gap-Filling Theory of Corporate Debt Maturity Choice, *The Journal of Finance*, *65*(3), 993–1028, doi:10.1111/j.1540-6261.2010.01559.x.

Gruber, J., and S. Kamin (2016), The Corporate Saving Glut and Falloff of Investment Spending in OECD Economies., *IMF Economic Review*, *64*(4).

Gruber, J., and S. Kamin (2017), Corporate Buybacks and Capital Investment: An International Perspective, *Tech. rep.*, Board of Governors of the Federal Reserve System (US).

Gutiérrez, G., and T. Philippon (2016), Investment-less Growth: An Empirical Investigation, *Tech. Rep. w22897*, National Bureau of Economic Research.

Han, C., and P. Phillips (2010), GMM Estimation for Dynamic Panels With Fixed Effects And Strong Instruments At Unity, *Econometric Theory*, *26*(01), 119–151.

Hansen, L. P., J. Heaton, and A. Yaron (1996), Finite-Sample Properties of Some Alternative GMM Estimators, *Journal of Business & Economic Statistics*, *14*(3), 262–280, doi:10.2307/1392442.

Harberger, A. C. (1962), The Incidence of the Corporation Income Tax, *Journal of Political Economy*, *70*(3), 215–240.

Hennessy, C. A., and T. M. Whited (2005), Debt Dynamics, *The Journal of Finance*, *60*(3), 1129–1165.

Hennessy, C. A., and T. M. Whited (2007), How Costly Is External Financing? Evidence from a Structural Estimation, *J. Finance*, *62*(4), 1705–1745.

Holmström, B., and J. Tirole (2011), *Inside and Outside Liquidity*, *MIT Press Books*, vol. 1, The MIT Press.

Jensen, M. C. (1986), Agency Costs of Free Cash Flow, Corporate Finance, and Takeovers, *American Economic Review*, *76*(2), 323–329.

Kadiyali, V., K. Sudhir, and V. R. Rao (2001), Structural analysis of competitive behavior : New Empirical Industrial Organization methods in marketing.

Kahn, R. J. (2019), Corporate Demand for Safe Assets and Government Crowding-In, *Working Paper*, Ross School of Business, University of Michigan.

King, A. T. (1977), Estimating Property Tax Capitalization: A Critical Comment, *Journal of Political Economy*, *85*(2), 425–431.

Krishnamurthy, A., and A. Vissing-Jorgensen (2012), The Aggregate Demand for Treasury Debt, *Journal of Political Economy*, *120*(2), 233–267.

Krishnamurthy, A., and A. Vissing-Jorgensen (2015), The impact of Treasury supply on financial sector lending and stability, *Journal of Financial Economics*, *118*(3), 571 – 600, doi:https://doi.org/10.1016/j.jfineco.2015.08.012.

Lee, B.-S., and B. Ingram (1991), Simulation estimation of time-series models, *Journal of Econometrics*, *47*(2-3), 197–205.

Li, S., T. M. Whited, and Y. Wu (2016), Collateral, Taxes, and Leverage, *The Review of Financial Studies*, *29*(6), 1453–1500, doi:10.1093/rfs/hhw008.

Li, Y. (2018), Fragile New Economy: The Rise of Intangible Capital and Financial Instability.

Loecker, J. D., and J. Eeckhout (2017), The Rise of Market Power and the Macroeconomic Implications, *NBER Working Papers 23687*, National Bureau of Economic Research, Inc.

Lucas, R. E. (2000), Inflation and Welfare, *Econometrica*, *68*(2), 247–274.

Michaelides, A., and S. Ng (2000), Estimating the rational expectations model of speculative storage : a Monte Carlo comparison of three simulation estimators, doi:10.1016/S0304-4076(99)00058-5.

Modigliani, F., and M. H. Miller (1958), The Cost of Capital, Corporation Finance and the Theory of Investment, *American Economic Review*, *48*(3), 261–297.

Moll, B. (2014), Productivity Losses from Financial Frictions: Can Self-Financing Undo Capital Misallocation?, *American Economic Review*, *104*(10), 3186–3221.

Nagel, S. (2016), The Liquidity Premium of Near-Money Assets*, *The Quarterly Journal of Economics*, *131*(4), 1927–1971, doi:10.1093/qje/qjw028.

Nikolov, B., and T. M. Whited (2014), Agency Conflicts and Cash: Estimates from a Dynamic Model, *The Journal of Finance*, *69*(5), 1883–1921.

Nikolov, B., L. Schmid, and R. Steri (2017), Dynamic corporate liquidity, *Tech. rep.*

Perez-Orive, A., and A. Caggese (2017), Capital Misallocation and Secular Stagnation, *2017 Meeting Papers 382*, Society for Economic Dynamics.

Peters, R. H., and L. A. Taylor (2017), Intangible capital and the investment-q relation, *Journal of Financial Economics*, *123*(2), 251 – 272, doi:https://doi.org/10.1016/j.jfineco.2016.03.011.

Petersen, M. A. (2009), Estimating Standard Errors in Finance Panel Data Sets: Comparing Approaches, *The Review of Financial Studies*, *22*(1), 435–480, doi:10.1093/rfs/hhn053.

Philippon, T. (2006), Corporate governance over the business cycle, *J. Econ. Dyn. Control*, *30*(11), 2117–2141.

Philippon, T. (2015), Has the US Finance Industry Become Less Efficient? On the Theory and Measurement of Financial Intermediation, *American Economic Review*, *105*(4), 1408–1438.

Poterba, J., and L. Summers (1983), Dividend taxes, corporate investment, and 'Q', *Journal of Public Economics*, *22*(2), 135–167.

Rampini, A., and A. Eisfeldt (2005), Financing Shortfalls and the Value of Aggregate Liquidity, *Tech. Rep. 889*, Society for Economic Dynamics.

Rampini, A., and S. Viswanathan (2013), Collateral and capital structure, *Journal of Financial Economics*, *109*(2), 466–492.

Riddick, L. A., and T. M. Whited (2009), The Corporate Propensity to Save, *The Journal of Finance*, *64*(4), 1729–1766, doi:10.1111/j.1540-6261.2009.01478.x.

Schroth, E., G. A. Suarez, and L. A. Taylor (2014), Dynamic debt runs and financial fragility: Evidence from the 2007 ABCP crisis, *Journal of Financial Economics*, *112*(2), 164–189, doi:10.1016/j.jfineco.2014.01.002.

Shanken, J., and G. Zhou (2007), Estimating and testing beta pricing models: Alternative methods and their performance in simulations, *Journal of Financial Economics*, *84*(1), 40–86, doi:10.1016/j.jfineco.2006.02.003.

Sinn, H.-W. (1990), Taxation and the Cost of Capital: The "Old" View, the "New" View and Another View, *NBER Working Paper 3501*, National Bureau of Economic Research, Inc.

Smith, A. A. (1993), Estimating nonlinear time-series models using simulated vector autoregressions, *Journal of Applied Econometrics*, *8*(S1), S63–S84, doi:10.1002/jae.3950080506.

Stokey, N. L., R. E. Lucas, and E. C. Prescott (1989), *Recursive methods in economic dynamics*, Harvard University Press, Cambridge, Mass., oCLC: 18835722.

Strebulaev, I. A., and T. M. Whited (2012), Dynamic Models and Structural Estimation in Corporate Finance, *Foundations and Trends® in Finance*, *6*(1–2), 1–163, doi:10.1561/0500000035.

Summers, L. H. (2018), Secular Stagnation and Macroeconomic Policy, *IMF Economic Review*, *66*(2), 226–250, doi:10.1057/s41308-018-0056-6.

Tauchen, G. (1986), Finite state markov-chain approximations to univariate and vector autoregressions, *Economics Letters*, *20*(2), 177 – 181, doi:https://doi.org/10.1016/0165-1765(86)90168-0.

Taylor, L. A. (2010), Why Are CEOs Rarely Fired? Evidence from Structural Estimation, *The Journal of Finance*, *65*(6), 2051–2087, doi:10.1111/j.1540-6261.2010.01610.x.

van Binsbergen, J., and C. C. Opp (2019), Real Anomalies, *The Journal of Finance*, doi:10.1111/jofi.12771.

Warusawitharana, M., and T. M. Whited (2016), Equity Market Misvaluation, Financing, and Investment, *The Review of Financial Studies*, *29*(3), 603–654, doi:10.1093/rfs/hhv066.

Whited, T. M. (1992), Debt, Liquidity Constraints, and Corporate Investment: Evidence from Panel Data, *J. Finance*, *47*(4), 1425–1460.