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Assia Elgouacem

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**ECOLE DOCTORALE DE SCIENCES PO**  
**Programme doctoral en Sciences économiques**

**Département d'économie**

**Doctorat en Sciences économiques**

# Essays on Investment and Saving

Assia Elgouacem

*Thesis supervised by:*

Nicolas Coeurdacier, Associate Professor, Sciences Po Paris

defended in Paris on 13 December 2018

*Jury:*

Mrs Kenza BENHIMA, Professeur ordinaire, Université de Lausanne  
(Rapporteur)

Mr Nicolas COEURDACIER, Associate Professor, Sciences Po Paris

Mr Stéphane GUIBAUD, Professeur assistant, HDR, Sciences Po Paris

Mrs Katheline SCHUBERT, Professeur des universités, Université Paris  
1 Panthéon-Sorbonne (Rapporteur)

Mr Rick VAN DER PLOEG, Professor, University of Oxford



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# Chapter 1

## Introduction

Investment and saving behavior of firms, industries, and countries have important implications for macroeconomic fluctuations, international capital flows, and commodity price dynamics. Among the many causes identified for the global financial crisis of 2008, persistent global imbalances driven in part by capital inflows from oil-exporting countries to industrialized countries, have been pegged as a precursor to the crisis. The surge in oil prices have resulted in large oil revenues for some MENA countries and others oil exporters such as Nigeria, Russia, Venezuela, which were then invested abroad, for a lack of safe domestic assets. As [Chinn \(2013\)](#) noted:

[...] the burgeoning surpluses of the oil exporters, ranging from the Persian Gulf countries to Russia, have moved to the fore as sources of excess saving. From this perspective, the US external imbalance is a problem made abroad; the lack of well developed and open financial markets encourages countries with excess savings to seek financial intermediation in well-developed financial systems such as the United States.

The more recent collapse in oil prices has reversed this trend, draining these countries' savings and placing their macroeconomic stability at risk ([Arezki et al. \(2018\)](#)). The tight link between oil prices and savings in oil-rich economies warranted a closer look. Understanding the determinants of oil price cycles is not only pertinent for oil-producing countries. The contribution of demand and supply conditions in driving oil price dynamics is closely monitored by financial markets, central banks, and all consumers of energy. In the recent years, weak global demand coincided with a supply boom emanating from the United States' shale boom led to a collapse in oil prices. The role of inventories in absorbing excess

supply is essential for the equilibrium of the oil market. The inability of supply to respond to market conditions in the short- and medium-term is often attributed to the substantial sunk costs associated with expanding productive capacity in the oil market. These adjustment rigidities render supply inelastic and hence the use of storage to smooth fluctuations in the market plays an essential role.

In parallel to the developments in the oil market that until recently suffered from a persistent weak global demand, this slow post-crisis recovery is in part explained by underwhelming private investment despite large monetary stimulus. Central banks, particularly in the United States and Europe have conducted large asset repurchasing programs to bring the cost of borrowing down and encourage firms to invest in the real economy and thus boost growth. However, the intended effects of the very accommodative stance of central banks have not materialized for several years. The lackluster investment behavior has been explained partially by the need for firms to deleverage and reduce their overcapacity as well as to high levels of economic uncertainty. These factors point to the presence of adjustment rigidities in the capital stock, much like in the oil market, that cause delays in investment and eventually lead to weak economic growth. Additionally, the lack of investment response to low borrowing costs has been attributed, among other factors, to the increasing role of share repurchases in absorbing low cost financing, rewarding shareholders and restructuring firms' balance sheets, instead of being channelled to expanding their productive capacities.

These recent developments in investment, savings, and oil prices have provided the fodder for my research herein. My thesis culminates into a research program that studies investment (and saving) from three different perspectives. It informs on 1) the saving behaviour of oil-rich countries, on 2) price formation and investment dynamics in the oil market, and on 3) the role of share buybacks in muting the positive effect of accommodative monetary policy on firm-level investment. The underlying common thread among these three work streams is understanding factors that mediate the investment decisions at the firm, industry, or country level.

## **Investment and uncertainty**

Firms exercise greater caution in their decisions to invest when the level of uncertainty is high, especially when they cannot easily adjust their capital stock. This is particularly true for capital-intensive industries, such as

the oil sector, where investment in physical capital and in the expansion of the productive capacity is irreversible. Once oil wells are drilled in the conventional sector, production is governed by well pressure instead of oil prices (Anderson et al. (2018)). In this sense, investment in expanding the production capacity through drilling oil well is an irreversible decision.

Equivalently, countries that are well-endowed in exhaustible resources are wary of the level of uncertainty about the future value of their wealth. As a result, they might speed up the depletion of the resource instead of storing it underground in order to reduce their exposure to uncertainty, particularly when they have the opportunity to accumulate wealth in a less risky asset. The mechanisms through which this uncertainty is transmitted and its implications warrant further investigation.

Work on the link between on uncertainty and investment (and saving) dates back to Bernanke (1983) and even before that. In fact, as early as the beginning 20th century, John Maynard Keynes remarked on the effect of uncertainty on investment decisions:

But I suggest that the essential character of the trade cycle ... is mainly due to the way in which the marginal efficiency of capital fluctuates .... (T)he marginal efficiency of capital depends, not only on the existing abundance or scarcity of capital-goods and the current cost of production of capital-goods, but also on current expectations as to the future yield of capital-goods .... But, as we have seen, the basis for such expectations is very precarious. Being based on shifting and unreliable evidence, they are subject to sudden and violent changes.

Keynes, *The General Theory*, Ch. 22.

This thesis hones in on the interaction of uncertainty with different features in an economy or a market to mediate investment and saving dynamics. The role of uncertainty in strengthening the precautionary motive for saving and directing capital flows from risky countries to safe countries has long been documented in the literature. Oil-rich countries are among countries that look abroad for diversification channels against oil price fluctuations. Their need to manage oil price booms and busts implies that they need to accumulate the commensurate savings that not only allocate their resource wealth across generations, but also to offset short term fluctuations. The exhaustibility of their resources and disruptive changes in the energy market, with the advent of alternative energy sources, increasingly more ambitious climate change policies, and tech-

nological advances unleashing shale resources, have brought new considerations for these countries. The way they manage their underground wealth is therefore key to their economic success.

The first chapter of my thesis, *External Saving and Exhaustible Resource Extraction*, addresses precisely the issue of exhaustible resource management in the face of uncertainty. In linking the extraction and saving behavior under a coherent theoretical framework, this chapter contributes to two veins of the literature that have developed separately until more recently. On the one hand, macroeconomic literature has shown the extent to which uncertainty creates a precautionary motive for saving that acts as a key determinant for the current account positions of countries. On the other hand, the literature on exhaustible resource management has focused on the optimal depletion rate of the resource but very few papers have made the link with macroeconomic outcomes for exhaustible resource-rich economies (ERREs).

The novelty to this work is to use a small-open economy framework to study a specific group of countries, i.e. ERREs, and to characterize and quantify the impact of uncertainty on their saving and extraction decisions. Since these decisions are closely intertwined, the chapter studies the interaction between them by embedding a model of precautionary saving in a model of exhaustible-resource extraction. This interaction gives rise to a powerful feedback effect between income risk and saving. Income risk –in this case resource price volatility–speeds up extraction and encourages the accumulation of external savings. As the underground resource continues to be depleted and transformed into a risk-free asset, the role of income risk in the economy is weakened, which in turn slows down extraction and dampens the need for savings.

This work lies at the intersection of the literature on optimal saving and consumption in the face of aggregate uncertainty on the one hand, and optimal extraction of exhaustible resources on the other. By exploiting the saving-extraction nexus, this paper bridges these two strands of literature. Many studies have focused on rationalizing the "saving glut" to try to explain an open economy's tendency to place its assets abroad in the face of uncertainty and lack of diversification channels domestically.

[Bems and de Carvalho Filho \(2011\)](#) take up the task of quantifying the extent to which uncertainty encourages savings in oil-exporting countries, but stops short of considering the feedback effect of extraction on savings. This chapter therefore addresses this shortcoming by quantifying the contribution of precautionary motive to the accumulation of external savings

all the while rendering the decision to extract as one of the choice variables in the model. [van den Bremer and van der Ploeg \(2013\)](#), [Cherif and Hasanov \(2013\)](#), discuss the optimal management of exhaustible resource windfalls whereby the influx of foreign exchange could be placed in different funds to mitigate volatility, ensure inter-generational equity, and ensure a sustainable development of the country. [van den Bremer et al. \(2016\)](#) address the interaction between extraction and above-ground wealth accumulation and focus on the effects of oil price volatility on the composition of a portfolio of assets used to manage the volatile underground oil wealth.

The first chapter focuses on the saving decision of exhaustible-resource-rich economics, but as it uses a partial-equilibrium framework, it is silent on the determinants of prices in the oil market. The second chapter, *The Delaying Effect of Storage on Investment: Evidence from the US Oil Sector*, continues to explore the role of uncertainty but this time analyses both price and investment dynamics when investment decisions are irreversible. Much in the spirit of [Pindyck \(1994\)](#), this model looks at how uncertainty influences firms' decisions to expand their productive capacity, and more particularly when storage can be used to intertemporally allocate supply. This chapter therefore departs from the macroeconomic literature on irreversible investment under uncertainty by introducing a new channel of investment that smooth out fluctuations. Embedding storage capacity in an investment model again bridges the gap between two veins of the literature: on the one hand the macroeconomic literature on the implications of capital adjustment costs on aggregate fluctuations, and on the other hand, the financial literature focusing on commodity price dynamics.

Price and production dynamics in storable commodity markets garner a lot of attention due to their implications for macroeconomic fluctuations and financial markets. Therefore, understanding which factors underlie decisions in such markets is at the heart of the chapter. In capital intensive industries, such as the oil industry, production requires substantial upfront fixed capital expenditures and once capital is installed, firms cannot easily adjust their capital stock in order to respond to unanticipated changes market conditions. The succession of booms and busts episodes in prices along with the clusters of high volatility show that production in the oil sector is subject to substantial uncertainty that varies over time. This creates an incentive for firms to hold off on their investment decision until the value of the project is sufficiently high.

The inability of firms to rapidly adjust their capital stock implies that, in the short-run, the supply of the commodity can be inelastic. Thus, when the productive capacity in the market exceeds the consumption demand and cannot be adjusted downward, storage plays the important role of intertemporally allocating excess supply and smoothing out demand and supply shocks. As a result, spot prices are more stable and persistent when inventories are full and increasingly more volatile as inventories are drawn down. At the same time, carrying inventories also implies that future prices are expected to be higher than spot prices, but more importantly, that future and spot price are in a lock-step relationship. As a result of having storage, spot price volatility is transmitted to future prices.

As uncertainty and future returns on investment determine whether firms expand their productive capacity, I sought to understand the role of storage in mediating volatility in prices and most importantly its feedback effect on investment, precisely because it introduces a lock-step variation in spot and future prices. This second chapter contributes to literature on irreversible investment by demonstrating how the availability of storage capacity in the market influences the investment decision via its effects on uncertainty and expected prices. To do so, we use the starkest irreversible investment model under uncertainty and introduce storage capacity. This setting allows us to capture the main features characterizing a storable commodity market, i.e. irreversible investment and storage, in order to rationalize price and investment dynamics observed in the data.

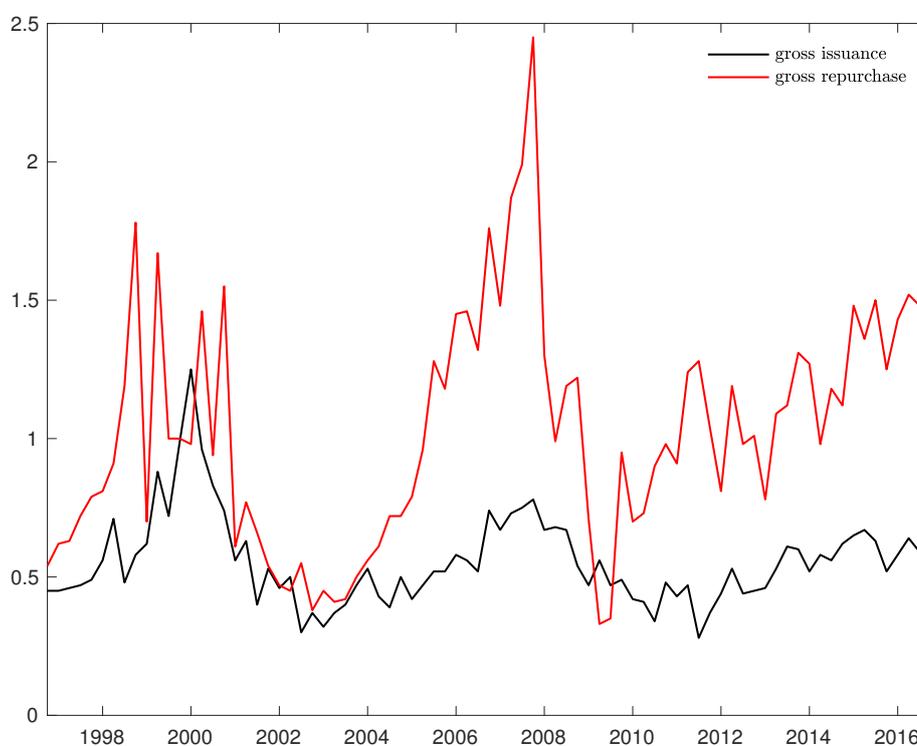
We use [Cooper and Haltiwanger \(2006\)](#)'s work on the role of adjustment costs as a point of departure for our paper to model the commodity supplier's capital dynamics. By working within this framework, we believe not only to capture firm (sector)-level investment non-linearities, but also to echo [Kogan et al. \(2009\)](#)'s motivation for emphasizing the importance of the supply side of the commodity market in order to reproduce the most prominent features of commodity price. The key assumption in their model is that the representative commodity producer cannot resell the already installed capital leading to a time-varying elasticity of supply with respect to shocks. While [Kogan et al. \(2009\)](#) abstract from the storage dimension in the commodity market, we wanted to bring together the price smoothing features of storage and capital adjustment rigidities in the same framework, so as to shed light on the inner working of commodity markets and the accompanying price dynamics. Additionally, we build upon the recent developments in the literature of the storage model

through a more complex specification of supply responsiveness and persistence in the shock processes.

## Investment and firms' capital structure

The last chapter of this thesis, *Share Buybacks, Monetary Policy and the Cost of Debt*, turns its attention to an empirical investigation of the determinants of investment. Starting from the capital structure of firms, this part of my thesis focuses on the role of repurchases in diverting low-cost debt away from investment and employment. The practice of share buyback, whereby firms reward their shareholders through share repurchases instead of dividend payments, dates back to 1985 in the United States. Very quickly since then, share buybacks have become common practice used to return cash to particular categories of investors, to send signals of confidence to markets, to concentrate firm's ownership or also to adjust stock prices. Yet, these operations redirect resources from pro-

Figure 1.1: Gross equity issuance and repurchase over GDP Q1/1996-Q4/2016



Note: Data are reported in billions of dollars at a quarterly rate and equals series FA103164103.Q of the Financial Accounts of the United States divided by 4000.

Source: <https://www.federalreserve.gov/releases/Z1/Current/default.htm>

ductive investments raising concerns about the legitimacy of repurchase programs, particularly on the way managers use their financial resources and its impact on the real economy. These concerns became of interests to legislators and economists in the aftermath of the Great Recession, a period in which firms, despite having at their disposal substantial internal and external liquidity, devoted a lot of resources to share buyback programs rather than to new investments and employment creation. Share buyback programs continue to cause much controversy after companies in the United States announced large repurchases programs after the recent corporate tax cuts. Repurchase programs have persistently outweighed equity issuance, represented a relatively larger share of GDP over the past two decades (Figure 1.1). By the end of 2018, share buybacks in the United States are expected to reach 800 billion dollars, an increase that dwarfs growth in capital expenditure and R&D.<sup>1</sup>

Much is already known about the negative effect of repurchases on real variables (Almeida et al. (2016)), on the market-timing of repurchases (Stein (1996), Ma (2014), Baker and Wurgler (2002)) and the reason why firms do buyback (Grullon and Michaely (2004), Hribar et al. (2006)). Yet, little is known about how firms finance this operation and to what extent the cost of financing influences managers' decision to buyback their own shares.

This chapter aims to fill this gap in the literature and shows that buyback programs are mostly financed through new corporate debt issuance and they are most likely launched in periods of accommodative monetary policy. In fact, for an exogenous fall in the Fed fund rate, firms who benefit from a downward adjustment of their corporate yield tend to repurchase more by issuing more debt in the same quarter. Using low-cost debt to finance repurchases takes away resources from capital expenditures and new employment, thus reducing the effectiveness of accommodative monetary policy at firm-level.

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<sup>1</sup>See: <https://www.ft.com/content/affbf078-1f6e-11e8-a895-1ba1f72c2c11>

# Chapter 2

## External Saving and Exhaustible Resource Extraction

This chapter examines the optimal saving and extraction policy of an exhaustible-resource-rich economy (ERRE). The recent surge in current account surpluses held by several ERREs, and the even more recent downturn in commodity prices, begs the following questions: 1) what are the main determinants of the demand for net foreign assets from ERREs; and 2) and how does the precautionary motive to increase external savings interact with the decision to deplete the exhaustible resource? To answer these questions, the paper provides a characterization of the optimal saving and extraction rate in such an economy and points to the key factors that govern the trade-off between keeping the resource underground and increasing external savings. I proceed to quantify the extent to which savings and the extraction rate respond to changes in uncertainty, prudence, impatience, and the cost of extraction.

*Keywords:* Precautionary saving, Exhaustible resources, Commodity exporters, Net foreign assets, Small-open economy

*JEL classification:* E21, F32, Q30

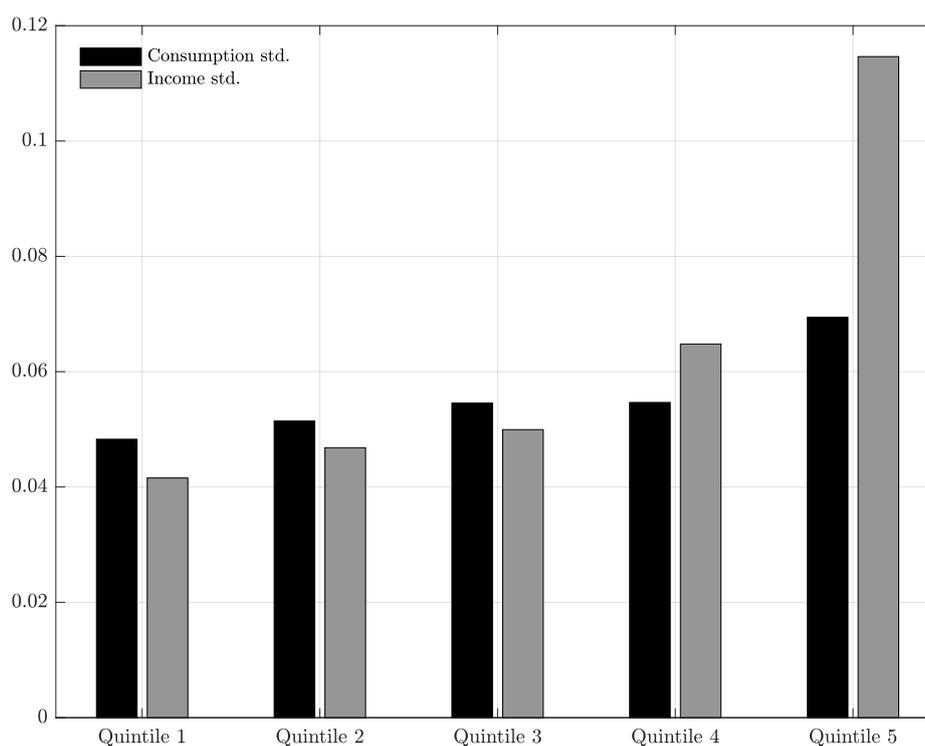
### 2.1 Introduction

This paper analyzes the effects of risk on the equilibrium saving and extraction path for an exhaustible-resource-rich economy in a model of optimal consumption, saving, and extraction. The analysis is cast in a small open economy framework whereby a social planner chooses to place its

exhaustible resource revenue abroad in order to inter-temporally transfer the exhaustible wealth and to mitigate income fluctuations. The analysis in the paper characterizes the interaction between saving and extraction and the impact of uncertainty on these decisions.

Exhaustible-resource-rich economies (ERREs hereafter) are associated with two features that make them an interesting group of countries to study. They face high income volatility and are endowed with a finite stock of underground wealth. Compared with countries for which exhaustible-resource income represents a small share of their total output, average income volatility among ERREs – those for which the share of the commodity export receipts represents more than 20 % of GDP – can be two to three times higher as depicted in Figure 2.1.

Figure 2.1: Income and Consumption Volatility (1995-2011)

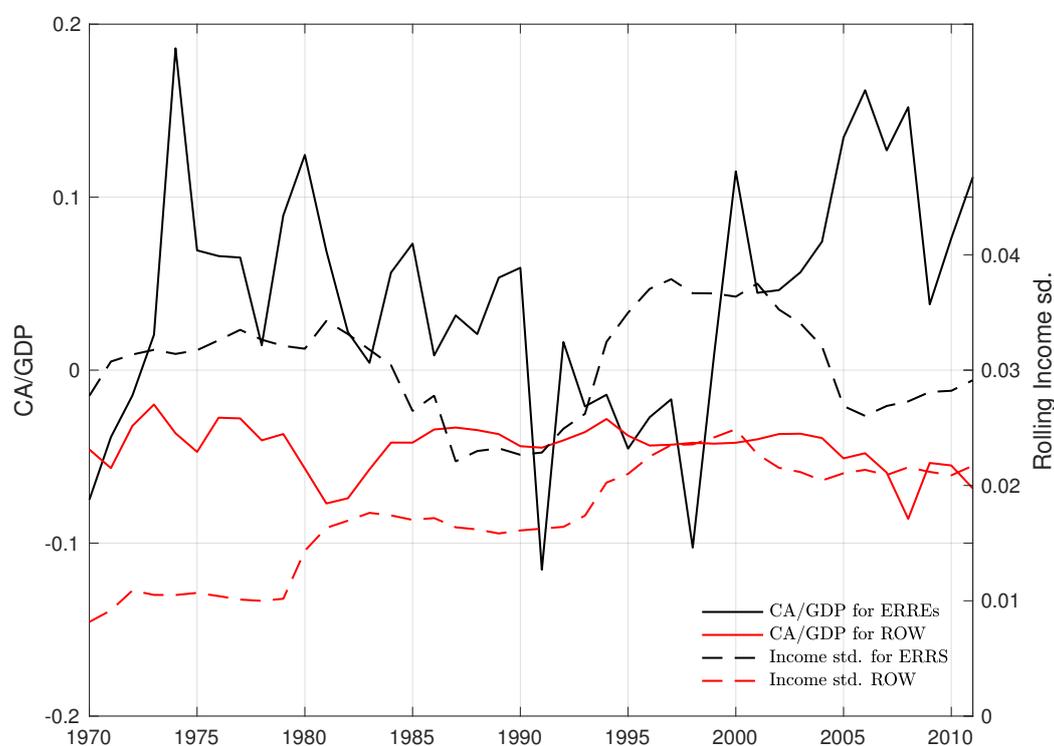


*Note:* Countries are placed into quintiles according to the share of net exhaustible resources exports in their GDP. Black bars represent consumption volatility measured as the standard deviation of per capita real consumption. red bars represent income volatility measured as the standard deviation of per capita real GDP.

*Source:* Consumption, GDP, population, and CPI data is from the World Bank World Development Indicators (WDI) data.

Since they derive a significant part of their income from volatile export

Figure 2.2: Current account and income volatility for ERREs and non-ERREs (1970-2011)



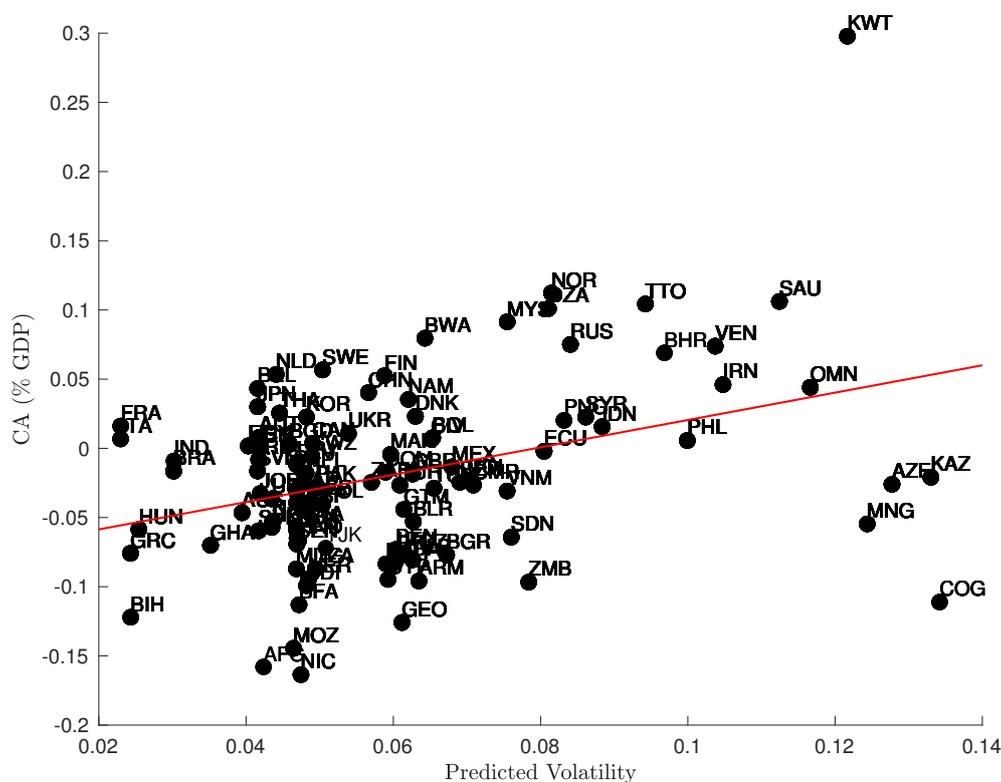
*Note:* Countries referred to as ERREs are those countries whose rents from oil and gas as well as mineral production makes up more than 10% of their GDP. Current account balances as a share of GDP (CA/GDP) are represented by the solid lines. Income volatility calculated over a 10-year rolling window is represented by the dashed lined. Data for ERREs are in blue and for the the rest of the world (ROE) in red.

*Source:* Consumption, GDP, population, and CPI data is from the World Bank World Development Indicators (WDI) data. Current account data is from Lane and Milesi-Ferretti (2007).

receipts, they have a strong motive to save, both for precautionary reasons – against short term income fluctuations – and to prevent a large drop in their domestic spending as they run down their exhaustible resources. Indeed, there is a strong correlation between the level of uncertainty generated by commodity prices and a country’s external savings position (Figure 2.3).<sup>1</sup> On average, over the 1995-2011 period, countries with a larger share of commodity income in their GDP tend to also have positive cur-

<sup>1</sup>The word commodity here is used to discuss non-renewable commodities. Commodities included are aluminum, copper, crude oil, nickle, tin, and zinc. The uncertainty generated by commodity prices is measured as the income volatility predicted by the price volatility of the most *dominant* commodity, or the commodity representing the largest share of exports revenue for the country.

Figure 2.3: Correlation between current account and volatility (1995-2011)



*Note:* On the horizontal axis, predicted volatility represents the average income volatility, measured as the average standard deviation of per capita GDP, that is predicted by volatility of the price of the commodity that represents the largest share in the country's GDP. On the vertical axis, current account is measured as the average share of GDP over the period 1995-2011.

*Source:* GDP data is from the World Bank World Development Indicators (WDI) data. Data on commodity production volumes and prices is from the United Nations Comtrade.

rent account balances. While ERREs face more income volatility, they still manage to limit their consumption volatility as revealed in Figure 2.1, whereby the standard deviation of consumption is significantly lower than their income volatility.

At the same time, their ability to save is intimately linked to the rate at which they deplete their resource. The exhaustibility of their underground resource and the uncertainty over its future value reinforce the need to accumulate external savings. As the resource is depleted, representing a lower share in the economy's wealth, the role of risk in determining savings becomes less important. The interaction between the saving and extraction decision, and particularly the feedback of extraction on uncer-

tainty, warrant an analytical framework that can simultaneously account for both decisions.

The novelty in this chapter is the use of a small-open economy framework to study a specific group of countries, i.e. ERREs, and to characterize and quantify the impact of uncertainty on their saving and extraction decisions. Since these decisions are closely intertwined, the paper studies the interaction between them by embedding a model of precautionary saving in a model of exhaustible-resource extraction. This interaction gives rise to a powerful feedback effect between income risk and saving. Income risk – in this case resource price volatility – speeds up extraction and encourages the accumulation of external savings. As the underground resource continues to be depleted and transformed into a risk-free asset, the role of income risk in the economy is weakened, which in turn slows down extraction and dampens the need for savings.

The model incorporates the main channels through which income risk affects saving and extraction outcomes: a time-varying precautionary motive and a feedback loop between risk and saving, resulting in an endogenously determined income risk. The need to diversify away from the income risk creates a trade-off between extracting today and transforming the resource wealth into external savings or holding on to the *in situ* asset. The model results center around an extraction decision that is governed by a *risk-adjusted* Hotelling Rule, whereby the relationship between returns on the *in situ* asset and savings play a decisive role. It is also amenable to disentangle and quantify savings emanating from the need to build a precautionary buffer from savings used for the purpose of ensuring a smooth consumption path in the long run. As the same time, it quantifies the effect of risk on extraction.

To study the saving-extraction nexus, I derive the optimality conditions governing the extraction and saving decisions and calibrate the model to match the average consumption, income, and extraction volatilities for a sample of oil-rich countries. I compare the savings path in a model with endogenous extraction and stochastic resource prices with the path from a model where the price is deterministic. The *in situ* resource acts as a risky asset for the exhaustible-resource-rich country that should be depleted rapidly and allocated in a safe asset. With risk-averse households, the model shows that it is optimal to put aside a substantial part of its wealth abroad to be able to smooth their consumption, and even more so when the value of the resource is uncertain.

**Literature Review** This work lies at the intersection of the literature on optimal saving and consumption in the face of aggregate uncertainty, on the one hand, and optimal extraction of exhaustible resources, on the other. By exploiting the saving-extraction nexus, this paper bridges these two strands of literature. Many studies have focused on rationalizing the "saving glut" to try to explain an open economy's tendency to place its assets abroad in the face of uncertainty and lack of diversification channels domestically.

This chapter complements the literature on precautionary saving by focusing on the behavior of a specific group of countries that is characterized by a volatile income stream and a strong precautionary motive to expand their external asset holdings. Therefore, it echoes the results of [Cabrero \(1991\)](#), [Carroll \(2001\)](#), [Carroll and Jeanne \(2009\)](#), [Deaton \(1991\)](#), [Fogli and Perri \(2015\)](#), [Ghosh and Ostry \(1997\)](#), and references therein, who focus on the determinants of precautionary savings. They explore the extent to which income uncertainty, expected income growth, and shock persistence can heighten the need for precautionary savings. However, these papers focus on consumption behavior of advanced economies in the face of uncertainty.

My work, in assessing the demand for external savings in exhaustible-resource-rich countries, complements the literature by placing this specific group of countries at the forefront, honing in on the interaction between uncertainty, saving, and extraction. As shown above, ERREs have played an important role in determining the direction of capital flows, and thus their contribution to global imbalances warrants a closer look. [Bems and de Carvalho Filho \(2011\)](#), [Van Den Bremer and van der Ploeg \(2012\)](#) do address the specificities of commodity exporting countries and quantify the contribution of precautionary savings to their external balances, but take the extraction path as exogenous and therefore do not exploit the relationship between the extraction rate and the saving decision.

On the other hand, the literature on optimal exhaustible resource extraction is more often than not set in a closed economy setting of a neoclassical growth model as in [Dasgupta and Heal \(1974\)](#), [Dasgupta and Stiglitz \(1981\)](#), [Pindyck \(1980\)](#) among others. This set up then places the focus on the linkages between the resource sector and the rest of the economy. My work is closely aligned with [Aarrestad \(1979\)](#) and [Farzin \(1999\)](#) who study the saving behavior of an ERRE, but both of these papers do not address the impact of uncertainty on savings. [Pindyck \(1981\)](#) establishes the relation between uncertainty and resource extraction conditional on non-

linear marginal extraction costs. [Gaudet and Khadr \(1991\)](#) approaches the optimal depletion problem in a stochastic environment and derive a risk-adjusted Hotelling rule. However, they stop short of quantifying the contribution of uncertainty to the stock of non-resource assets.

This chapter builds on this literature by quantifying the contribution of the precautionary motive to save when the decision to extract is a choice that is simultaneously determined. [Bems and de Carvalho Filho \(2011\)](#) quantify the demand for savings both in a deterministic world and under certainty but abstract from the extraction decision; they take it as exogenously determined. Another collection of papers, such as [van den Bremer and van der Ploeg \(2013\)](#), [Cherif and Hasanov \(2013\)](#), provide quantitative results on the allocation of exhaustible resource windfalls across different types of saving funds: one to mitigate volatility, another to ensure intergenerational equity, and one to ensure a sustainable development of the country. This latter exercise is taken across a different set of countries to underline the role of country specificities in determining the usefulness of the different types of savings. [van den Bremer et al. \(2016\)](#) address the interaction between extraction and above-ground wealth accumulation and focus on the effects of oil price volatility on the composition of a portfolio of assets used to manage the volatile under-ground oil wealth.

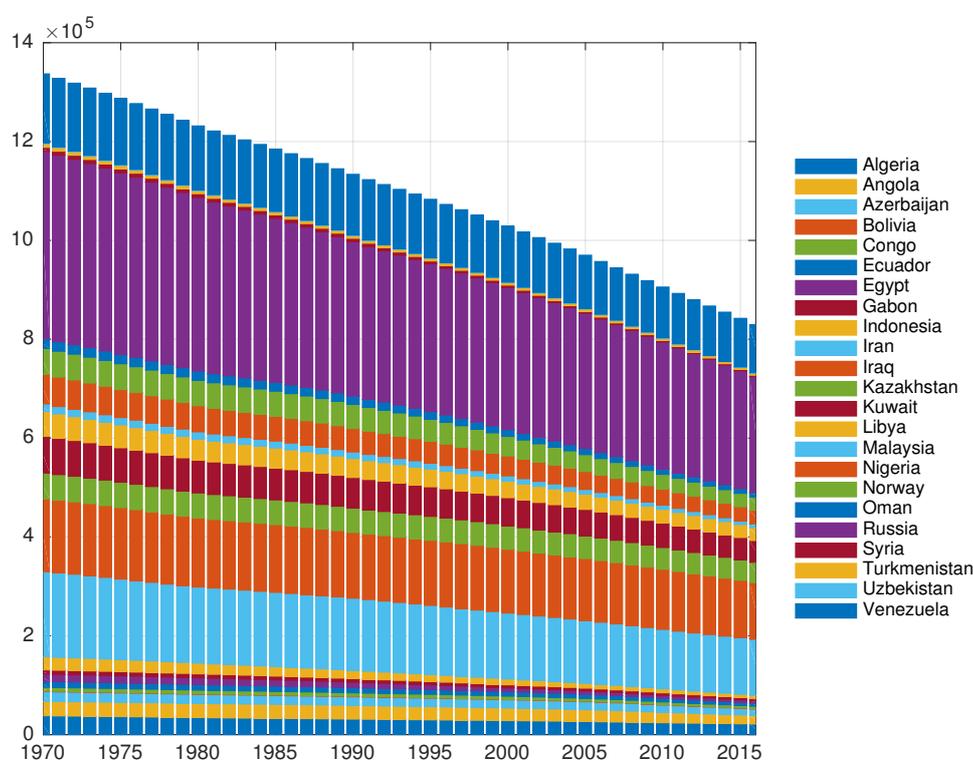
This paper is certainly inspired by work which speaks on the management of nonrenewable resources, and goes further by focusing on the effects of endogenous extraction on the saving behavior and quantifying the excess demand for saving when we allow households to choose the rate at which to deplete the underground resource. The paper also comments on the quantitative performance of this model in matching the empirical moments to the simulated data. I find that the model performs well for countries with moderate oil and gas reserves. For countries endowed with significant resources, the model generates too much income and consumption volatility, and the opposite is true for countries with lower than average (within the sample of ERREs) underground wealth.

The rest of the paper is organized as follows. Section 2.2 describes the model, from the social's planner's problem to the definition of the equilibrium. Section 2.3 explains the numerical solution, calibration strategy, the model's results, and evaluates its empirical performance for country-specific calibrations. Section 2.4 explores some parameter ranges and possible extensions. Section 2.5 offers some concluding remarks.

## 2.2 A model of a small exhaustible resource rich open economy

The small open economy is endowed with beginning of period  $t + 1$  reserves of an exhaustible resource denoted by  $S_{t+1}$ , representing the remaining stock after extracting  $X_t$  in period  $t$  at a cost  $G(S_t, X_t)$ . There is no renewal of the stock of the exhaustible resource. The ERRE is endowed with a fixed beginning of time reserves of an exhaustible resource and will run them down over time.

Figure 2.4: Crude oil resources (1970-2015)



Note: Crude oil resources are measured in million barrels of oil equivalent

Source: Rystab UCUBE.

Among the countries that will be studied in this paper, their total recoverable underground resources have been diminishing over time as depicted in Figure 2.4. Compared to reserve levels in 1970, today's total reserves among the ERREs studied in this paper are 20% lower. Therefore, it is reasonable to cast the small open economy in a cake eating framework where the size of the cake, in this case the reserves, is fixed at the beginning of time. Additionally, the number of discoveries have also decreased over the period between 1970 and 2015, further supporting the

abstraction from discoveries.

### 2.2.1 The Cost Function

The cost function of extraction depends both on the stock remaining and the amount extracted in period  $t$  and is convex in both of its arguments. The larger is the quantity to be extracted, the higher is the cost. This can be due to a constraint imposed by the available capital stock used in the extractive activity or physical properties of a well that restrict the feasible per-period extraction quantity. The cost of production is also affected by the remaining reserves. At lower stock levels, extraction becomes more difficult due to increasingly difficult physical conditions. For instance, oil and natural gas extraction is a function of the underground pressure. Over the years, this pressure drops rendering extraction more difficult and hence more costly.

Also, wells that are easiest (or less costly) to exploit are the first to be exhausted. The earliest discoveries of mineral deposits or fossil fuels reserves are the largest. Their exploitation is easier than if the resource deposits were dispersed throughout several smaller units. These large deposits around the world are also the more mature reserves, i.e. the ones that have been exploited the longest. More recent discoveries are, on average, smaller, or of less favorable geological conditions for exploitation. Therefore, it is plausible to assume that the extraction cost would be higher at lower stock levels, since the currently exploited and developed fields are the ones that have been discovered a while ago and the recently added reserved to *proven reserves* might be still uneconomical.

Following [Sweeney \(1993\)](#), the following assumptions place restrictions on the functional form of the extraction cost function.<sup>2</sup>

**Assumption 1 (Dominance of extraction rate on marginal cost.).** Marginal cost is more sensitive to extraction rate than to the stock level.  $\frac{\partial^2 G}{\partial x^2} \geq \frac{\partial^2 G(s, x)}{\partial x \partial s}$

The first assumption ensures that the discrete time cost function is consistent with its underlying continuous time representation.<sup>3</sup>

<sup>2</sup>More recent models, such as in [Kellogg \(2014\)](#) and [Anderson et al. \(2018\)](#), separate the production decision from the drilling decision to capture the fact that it is the drilling decision and not the production decision that responds to oil price changes. By modelling the extraction cost to be convex and to have stock effect, I capture some of the features delivered by these model. More precisely, the convexity in costs allows for the extraction to be concave.

<sup>3</sup>This condition ensures that the marginal cost during a discrete time interval consists

**Assumption 2 (Weak convexity).** The principal minor determinants should be nonnegative  $\frac{\partial^2 G}{\partial x^2}, \frac{\partial^2 G}{\partial s^2}, \left[ \frac{\partial^2 G}{\partial x^2} \frac{\partial^2 G}{\partial s^2} \right] - \left[ \frac{\partial^2 G}{\partial x \partial s} \right]^2$

The second assumption does not allow for possibility of learning-by-doing externality. Also the convexity assumption on the cost function ensures that the second-order conditions for optimality are satisfied. The objective function for the maximization problem below is concave and the set of optimal choices is convex.

## 2.2.2 Resource Price

This paper is concerned with the simultaneous determination of the optimal extraction and saving path for a exhaustible-resource-rich small-open economy. It is, however, not concerned with the determination of the expected price trajectory or the reasons for the fluctuations of the price. Therefore, taking  $p_t$  to be trendless in the long-run as in [Cynthia Lin and Wagner \(2007\)](#) and [Borensztein et al. \(2013\)](#), it can be specified as an AR(1) multiplicative error process, such that

$$p_{t+1} = ((1 - \rho)\bar{p} - \rho p_t)\varepsilon_{t+1}$$

$\bar{p}$  is the unconditional mean of the resource price,  $\rho$  is the persistence parameter of the price process, and  $\varepsilon$  is a lognormally distributed random shock. [Cynthia Lin and Wagner \(2007\)](#) show the inclusion of convex extraction costs in conjunction with technological progress in the extraction of exhaustible resources result in a trendless price process. Also, [Borensztein et al. \(2013\)](#) maximum likelihood estimation of several commodity prices give reason to believe that this specification adequately represents the price process of an exhaustible resource. Mean-reversion in commodity prices is supported in the literature on commodity price dynamics such as [Deaton and Laroque \(1992\)](#) and the subsequent works, [Litzenberger and Rabinowitz \(1995\)](#), [Routledge et al. \(2000\)](#), and [Kogan et al. \(2009\)](#). In these models, storage and exhaustibility of the resource or constraints on investment in the resource sector give way to a mean-reverting price process.

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of two components: the additional cost incurred through additional extraction and the incremental cost of having lower stock within the period.

### 2.2.3 Resource Revenue

The government is the sole owner of the extractive sector and thus is in charge of the production of the resource. While full state ownership can be regarded as a strong simplification, many ERREs have been leaning towards nationalization of their resources. This is in part due to the surge in prices tipping the scale in favor of the state in the bargaining over production contracts with international companies. The government, as the benevolent social planner, thus sells the exhaustible resource,  $X_t$ , produced in time  $t$  abroad at price  $p_t$ , and can save part of its export receipts abroad,  $A_t$  at the world risk free rate  $r$  and use its external savings to transfer the resource wealth from one period to another. There is a non-exhaustible resource sector or a conventional sector that uses only labor to produce the consumption good in the economy:

$$Y_t = ZL_t \quad (2.1)$$

where  $Z$  stands for a constant productivity and where labor grows over time deterministically such that,

$$L_{t+1} = (1 + n)L_t \quad (2.2)$$

### 2.2.4 Social Planner's Problem

Assuming the planner of the economy is a benevolent social planner maximizing lifetime utility of its agents, the optimal consumption, saving, and extraction paths are the solution to the following problem,

$$\max_{\{C_t, X_t, A_{t+1}, S_{t+1}\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t L_t U(C_t/L_t)$$

subject to:

$$C_t + A_{t+1} = Y_t + (1 + r)A_t + p_t X_t - G(S_t, X_t)$$

$$L_{t+1} = (1 + n)L_t$$

$$X_t = S_t - S_{t+1}$$

$$p_{t+1} = ((1 - \rho)\bar{p} + \rho p_t)\epsilon_{t+1}$$

with  $X_t \geq 0$ ,  $S_0$  and  $A_0$  are given.

The social planner chooses the optimal consumption and extraction today, next periods net foreign asset holdings,  $A_{t+1}$  and the next beginning period remaining resource stock  $S_{t+1}$ , given the remaining resource stock today and the net foreign asset holdings today. Household preferences are described by a CRRA utility function with  $\gamma$  as the degree of risk aversion and the inverse elasticity of intertemporal substitution.

Recasting the problem in terms of effective units of labor, denoted with their lower case counterparts, such that  $c_t = \frac{C_t}{ZL_t}$ , the representative agent's utility maximization problem becomes:

$$\begin{aligned} & \max_{\{c_t, x_t, a_{t+1}, s_{t+1}\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} (\beta(1+n))^t \frac{c_t^{1-\gamma}}{1-\gamma} \\ (\lambda_t) \quad & c_t + (1+n)a_{t+1} = y_t + (1+r)a_t + p_t x_t - G_t(s_t, x_t) \\ (\theta_t) \quad & s_{t+1} = \frac{s_t - x_t}{1+n_t} \\ (\zeta_t) \quad & x_t \geq 0 \\ & p_{t+1} = ((1-\rho)\bar{p} + \rho p_t)\epsilon_{t+1} \\ & s_0, a_0, \text{ given} \end{aligned}$$

$\lambda_t$ ,  $\theta_t$ , and  $\zeta_t$  are the per-period Lagrange multipliers corresponding to each one of the constraints.

## 2.2.5 Optimality conditions

The resulting optimality conditions are:

$$u'(c_t) = \beta(1+r)E_t \{u'(c_{t+1})\} \tag{2.3}$$

$$u'(c_t) \left( p_t - \frac{\partial G(s_t, x_t)}{\partial x_t} \right) \begin{cases} = \theta_t & : x_t > 0 \\ \leq \theta_t & : x_t = 0 \end{cases} \tag{2.4}$$

$$\theta_t = \beta E_t \left\{ \theta_{t+1} - u'(c_{t+1}) \frac{\partial G(s_{t+1}, x_{t+1})}{\partial s_{t+1}} \right\} \tag{2.5}$$

$$\lim_{t \rightarrow \infty} \theta_t \beta^t s_{t+1} = 0 \quad \text{and} \quad \lim_{t \rightarrow \infty} \lambda_t \beta^t a_{t+1} = 0 \quad (2.6)$$

### Extraction decision

Equation (2.4) characterizes the optimal extraction decision at price  $p_t$ . In any given period, the optimal extraction incurs two costs. There is the direct cost of extracting an additional unit of the exhaustible resource,  $\frac{\partial G(s_t, x_t)}{\partial x_t}$ , and the opportunity cost of having one less unit of reserves in the future, as captured by the shadow price of extraction  $\theta_t$ . This optimality condition tells us that in the case where the marginal net benefit of extraction in util terms,  $u'(c_t) \left( p_t - \frac{\partial G(s_t, x_t)}{\partial x_t} \right)$ , is too low relative to the opportunity cost of extracting one more unit, then it is optimal not to extract. It would be optimal to keep the resource underground until the marginal benefit,  $u'(c_t)p_t$ , would be high enough to offset the prohibitive costs of extraction.<sup>4</sup>

Equation (2.5) describes the law of motion for the opportunity cost of extraction,  $\theta_t$ . Stock effects are associated with a time-varying growth in opportunity cost of extraction. Without the dependence of the extraction cost on the stock level, the opportunity cost incurred when extracting a unit of the underground resource would be would grow at the rate of interest.

Iterating forward, we can derive an expression for the opportunity cost of extraction as the present discounted value of the cumulative incremental increases in the cost of extraction (in util terms) due to one unit of extraction today.

$$\theta_t = -E_t \sum_{\tau=t+1}^{\infty} \beta^{\tau-t} u'(c_\tau) \frac{\partial G(s_\tau, x_\tau)}{\partial s_\tau} + \lim_{T \rightarrow \infty} \beta^{T-t} E_t \{ \theta_T \} \quad (2.7)$$

The last term on the right hand side equals zero at the limit and therefore can be discarded. The opportunity cost amounts to the subsequent

<sup>4</sup>For the rest of the paper, the cost function specification is a convex function such that  $G(s_t, x_t) = \frac{K}{2} \frac{x_t^\zeta}{s_t^\chi}$ , where  $K$  is an adjustment cost parameter associated with the physical and other exogenous factors governing the speed of extraction.  $\zeta$  controls the convexity of the cost function and  $\chi$  governs whether to account for stock effects for extraction. The baseline cost function is quadratic in extraction ( $\zeta = 2$ ) and accounts for stock effects ( $\chi = 1$ ). This specification allows for stock effects to extraction but no full depletion. Should there be complete depletion of the exhaustible resource, the opportunity cost would be infinite. Other parametrization will be explored in the sensitivity analysis in section 2.4.

extraction cost increases, in util terms, attributed to having on less unit of the exhaustible resource today.

### **Saving in the risk-free asset**

Equation (2.3) is the standard Euler equation governing the decision of forgoing one unit of consumption today for tomorrow. The agent, thus, must be indifferent between the utility loss from the forgone unit of consumption today and the present discounted value of utility gain of consuming an extra unit tomorrow.

### **Saving in the risky asset**

The decision to keep the marginal unit of the exhaustible resource underground is governed by the Euler equation (2.5) and is re-written by substituting in (2.4) for  $\theta$  and assuming an interior solution, such that:

$$u'(c_t) \left( p_t - \frac{\partial G(s_t, x_t)}{x_t} \right) = \beta E_t \left\{ u'(c_{t+1}) \left( p_{t+1} - \frac{\partial G(s_{t+1}, x_{t+1})}{x_{t+1}} - \frac{\partial G(s_{t+1}, x_{t+1})}{s_{t+1}} \right) \right\}$$

The marginal loss from not extracting in the current period, in util terms, must be compensated by an expected marginal benefit from extracting in the next period, taking into account the marginal value of not depleting the resource (the last term on the right-hand side of the expression). The underground resource acts as a second vehicle for allocating an economy's wealth intertemporally with a return that is determined by the expected growth in the marginal benefit from extraction. This expression also shows that the decision depends on the intertemporal marginal rate of substitution. The interaction between consumption growth and the payoff on the *in situ* asset will be explicitly defined in the section below.

### **A risk-adjusted Hotelling rule and the extraction-saving nexus**

The extraction and saving decision facing households is akin to an optimal portfolio decisions whereby households can either hold their savings above ground in a risk-free asset or keep the resource underground, thus holding on to the *in situ* asset and expecting a payoff that would compensate for the associated risk. Combining the two Euler equations of the model, by substituting equation (2.4) in (2.5) when  $x_t > 0$  and  $s_{t+1} > 0$  and

using the Euler equation (2.3), delivers a risk-adjusted Hotelling rule.<sup>5</sup> The return on the *in situ* asset, and therefore the incentive to keep the marginal unit of the resource underground instead of extracting it, is thus a function of the relation between its payoff and consumption, as well as the risk-free rate.

$$E_t\{r_{x,t+1}\} - r = -(1+r)cov_t\{m_{t+1}, 1+r_{x,t+1}\} \quad (2.8)$$

Assuming that the price of the resource varies positively with consumption, households demand a positive premium above the risk-free rate to keep the marginal unit of the exhaustible resource underground.<sup>6</sup> Without uncertainty, the covariance term would be zero and households would be indifferent towards either increasing their external savings or keeping the resource underground. Uncertainty introduces a wedge between the two returns to compensate households for taking the risk of holding on to the resource. The stronger the relation between consumption and the return on the resource the greater the return required. With an exogenously given resource price, increases in the return on the *in situ* resource entail decreasing the marginal cost of extraction. Thus, when the share of resource wealth dominates in the economy, the undiversified risk (i.e. a strong correlation) requires rapid extraction. As the role of resource wealth in the economy weakens, so does the economy's exposure to risk and the correlation between consumption and the payoff.

To show more explicitly how uncertainty and prices influence the extraction decision, we can re-formulated the risk-adjusted Hotelling rule, by writing the current marginal cost as a function of the next-period marginal cost, the rate of change in price and the covariance between consumption growth and the marginal benefit from extracting the resource. Since the price shock,  $\varepsilon$ , is lognormally distributed with mean  $\mu$  and standard deviation  $\sigma$ , its the expected value can be written as  $E_t\{p_{t+1}\} = ((1-\rho)\bar{p} - \rho p_t)e^{(\mu_\varepsilon + \sigma_\varepsilon^2/2)}$ .<sup>7</sup>

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$${}^5 m_{t+1} = \beta E_t \left\{ \frac{u'(c_{t+1})}{u'(c_t)} \right\}, \text{ and } 1 + r_{x,t+1} = \frac{\left( p_{t+1} - \frac{\partial G(s_{t+1}, x_{t+1})}{\partial x_{t+1}} - \frac{\partial G(s_{t+1}, x_{t+1})}{\partial s_{t+1}} \right)}{\left( p_t - \frac{\partial G(s_t, x_t)}{\partial x_t} \right)}$$

<sup>6</sup>The positive relation between asset markets and oil prices is documented in [Kilian et al. \(2009\)](#) and [van den Bremer et al. \(2016\)](#).

<sup>7</sup>Let  $\tilde{p}_{t+1} = p_{t+1} - \frac{\partial G(s_{t+1}, x_{t+1})}{\partial x_{t+1}} - \frac{\partial G(s_{t+1}, x_{t+1})}{\partial s_{t+1}}$ .

$$\begin{aligned} \frac{\partial G(s_t, x_t)}{\partial x_t} = & p_t - \frac{1}{1+r} E_t \left\{ p_{t+1} - \frac{\partial G(s_{t+1}, x_{t+1})}{\partial x_{t+1}} - \frac{\partial G(s_{t+1}, x_{t+1})}{\partial s_{t+1}} \right\} \\ & - COV_t \left\{ \beta \frac{U'(c_{t+1})}{U'(c_t)}, p_{t+1} - \frac{\partial G(s_{t+1}, x_{t+1})}{\partial x_{t+1}} - \frac{\partial G(s_{t+1}, x_{t+1})}{\partial s_{t+1}} \right\} \end{aligned}$$

This expression delivers three important insights about factors affecting the extraction decision in the current period. First, extraction depends on the expected increase in the marginal extraction cost. As extraction costs become penalising in the future, extraction today increases. Second, a high current price speeds up extraction. An increase in the volatility of the price shocks,  $\sigma_c^2$ , increases the conditional expected value  $E_t\{p_{t+1}\}$ , therefore lowering the incentive to extract today. Third, a second effect of uncertainty on extraction emanates from relation between consumption growth with the marginal benefit of extracting the resource; a strong positive covariance term between the consumption growth and the future payoff from extraction leads to a higher extraction rate today.

This time-varying covariance arises precisely because the underground resource is exhaustible and its share in the economy is eventually outweighed by the share of external assets. As the underground wealth dwindles over time, taking up a smaller share in the economy, the covariance between consumption growth and the net marginal benefit from the resource would grow weaker. The economy would accumulate large external savings that the relative share of the resource income in the total output is no longer so significant, and the change in consumption would not be strongly linked to the growth in the net marginal revenue from the extractive sector. Thus, the smaller is the share of the resource in total output, the weaker is the covariance term and the less the positive effect it has on the current extraction rate.

The above expression therefore indicates two opposing effects of uncertainty on the extraction rate. On the one hand, higher price shock volatility increases the conditional expected price of the *in situ* resource and thus creates an incentive to hold on to the marginal unit of resource. On the other hand, uncertainty renders the underground resource a risky asset and therefore encourages extraction today. Since a stronger covariance terms induces higher extraction, the incentive to rapidly deplete the resource is higher when reserves are high and the share of the exhaustible resource is a significant part of the country's wealth. As its reserves decline and the country is exposed to less risk, the covariance term weakens

and the extraction rate slows down. While the amount of external savings does not directly affect the extraction decision, it does so through the feedback effect of savings on the risk in the economy. A high share of external savings relative to the share of the underground asset affects the exposure of the economy to risk.

### **Time-varying precautionary saving**

The discussion thus far has focused on how uncertainty creates an incentive to rapidly extract the resource by imposing a risk premium on the *in situ* asset. Another implication of the result is that the incentive to lower the economy's exposure to risk translates into accumulating risk-free assets abroad and diminishing the role of the exhaustible resource in the economy.

The linearized version of risk-adjusted Hotelling equation shows how consumption growth is in part driven by a time-varying precautionary motive.<sup>8</sup> The motive to save is driven by the expected return on the resource, its variance, the variance of the consumption path, and the correlation between consumption and the payoff on the resource.

$$E_t(\ln \Delta C_{t+1}) = \frac{1}{\gamma} \left[ -\ln \beta + E_t(\ln R_{t+1}) + \frac{1}{2}(\sigma_{r,t}^2 + \gamma^2 \sigma_{\Delta,t}^2 - 2\gamma \sigma_{r\Delta,t}) \right] \quad (2.9)$$

Since these uncertainty-driven terms are time-varying, weakening as the risk in the economy disappears along with the depletion of the resource, the larger are the external savings relative to the resource wealth, the lower is the risk. This feedback effect implies a weaker covariance between consumption and the return on the resource, and eventually a slower extraction rate.

To summarize, the discussion thus far has shown how returns on the exhaustible resource and uncertainty influence the rate at which the exhaustible resource is depleted and the role of saving in managing the resource wealth and the economy's exposure to risk. The theoretical results deliver the following insights: 1) the accumulation of external savings is accompanied by faster extraction; 2) the expected growth in prices lower current extraction; 3) uncertainty about the return on the resource speeds up extraction because the covariance between consumption the return on the *in situ* risky asset is positive and strong when the economy is resource

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<sup>8</sup>Where  $G_x = \frac{\partial G}{\partial x_t}$ ,  $\ln \Delta C_{t+1} = \ln C_{t+1} - \ln C_t$  and  $\ln R_{t+1} = \ln \tilde{p}_{t+1} - \ln \tilde{p}_t$ .  $\sigma_r^2$  is the variance of the return on the *in situ* resource,  $\sigma_{\Delta}^2$  is the variance of  $\ln \Delta C_{t+1}$ , and  $\sigma_{r\Delta}$  is the covariance between the return on the *in situ* resource and consumption growth.

rich and cannot completely diversify away from the related risk.

## 2.3 Simulation and results

### 2.3.1 Numerical method

The model is solved numerically using the value function iteration method over the recursive formulation of the representative agent's problem. The stochastic price process is approximated by gauss-hermite quadrature. The state space is discretized over  $[\underline{A}, \bar{A}] \times [\underline{S}, \bar{S}] \times [\underline{P}, \bar{P}]$  and the value function specified below is maximized with respect to next period assets and remaining reserves over all possible combinations in the state space. To circumvent the curse of dimensionality presented by the three dimensional state space, I approximate the value function using a cubic spline approximation scheme.

$$V_t(a_t, s_t, p_t) = \max_{c_t, x_t, a_{t+1}, s_{t+1} \in \Gamma(s_t)} \{U(c_t) + \beta E_t[V_{t+1}(a_{t+1}, s_{t+1}, p_{t+1})]\}$$

$$c_t = y_t + (1 + r)a_t - (1 + n)a_{t+1} + p_t x_t - G(s_t, x_t)$$

$$s_{t+1} = \frac{s_t - x_t}{(1 + n)}$$

$$p_{t+1} = ((1 - \rho)\bar{p} - \rho p_t)\varepsilon_{t+1}$$

$$\Gamma(s_t) = \{s_{t+1} \in S : 0 \leq (1 + n)s_{t+1} \leq s_t\}$$

The solution of the value function iteration delivers two time-invariant policy functions  $a_{t+1} = g(a_t, s_t, p_t)$  and  $s_{t+1} = h(a_t, s_t, p_t)$ . The average time paths of the model's variables are based on initial foreign asset holdings and reserves that match the sample average net foreign asset holdings over GDP and oil and gas reserves in 1980. Since reserves data availability is limited for many commodities, the calibration in this dimension is set to match the average initial state variable values for oil and gas producers.

In order to determine the contribution of the precautionary saving, we normally compare the solution of the stochastic problem, with the deterministic solution using the conditional mean of the price process as in [Bems and de Carvalho Filho \(2011\)](#). While the difference between the net foreign asset position from the two solutions hints at the contribution of

the precautionary savings, it does not capture the full picture as it abstracts from addressing the interaction between the saving decision and the extraction decision. Therefore, I solve the stochastic model, taking the extraction path as given and compare its equilibrium saving path to the stochastic version with endogenous extraction. The exogenous extraction path is taken from the stochastic extraction equilibrium solution. The difference between the full solution (stochastic model with endogenous extraction) and the partial solution (stochastic model with a given extraction path) will capture the demand for foreign assets which reflects the impact of endogenously time-varying income uncertainty.

### **2.3.2 Baseline parametrization**

The model is calibrated to match some key moments of the average economy out of the sample of the ERREs introduced in the above discussion. The sample of countries includes those that have observed data for net foreign assets, oil and gas reserves, real consumption and income growth. The sample in consideration for the numerical exercise includes: Algeria, the Republic of Congo, Gabon, Iran, Kuwait, Libya, Nigeria, Norway, Oman, Saudi Arabia, Trinidad and Tobago. Although this sample is not exhaustive with regards to all the possible ERREs, it offers a diverse group of countries with differing resource endowments, geological conditions for their reserves, and net foreign asset positions.<sup>9</sup> The baseline model parameters are set to generate a standard deviation of consumption, income, and extraction growth close to their empirical counterparts for the sample average over the past three decades (1980 to 2011).

Two parameters are most relevant to the solution of the problem at hand. First, the degree of prudence, which governs the strength of the precautionary motive plays a central role in determining the saving behavior and consequently the rate of depletion of the exhaustible resource. The second key parameter is the extraction cost adjustment parameter. This parameter is a catch-all parameter and encompasses the exogenous factors that affect the extraction rate. Taking the adjustment cost parameter as closely related to the physical conditions associated with extraction, its calibrated value is central to extraction and saving equilibrium outcomes. While there is guidance from the literature on the prudence parameter of a small-open economy, the parameter for the extraction cost is not as well

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<sup>9</sup>The sample is determined by data availability for countries for which oil and gas plays an important macroeconomic role.

informed. In order to pin down these two parameter, I minimize the square distance between sample moments and their empirical counterparts. The volatility of the extraction rate, income and consumption are intimately intertwined through the extraction rate cost parameter and the strength of the precautionary motive, I use them as the three moments that help identify the two aforementioned parameters for the sample average.

$$\min_{\phi} \frac{1}{T} \sum_{t=1}^T \left[ (h_t - \bar{h}_t^S(\phi))^2 - \frac{1}{S(S-1)} \sum_{t=1}^T (h_t(u_t^S, \phi) - \bar{h}_t^S(\phi))^2 \right]$$

with  $h_t = [\ln \Delta y_{t+1}; \ln \Delta c_{t+1}, \ln \Delta x_{t+1}]$  and  $\phi = [K, \gamma]$ .

The remaining parameters are well informed in the literature. The preference parameters ( $\beta, r$ ) are standard in the literature:  $\beta = 1/(1+r)$ , and the risk-free interest rate is  $r = 0.04$ . The growth rate in the economy is set to the average rate among the ERREs over the last four decades,  $n = 0.02$ . The parameters for the price process ( $\rho, \sigma_{\epsilon}, \bar{p}$ ) are those delivered from a maximum likelihood estimation, following [Bems and de Carvalho Filho \(2011\)](#) and [Borensztein et al. \(2013\)](#) for the observed average crude oil prices in the period. The unconditional mean of the commodity price,  $\bar{p} = 39.1$ , the persistence parameter is  $\rho = 0.89$ , and the standard deviation of the shock is  $\sigma_{\epsilon} = 0.2$ . The baseline calibration is summarized in [Table 2.1](#).

Table 2.1: Baseline calibration

Parameters	Baseline
$\gamma$ : inverse EIS	2
$\beta$ : discount factor	$1/(1+r)$
$r$ : risk-free rate	0.04
$K$ : extraction cost	30
$\rho$ : persistence of price	0.89
$\sigma_{\epsilon}$ : std. of shock	0.2
$\bar{p}$ : unconditional mean	39.1
$n$ : population growth	0.02
$\zeta$ : curvature of $G$	2
$\chi$ : stock effects	1

### 2.3.3 Baseline model results

The simulation of the model delivers the average equilibrium path for net foreign assets and remaining reserves using the aforementioned calibration of an average country in the sample, with initial values for assets and

reserves representing the average values in 1980. The problem was solved under three specifications: 1) a model with no uncertainty ( $\sigma_\epsilon = 0$ ), in which the path of extraction is determined endogenously; 2) a full model with both resource price shocks and endogenous extractions; 3) a partial model where the extraction path is exogenous and taken as the same path as the one generated by the full model with endogenous extraction. Using the resulting policy functions from these specifications, I simulate time paths for each model specification and take the average path for the variables of interest. The results are depicted in Figure 2.5 and Figure 2.6.

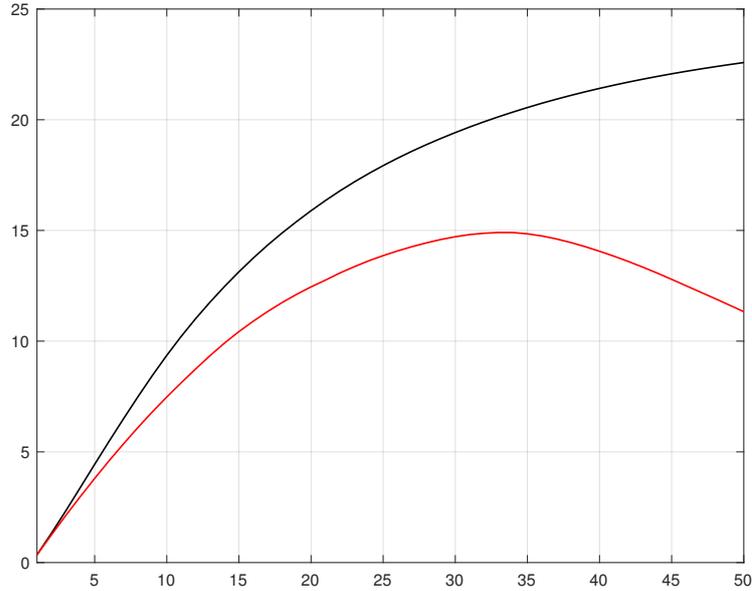
**Endogenous extraction** Noting that the average time paths for the remaining reserves in the exogenous and endogenous stochastic solutions are the same, the saving behavior differs substantially as depicted in Figure 2.5. Allowing for the endogenous determination of the extraction path delivers a stark difference between the level of net foreign assets held in the two specifications of the model. Endogenous extraction offers two ways for households to intertemporally allocate their wealth and to protect themselves against uncertainty. Households can manage their wealth and smooth their consumption by not only deciding how much consumption to forgo and save at the risk-free rate at any one time, but also by how much of the underground resource to deplete today instead of saving it underground and extracting it tomorrow. These decisions are governed by the relative returns on risk-free foreign assets and the expected return on the underground asset as captured in equation (2.8).

In a model where extraction is exogenous, the saving decision is determined by the risk-free rate of return, by household preferences, and the volatility in consumption path. When extraction becomes a choice variable, additional factors enter into the decision making process. Households care about the opportunity cost of extracting today and about the risk underlying the value of the *in situ* resources. These additional considerations heighten the need to accumulate safer assets, precisely because there is a link between growth in consumption and the return on the *in situ* resource.

The excess demand for the risk-free asset expresses the need for the ERREs to shift their wealth from the exhaustible resource to savings with more certain returns.<sup>10</sup> A novel insight that this model delivers, unlike

<sup>10</sup>Of course, insights from this model are those of a partial equilibrium setting that cannot account for the feedback of the extraction and saving decision on prices for both

Figure 2.5: Optimal saving and endogenous extraction



*Notes:* The average time paths for net foreign asset holdings  $\bar{A}$  under the partial model with exogenous extraction and the full model with endogenous extraction represented in red and black lines, respectively.

its partial counterpart with exogenous extraction, is the link between extraction and the accumulation of external savings. Total savings, both for intergenerational allocation and for shielding the economy against fluctuation, are significantly larger.<sup>11</sup> Therefore having control over the extraction rate of the exhaustible resource generates greater savings.

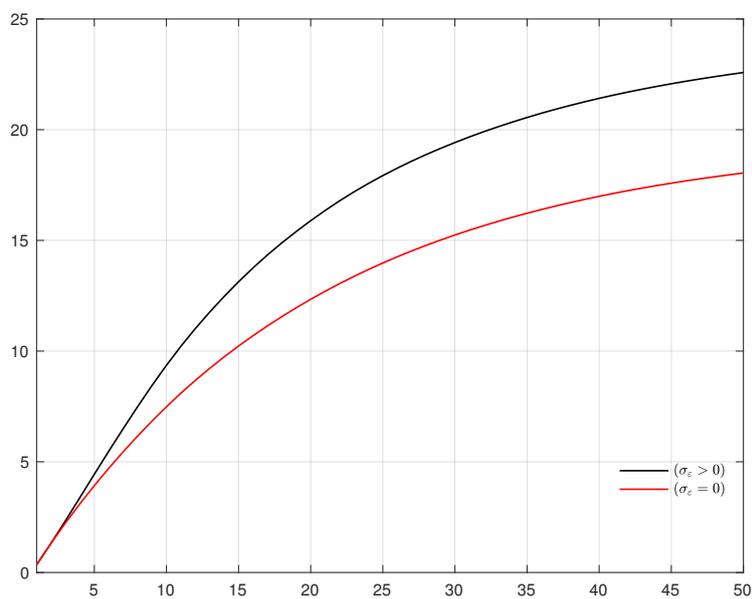
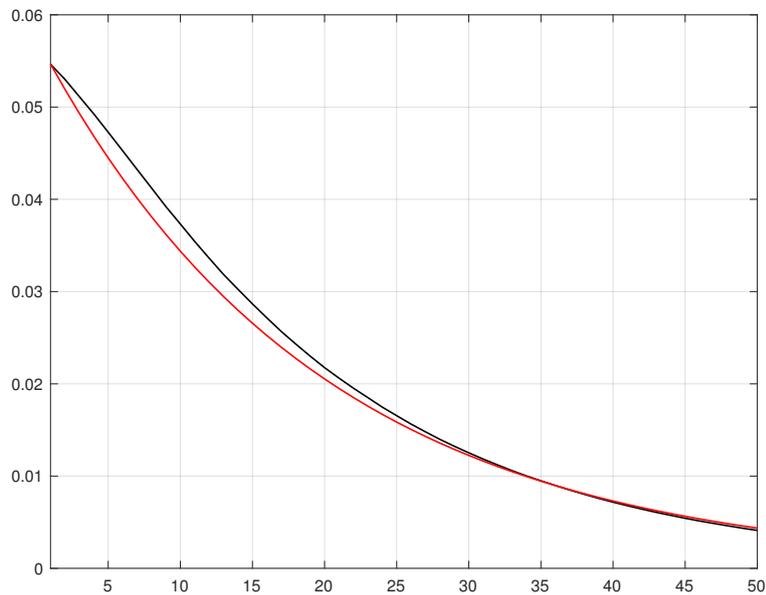
**Extraction and uncertainty** Uncertainty creates a precautionary demand for external savings and speeds up extraction of the exhaustible resource (Figure 2.6a). As in van den Bremer et al. (2016), uncertainty reduces the opportunity cost of depleting a marginal unit of the exhaustible resource and therefore results in a faster extraction rate than in the absence in price volatility, at least while reserves are still high and the share of resource wealth in the economy is high. As the exhaustible resource

types of assets: the return on the risk-free asset and the price of the resource.

<sup>11</sup>The difference in expected growth rates between the two models – the specification with exogenous extraction has two state variables  $a$  and  $p$  and the full specification adds  $s$  as a state variable – can be derived from the linearized version of the euler equation 2.9 such that :

$$E_t\{\ln \Delta C_{t+1}(a, p)\} - E_t\{\ln \Delta C_{t+1}(a, s, p)\} = \gamma^2(\sigma_{\Delta}^2(a, p) - \sigma_{\Delta}^2(a, s, p))$$

Figure 2.6: Uncertainty, saving and extraction

(a)  $\bar{A}$ (b)  $\bar{X}$ 

Notes: The average time paths for net foreign asset holdings  $\bar{A}$  and for extraction  $\bar{X}$  under the deterministic and stochastic versions of the model are represented in black and red lines, respectively.

takes a less significant role in the whole economy, the extraction rate ap-

proaches that of the deterministic model. Under this parametrization, uncertainty results in 16 % less reserves (Figure 2.6b).

### 2.3.4 Country-specific results

To simulate country-specific results, heterogeneity across countries is limited to their initial net foreign asset holdings and their initial reserves, which are both set to their country-specific 1980 value. Initial values for net foreign assets are obtained from Lane and Milesi-Ferretti (2007) and for the reserves, initial values are based on Rystad's UCube data. Countries are also set to differ in their extraction cost parameter that captures exogenous factors affecting a country's ability to deplete its resources. This parameter is calibrated using two sets of information. First, I calculate the relative of average cost using information from World Bank Development Indicators data on gas and oil rents. I set the reference average cost as Algeria's average cost in 2007 and create a ratio of the average 2007 cost of countries in the sample with respect to the reference country's average cost:  $\frac{\bar{G}_i}{\bar{G}_{DZA}}$ . Average production cost ranges from USD 3.7 to USD 15 per barrel. I also obtain a production per reserve ratio for each country relative to the reference country's production per reserve ratio:  $\frac{(X/S)_i}{(X/S)_{DZA}}$ . Since the latter ratio is a proxy for scarcity of the resource, it can be used conjointly with the relative cost ratio to back out a relative adjustment cost parameter  $\frac{K_i}{K_{DZA}}$ . The values for the relative adjustment cost parameter range from 0.24 to 2.80.  $K_{DZA}$  is then set such that the share of extraction in output in the data for Algeria matches the one in the model. This reference parameter value

The results for the country-specific calibration are summarized by the time series moments in 2.4. Given that the reference country used in this exercise is Algeria, the model matches quite well its empirical moments, particularly the volatility in GDP growth and the correlation between growth in resources rents and GDP. However, the model generates much more consumption smoothing, which lowers the correlation between consumption growth and GDP growth. The model generates excessive consumption smoothing for most countries and fails to match the correlation between output growth and the growth rate in resource rents, although it generates the right relationship in most cases.

For the Congo, Gabon, and Trinidad, countries endowed with small reserves compared to the rest of the sample, the share of the resource in total output is small leading to a small role of risk emanating from price

Table 2.2: Comparison of data and model moments

Countries	$A_{1980}$	$S_{1980}$	$\frac{K_i}{K_{DZA}}$
COG	-1.81	3.87	1.56
DZA	-0.48	67.64	1.00
GAB	-0.97	4.88	1.44
IRN	0.22	416.06	0.24
KWT	9.03	135.06	0.33
LBY	1.23	74.03	0.46
NGA	0.09	94.13	0.54
NOR	-0.41	53.99	2.15
OMN	0.37	18.89	1.48
SAU	3.59	417.53	0.46
TTO	0.10	8.30	2.80

Notes:  $A_{1980}$  is the net foreign asset position as a share of non-resource GDP.  $S_{1980}$  is the reserves quantity in billions of barrels of oil equivalent. A relative adjustment cost parameter  $\frac{K_i}{K_{DZA}}$  that is obtained by the ratio of two ratios: the relative average cost  $\frac{\bar{G}_i}{\bar{G}_{DZA}}$  and the relative production per reserve ratio:  $\frac{(X/S)_i}{(X/S)_{DZA}}$ .

fluctuations. This is reflected in a very low standard deviation of consumption and income in the model because the only source of uncertainty in the model is linked to resource income; the model abstracts from other possible sources that can create more volatile income and consumption streams.

Iran, Kuwait, and Saudi Arabia are on the other end of the spectrum in terms of their resource endowments. The large share of resource income in their economy exposes them to higher risk giving rise to the opposite problem of having much more volatile consumption and income paths than in the data.

The model performs well for countries with moderate resource endowments such as Algeria, Libya, and Norway. For Norway, the moments match quite well, except the correlation between income and the return on the underground resources (as measures by the growth in resource rents). This could be due to their ability to hedge the resource risk through their well diversified sovereign wealth fund.

## 2.4 Sensitivity analysis and extensions

Several assumptions about the functional form of the extraction cost function, about the strength of mean reversion in the resource price, the variance of the price shock, and household preferences have been made. To

Table 2.3: Comparison of data and model moments

Countries		std. $\Delta C$	std. $\Delta Y$	std. $\Delta X$	$Cor(\Delta C, \Delta Y)$	$Cor(\Delta R, \Delta Y)$
COG	<i>Model</i>	0.00	0.01	0.23	0.50	0.20
	<i>Data</i>	0.08	0.20	0.09	0.51	0.11
DZA	<i>Model</i>	0.03	0.16	0.24	0.33	0.14
	<i>Data</i>	0.15	0.16	0.11	0.87	0.15
GAB	<i>Model</i>	0.00	0.02	0.23	0.71	0.43
	<i>Data</i>	0.08	0.16	0.09	0.59	-0.02
IRN	<i>Model</i>	0.21	0.39	0.31	0.12	0.05
	<i>Data</i>	0.06	0.14	0.18	0.92	-0.26
KWT	<i>Model</i>	0.08	0.28	0.28	0.18	0.05
	<i>Data</i>	0.08	0.19	0.91	0.48	0.25
LBY	<i>Model</i>	0.04	0.21	0.26	0.24	0.08
	<i>Data</i>	0.15	0.24	0.19	0.59	0.24
NGA	<i>Model</i>	0.05	0.22	0.25	0.26	0.12
	<i>Data</i>	0.17	0.27	0.32	0.88	0.36
NOR	<i>Model</i>	0.02	0.10	0.22	0.84	0.62
	<i>Data</i>	0.02	0.09	0.10	0.92	-0.00
OMN	<i>Model</i>	0.01	0.06	0.23	0.87	0.62
	<i>Data</i>	0.04	0.14	0.16	0.61	0.38
SAU	<i>Model</i>	0.17	0.37	0.26	0.16	0.09
	<i>Data</i>	0.06	0.12	0.16	0.58	0.47
TTO	<i>Model</i>	0.00	0.02	0.22	0.86	0.61
	<i>Data</i>	0.14	0.14	0.10	0.60	0.13

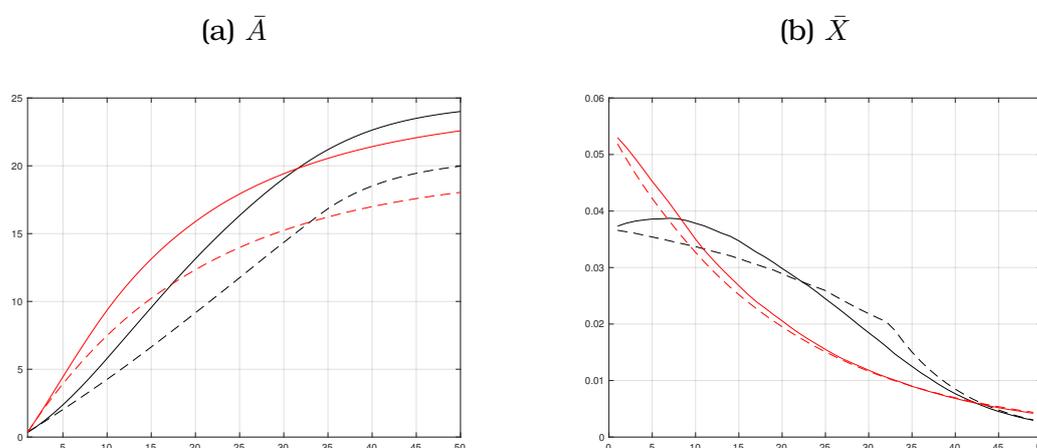
*Notes:* The sample is based on data coverage years 1980 to 2011.  $\Delta C$ ,  $\Delta Y$  represent the per capita growth rates in consumption and output, respectively.  $\Delta X$  and  $\Delta R$  represent growth in the extraction rate and in resource rents, respectively. Data series for per capita consumption and per capita output are from the World Bank Development Indicators. Production and reserves data from Rystab UCube.

examine the sensitivity of the results of these specification and to understand how different features affect the saving and extraction decisions, several parameter changes are studied.

**Cost function** The extraction path is very much determined by the functional form of the extraction cost function, thus it can not only affect the rate at which the exhaustible resource is depleted but also the saving behavior in the economy. As discussed in section 2.2.4, stock effects render the growth rate in the opportunity cost (or the value of the marginal unit

of reserve) time-varying and lower than the rate of interest. With no stock effects,  $G(x, s) = \frac{K}{2}x^2$ , the opportunity cost of depleting the resource grows at the rate of interest, which is faster than in the case of a cost function with stock effects. As a consequence, the extracted quantity, depicted in Figure 2.7b, is higher in the beginning when  $S$  is large but declines steadily and faster than in the case with stock effects precisely because the stock effects become increasingly more punishing. In the end, more of the resource is depleted when stock effects are removed with 15 % more extraction (see the second row in Table 2.4).

Figure 2.7: Extraction cost function with no stock effects ( $\chi = 0$ )



*Notes:* The red lines represent time path for net foreign assets and extraction from the baseline calibration. The black lines represent the solution with a cost function that does not account for stock effects. The dashed line is the average time path from the deterministic solution and the solid line is the stochastic solution.

The effect of uncertainty on the amount extracted is smaller, with 2.5 % more extraction than the 4.8 % with stock effects. The demand for external saving is also lower (4 % lower) with a smaller buffer stock (8 % smaller). An extraction function with no stock effects provides more flexibility to the extraction decision and therefore allows for greater ability to allocate underground resources through time and across states of the world.

The extraction cost adjustment parameter can either slow down or speed up the rate at which the resource is depleted. The lower the adjustment cost (e.g. a 25% decrease), the faster the economy depletes its resources and the more it accumulates in external savings (12 % more over 50 years for both). The easier it is to adjust the extraction rate, the weaker the effect of uncertainty on the extraction decision and the less

Table 2.4: Comparative statics and the effect of uncertainty

Scenarios	$\frac{CA_{\sigma_\varepsilon > 0}}{CA_{\sigma_\varepsilon = 0}}$	$\frac{\sum_{t=1}^{50} X_{\sigma_\varepsilon > 0}}{\sum_{t=1}^{50} X_{\sigma_\varepsilon = 0}}$
baseline	16.24	4.41
$\chi - 1$	11.89	1.38
$\sqrt{0.75K}$	7.52	2.82
$\rho - 0.49$	10.85	2.44
$\sigma_\varepsilon - 0.1$	6.70	1.29
$\gamma + 2$	16.76	2.53
$\gamma - 1$	15.90	4.54

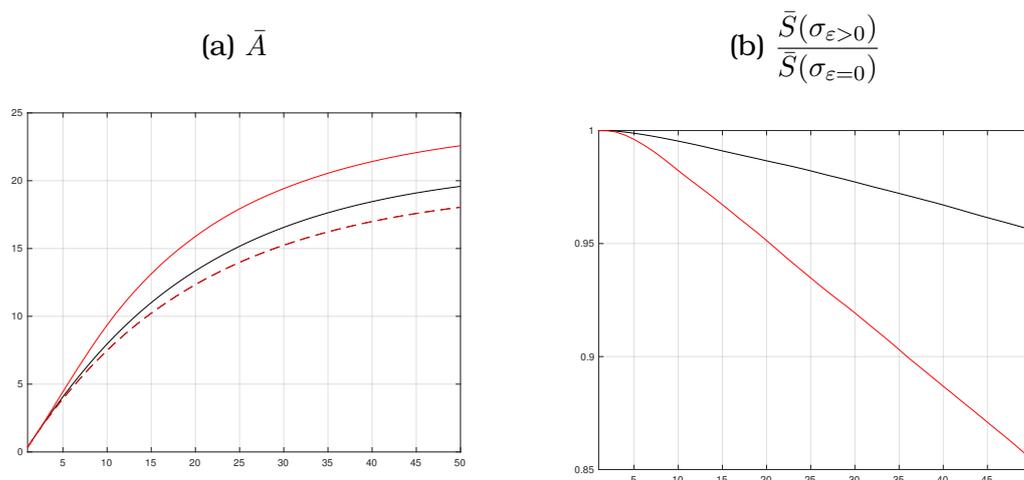
*Notes:*  $CA_{\sigma_\varepsilon = 0}$  represents the mean current account position over a 50 year period in the absence of resource price shocks.  $CA_{\sigma_\varepsilon > 0}/CA_{\sigma_\varepsilon = 0}$  represents the difference in the current account position between the deterministic model and its stochastic version, in percentage points. This difference measures the precautionary demand for external savings. Notation is equivalent for the extraction path under the two specifications.

precautionary savings (17 % less) the economy demands to mitigate price fluctuations, since it can do so, partially, by adjusting its production.

**Price process** The resource price process drives the dynamics of the model and the effect of uncertainty on the allocation of resources through different states of the world. Therefore parameters governing the persistence ( $\rho$ ) and volatility ( $\sigma_\varepsilon$ ) of the price shocks are essential for its quantitative performance. A decrease in either parameter weakens the effects of uncertainty on the decision to save and extract. Since this model tell us that uncertainty heighten the needs for savings and speeds up extraction, a lower level of uncertainty weakens the precautionary motive for building a buffer stock and at the same time, leaves more resources underground as depicted in Figure 2.8.

**Household preferences** Changes in risk aversion and the inverse intertemporal elasticity of substitution (*EIS*) parameter,  $\gamma$ , determine the degree to which households use savings to smooth out fluctuations in consumption through time and through unexpected price shocks. The savings and extraction do not change by much in this model when  $\gamma$  is increased or lowered. The only notable change is the effect of uncertainty on the extraction path. A higher  $\gamma$  lowers the total additional quantity extracted and a lower value increases this quantity. Since the utility function used thus far does not allow us to study the contribution of risk aversion,  $\phi$ , and *EIS*,  $\frac{1}{\gamma}$  seperately, I examine the results from the model using a Epstein-Zin recursive preferences captured in the following recursive for-

Figure 2.8: Less volatile prices



*Notes:* The dashed line is the average time path from the deterministic solution and the solid line is the stochastic solution. The red lines represent time paths for net foreign assets and the ratio of the reserves from the baseline calibration to the reserves from the deterministic solution. The black lines represent the time path for the model with a less volatile price.

mulation:<sup>12</sup>

$$V_t(a_t, s_t, p_t) = \max_{c_t, x_t, a_{t+1}, s_{t+1} \in \Gamma(s_t)} \left\{ (1 - \beta)c_t^{1-\gamma} + \beta E_t[V_{t+1}(a_{t+1}, s_{t+1}, p_{t+1})^{1-\phi}]^{\frac{1-\gamma}{1-\phi}} \right\}^{\frac{1}{1-\gamma}}$$

Table 2.5: Model moments with recursive preferences

Scenarios	$\frac{CA_{\sigma_\varepsilon > 0}}{CA_{\sigma_\varepsilon = 0}}$	$\frac{\sum_{t=1}^{50} X_{\sigma_\varepsilon > 0}}{\sum_{t=1}^{50} X_{\sigma_\varepsilon = 0}}$
$\gamma = \phi$	26.69	4.71
$\gamma > \phi$	105.80	5.06
$\gamma < \phi$	27.06	4.81

*Notes:*  $CA_{\sigma_\varepsilon = 0}$  represents the mean current account position over a 50 year period in the absence of resource price shocks.  $CA_{\sigma_\varepsilon > 0}/CA_{\sigma_\varepsilon = 0}$  represents the difference in the current account position between the deterministic model and its stochastic version, in percentage points. This difference measures the precautionary demand for external savings. Notation is equivalent for the extraction path under the two specifications.  $\gamma = \phi = 2$ ,  $\gamma = 4 > \phi = 2$ ,  $\gamma = 2 < \phi = 12$ . Values for  $\phi$  in the literature range from 2 to 12.

From the results in Table 2.5, lowering the elasticity of intertemporal substitution (EIS) while keeping the risk aversion coefficient constant gen-

<sup>12</sup>The baseline calibration is slightly modified such that  $\beta = .94$ . A smaller discount factor implies that households are more impatient than the market  $\beta(1+r) < 1$  and prefer to consume more today; they save less. The resulting external savings are less than in the baseline calibration.

erates substantially larger the precautionary saving relative to the baseline case, the expected utility model. This is accompanied by a greater depletion of the exhaustible resource. Therefore the EIS,  $\frac{1}{\gamma}$ , plays an important role in deciding the saving and extraction path. An increase in  $\gamma$  from 2 to 4, i.e a lower intertemporal rate of substitution, generates significantly more savings. This is because, uncertainty increases the probability of low consumption in the future. In order to prevent that from happening, it is optimal to consumer less in the first place and accumulate substantial to mitigate intertemporal fluctuations.<sup>13</sup> Increasing the risk aversion parameter,  $\phi$ , while keeping the EIS fixed has a relatively limited impact on the saving behavior and extraction. This exercise shows that in this model, the saving and extraction behavior is much more sensitive to changes in the EIS as opposed to RRA coefficient.

## 2.5 Conclusion

I have used a small-open economy framework to understand the optimal saving and extraction decision of an exhaustible resource rich country. I find that to fully capture the precautionary demand for net foreign assets of an ERRE, it is important to heed attention to the factors that drive their extraction decision. This set up then brings forward an important result: the decision to extract is closely intertwined with the the saving decision and conditional on the net foreign asset holdings, the extraction rate could speed up or slow down. The higher are the savings held by the ERRE, the better it is capable to limit its exposure to the volatile income stream, and slower it would deplete its underground resources. This paper also quantifies the contribution of the precautionary motive to save in the accumulation of external savings. The size of the precautionary demand for saving hinges on the degree of the risk aversion and the uncertainty facing the economy. In an economy with very risk aversion consumers, the exhaustible in situ resource is depleted more rapidly since it is regarded as a risky asset to hold. Additionally, given the irreversibility of the extraction decision, a higher degree of uncertainty results in a faster depletion of the exhaustible resource.

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<sup>13</sup>This is consistent with the discussion on the role of the EIS in determining the strength of the precautionary motive in [Weil \(1990\)](#) and more recently [Colacito and Croce \(2013\)](#).

## **Chapter 3**

# **The Delaying Effect of Storage on Investment: Evidence from the US Oil Sector**

*This chapter is based on joint work with Nicolas Legrand*

### Abstract

Our paper provides a theoretical framework able to represent with accuracy a consistent relationship between fixed capital investment, storage and the term structure of prices in a storable commodity market. It aims at understanding the interaction of storage capacity with irreversible investment decisions in mediating investment and commodity price dynamics. The results show that the presence of storage, while smoothing the spot price tends also to channel volatility into the future, thereby raising the options value of waiting and eventually delaying investment in fixed capital. The time-varying expected price volatility generated by the interaction of storage with irreversible investment is a new channel we identify to capture more accurately both price and investment dynamics observed in the data as compared to an irreversible investment setting without storage capacity.

*Keywords:* Investment, Irreversibility, Storage, Commodity prices, Forward curve.

*JEL classification:* C51, C52, Q11.

### 3.1 Introduction

Price and production dynamics in storable commodity markets garner a lot of attention due to their implications for macroeconomic fluctuations and financial markets. Therefore, understanding which factors underlie decisions in such markets is at the heart of this chapter. In capital intensive industries, such as the oil industry, production requires substantial upfront fixed capital expenditures and once capital is installed, firms cannot easily adjust their capital stock in order to respond to unanticipated changes market conditions. The succession of boom and bust episodes in prices along with the clusters of high volatility show that production in the oil sector is subject to substantial uncertainty that varies over time (Figure 3.1). This creates an incentive for firms to hold off on their investment decision until expected value of the project is sufficiently high.

The inability of firms to rapidly adjust their capital stock implies that, in the short-run, the supply of the commodity can be inelastic. Thus, when the productive capacity in the market exceeds the consumption demand and cannot be adjusted downward, storage plays the important role of inter-temporally allocating excess supply and smoothing out demand and supply shocks. As a result, spot prices are more stable and persistent when inventories are full and increasingly more volatile as inventories are drawn down. At the same time, carrying inventories also implies that future prices are expected to be higher than spot prices.<sup>1</sup>

On the other hand, when inventories are low and cannot smooth out shocks, commodity prices spike, and if the shock is persistent, the high price regime might encourage investment, that eventually restores some slack in the market. This behavior translates into an asymmetric price distribution, shown as a positively skew in prices in Table 3.3. Similarly, because investment is irreversible, the industry can experience a lull in capital expenditures, allowing the existing capital stock to depreciate. Once the trigger value for investment sets in, investment spikes as seen in Figure 3.2. The investment rate in the oil industry is characterized by a positively skewed distribution further confirming the existence of this nonlinearity.

With this in mind, as uncertainty and future returns on investment determine whether firms expand their productive capacity, we look to understand the role of

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<sup>1</sup>The literature built upon the theory of storage in the tradition of [Kaldor \(1939\)](#), [Working \(1949\)](#) and [Brennan \(1958\)](#) use a standard expression to link forward and spot prices according to the following storage arbitrage equation:

$$F_t(T) = S_t(1 + R_t(T)) + C_t(T). \quad (3.1)$$

$F_t(T)$  stands for the forward price as of time  $t$  for delivery at time  $T$ ,  $S_t$  is the spot price,  $R_t$  is the interest cost of storage and  $C_t$  is the total net of interest cost of carry.  $C_t(T) = W_{f_t}(T) + R_{p_t}(T) - C_{y_t}(T)$ .  $C_t(T)$ , total net of interest cost of carry, which can possibly include transportation and warehousing fees  $W_{f_t}$ , risk premia  $R_{p_t}$  and convenience yield  $C_{y_t}$ .

storage in mediating volatility in prices and most importantly its feedback effect on investment. This paper contributes to literature on irreversible investment by demonstrating how the availability of storage capacity in the market influences the investment decision via its effects on uncertainty and expected prices. To do so, we use the starkest irreversible investment model under uncertainty and introduce storage capacity. This setting allows us to capture the main features characterizing a storable commodity market, i.e. irreversible investment and storage, in order to rationalize the price and investment dynamics observed in the data.

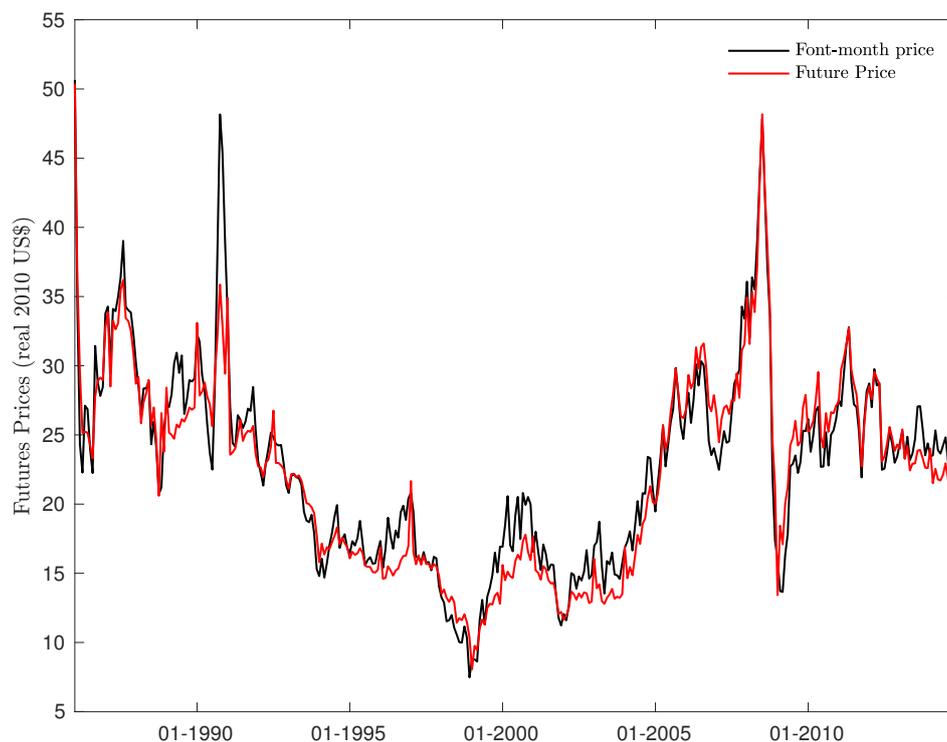
Dixit and Pindyck (1994) have laid out the theoretical groundwork for irreversible investment behavior under uncertainty and explained how investment irreversibility creates an option value of waiting. Subsequently, models of fixed capital investment in the macroeconomic literature have been used to study the implications of sunk costs and the associated irreversibilities on the timing of firm investment decisions and on aggregate investment fluctuations. But this family of micro-founded macroeconomic models is silent in regards to the contribution of investment irreversibilities to commodity price dynamics.

Much information can be inferred from the relationship between the spot price and future prices, also referred to as the slope of the forward curve. Among other things, it indicates how much slack there is in the market (Telser (1958)). Evidence from Routledge et al. (2000), Carlson et al. (2007), and Kogan et al. (2009) shows that low inventory levels signalled by a market in *backwardation*, i.e. the spot price exceeding the future price, is linked with bouts of volatile prices. In *contango*, when future prices are higher than the spot price, inventory levels are positive and can buffer the impact of shocks.

Nonetheless, the relationship between future price volatility and inventories is nonlinear. Ng (1996), Routledge et al. (2000), Kogan et al. (2009), show that when inventories are moderately full or when the slope of the forward curve is sufficiently positive (i.e. in *contango*), future price volatility increases and can be higher than that of the spot price. Although over the whole sample length, the market is nearly as often in *contango* (i.e. spot prices below futures prices) as in *backwardation*, both states are quite long-lasting. For instance, between the mid-1990's to the early 2000's, the market was mostly in *backwardation* before reverting back to a sustained *contango* since 2005. The persistence of these regimes hints at the irreversible nature of investment inherent to capital intensive industries such as the oil sector.

This article connects the literature on investment, storage, and futures prices as a mean to feature the essential structural forces driving commodity prices. In particular, it draws close attention to the interaction between storage and investment by showing that the presence of storage delivers features in the investment and commodity price dynamics that cannot be accounted for when focusing only

Figure 3.1: Oil futures prices (01/1986-12/2014)



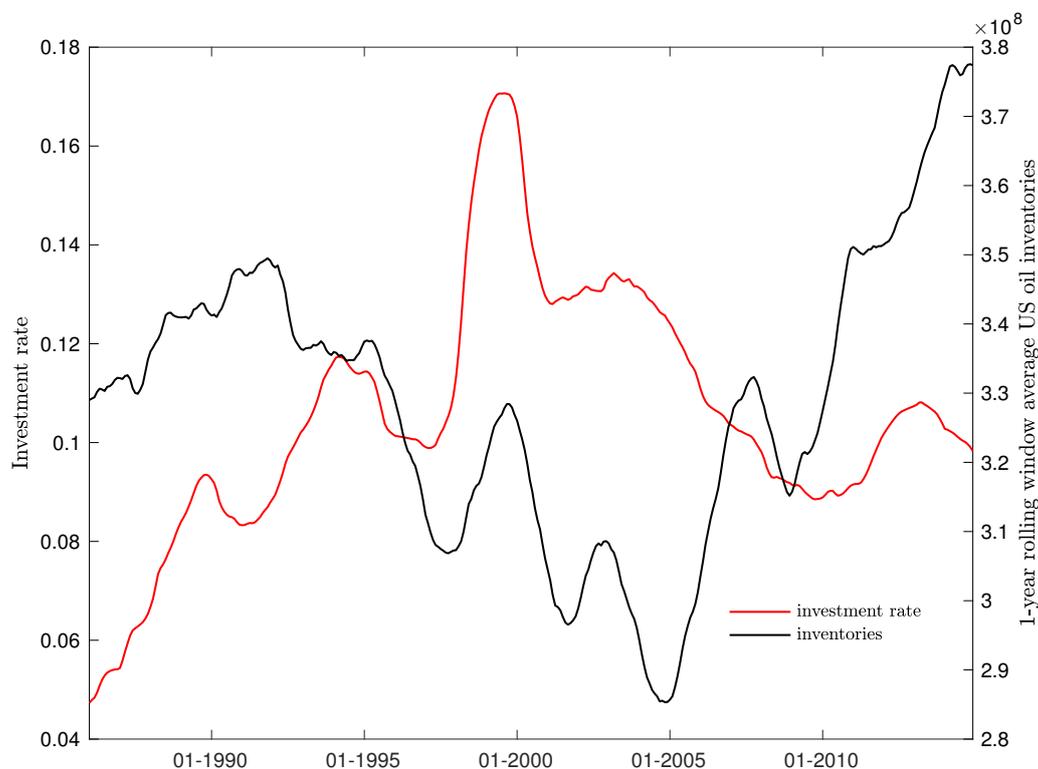
*Note:* NYMEX front-month and 12-Month oil futures prices (real 2010 US\$). The prices have been deflated by the US CPI before being log-linearly detrended. The investment rate represents real capital and exploration expenditures in the US oil sector divided by the number of development wells as the stock of capital. Details about the data sources and calculations are in the Appendix 3.5.

on investment. The crude oil market will be used as a guideline illustration since it embodies, fairly well, the occurrence of booms and busts cycles characterizing the prices behavior of most commodities on spot and futures markets.

The results shed light on (i) the importance of introducing storage in an irreversible investment model to generate the price and investment dynamics observed in the data, (ii) the key role of the storage arbitrage condition in dictating the impact of the irreversibility constraint on the timing of investment, i.e. causing a delaying effect of storage on investment, and (iii) the close relationship between the supply and demand with the term structure of forward curves. Nonetheless, if our theoretical framework manages to capture the core forces governing the observed dynamics in the crude oil market, it remains unable to generate sufficiently persistent volatility in the futures prices, a common issue of this type of dynamic commodity market models.

The article falls as follows: Section 3.2 summarizes the main streams of literature addressing nonlinearities in investment, storage, and equilibrium com-

Figure 3.2: US investment rate and inventories in the oil market (01/1986-12/2014)



*Note:* The investment rate is calculated as the deflated capital and exploration expenditure divided by the capital stock as proxied by the number of development wells in the United States. Inventories are commercial stocks in the United States excluding the Strategic Petroleum Reserve (SPR). The series are smoothed over a two-year rolling window. Details about the data sources and calculations are in the Appendix 3.5.

modity prices. The general framework with its associated theoretical insights are outlined in Section 3.3. Section 3.4 follows with simulations experiments and discusses the results. Section 3.5 concludes.

## 3.2 Literature review

The cost of adjusting the capital stock has drawn much attention in the investment literature. Evidence on the presence of nonconvex firm-level capital adjustment costs and investment irreversibilities is extensive. Doms and Dunne (1998) cast doubt on the smoothness of capital adjustment at the firm level using micro-data on firm-level fixed capital investment. Subsequently, Abel and Eberly (1994), Caballero and Engel (1999) and Cooper and Haltiwanger (2006) as well as references therein, investigate the relevance of different adjustment costs for both firm-level and aggregate investment dynamics. They show that firm-

level investment is indeed lumpy as they would like to invest more aggressively the wider the gap between the actual and targeted levels of capital. These features of investment point to microeconomic nonlinearities, i.e. both non-convex adjustment functions and investment irreversibility.

Nevertheless, lumpiness of investment at the firm-level has been found to disappear at the aggregate level. [Thomas \(2002\)](#) demonstrates how general equilibrium price effects wash out firm-level investment lumpiness and thus pegs nonconvexities in capital adjustment costs as inconsequential for business cycle analysis. More recently, [Bachmann et al. \(2013\)](#) and [Bachmann and Ma \(2016\)](#) nuance the debate on the relevance of micro-economic lumpiness for macroeconomics by pointing out that what can settle the issue is the relevant strengths of price and adjustment cost responses. The presence of a hazard rate of adjustment that depends on the gap between the firm's level of capital and the desired one is the key to matching higher moments of aggregate investment. Therefore as in [Caballero \(1999\)](#), these microeconomic non-convexities generate an important "time-varying and history-dependent aggregate elasticity" of investment to shocks by allowing changes in the synchronization of firms' capital adjustments. [Cooper and Haltiwanger \(2006\)](#) investigate the relevance of different adjustment cost specification for investment at the firm, sector and aggregate levels. They found that investment whether at the firm or sector level is best described by a model which includes non-convex capital adjustment costs as in [Abel and Eberly \(1994\)](#) and [Caballero and Engel \(1999\)](#). Our paper therefore follows this vein of the literature, by exploiting the irreversibility of fix capital expenditure a source of nonlinearity in the equilibrium investment behaviour for the oil sector.

However, the micro-founded investment literature has thus far been silent on the effect of these nonlinearities on prices. A more complete examination of the commodity market dynamics calls for looking at the second pillar of the supply and demand fundamentals: the speculative demand for storage.

In the theory of storage, price dynamics in a commodity market are dictated by supply and demand conditions.<sup>2</sup> Among the predictions derived from the equilibrium relationship between the prices and supply and demand conditions is that futures prices uncertainty can increase with storage to converge to the volatility of spot price at high inventory levels. The key insight being that the gap between the spot and futures price volatility is negatively correlated with inventories. At low inventory levels, spot prices react much more to supply and demand conditions to balance the market and therefore tend to be more volatile than and less correlated to futures prices. At higher inventory levels, as a result of

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<sup>2</sup>Theory of storage refers to models linking the spread between spot price and future prices to inventory levels. Both the theory of storage in the tradition of [Kaldor \(1939\)](#), [Working \(1949\)](#) and [Brennan \(1958\)](#) or the one following [Gustafson \(1958\)](#) and [Wright and Williams \(1982\)](#) deliver similar predictions regarding the relationship between inventory levels and the wedge between spot and futures price volatilities.

the exploitation of storage arbitrage opportunities, spot and futures prices move together (i.e., are in lockstep variation) and are therefore equally as volatile. This prediction has been empirically validated early on by [Fama and French \(1988\)](#), [Ng and Pirrong \(1994\)](#) and [Routledge et al. \(2000\)](#) and more recently by [Gorton et al. \(2013\)](#). It is therefore this relationship, between futures price volatility and inventories that creates a delaying effect of storage on investment. Our paper thus studies the extent to which the lockstep variation between both the spot and futures prices in the presence of storage capacity affects the investment dynamics.<sup>3</sup>

Models based on competitive storage alone cannot account for the longer term dynamics of the term structure since inventories only affect the short end of the forward curve. It turns out that the long-term behavior of the term structure might be governed by elements such as the structure of production, new discoveries, investment dynamics, and prices of substitutes. Two avenues have emerged to address this shortcoming. On the one hand, reduced form models of futures prices as in [Brennan and Schwartz \(1985\)](#), [Schwartz \(1997\)](#), and [Schwartz and Smith \(2000\)](#), take spot prices and other factors which can influence futures prices as exogenous stochastic processes. On the other hand, [Litzenberger and Rabinowitz \(1995\)](#), [Carlson et al. \(2007\)](#) and [Kogan et al. \(2009\)](#), use a production economy with adjustment costs to endogenously determine both the spot and futures prices. A common assumption in these models is the irreversibility of the investment or extraction decision. The study of the impact of investment dynamics on prices builds the link between the literature related to investment project valuation and prices with the one focusing on investment dynamics at the different firm, sector and aggregate levels.

With this in mind, we use [Cooper and Haltiwanger \(2006\)](#)'s work as a point of departure for our paper to model the commodity supplier's capital dynamics. By working within this framework we believe not only to capture firm (sector)-level investment non-linearities, but also to echo [Kogan et al. \(2009\)](#)'s motivation for emphasizing the importance of the supply side of the commodity market in order to reproduce the most prominent features of commodity price. The key assumption in their model is that the representative commodity producer cannot resell the already installed capital leading to a time-varying elasticity of supply with respect to shocks. While [Kogan et al. \(2009\)](#) abstract from the storage dimension in the commodity market, we want to bring together the price smoothing features of storage and capital adjustment rigidities in the same framework, so as to shed light on the inner working of commodity markets and the accompanying price dynamics. Additionally, we build upon the recent developments in the literature of the storage model through a more complex specification of supply

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<sup>3</sup>[Kellogg \(2014\)](#) tests this theory on oil drilling investment in Texas and confirms that producers do indeed take into account time-varying volatility when making their investment decisions.

responsiveness and persistence in the shock processes.

### 3.3 A model of irreversible investment and storage

#### 3.3.1 Model's setup

**Commodity production** There is an infinitely-lived representative commodity producer operating a stock of capital goods with a decreasing returns technology,  $Q_t = AK_t^{\alpha_Q} \eta_t^Q$ , with diminishing returns to scale,  $\alpha_Q < 1$ .<sup>4</sup> Production is affected by a multiplicative i.i.d shock  $\eta_t^Q$ . This disturbance can be emanating from supply disruptions such as unfavorable weather variations, labor strikes, or geopolitical events. The producer can invest in new capital goods each period, which are added to the existing productive stock next period. We assume that capital goods require one period for initial installation before they become productive and installation of the newly purchased capital goods is costly.<sup>5</sup> Capital depreciates at rate  $\delta_K$ . There is no secondary market for capital goods: once they are installed, they have no scrap value and thus investment is irreversible. This capital could be considered as industry specific and if there is an unfavorable industry-specific shock, there would be no party willing to purchase it. The irreversibility constraint on investment may lead the investment rate distribution to exhibit the same lumpiness, positive skewness and excess kurtosis as observed in the data 3.3.

Total beginning next period capital stock  $K_{t+1}$  equals to the undepreciated capital stock from last period plus the newly purchased capital in the previous period such that

$$K_{t+1} = (1 - \delta_K) K_t + I_t. \quad (3.2)$$

The rational commodity producer is risk-neutral and price-taker of the spot price

<sup>4</sup>It is widely documented that the rate of extraction of a given well is decreasing with the pressure function of the oil level remaining. As a result, it requires an ever-increasing amount of effort to keep production from declining. According to [Hamilton \(2009\)](#), over the decade from 1970 to 1980 the US tripled the number of wells without preventing the oil production from falling. Furthermore, if it is true that the recent emergence of new extraction techniques such as the horizontal drilling allowed for significant productivity gains and reductions in the production costs, it has to be noted that the lifetime of fracking wells is even shorter than the conventional ones so that the only way to keep the oil supply steady is to drill at a growing pace. Put it another way, an increasing amount of resources devoted to production can only offset the supply depletion from old wells. Finally, it is also hard to deny that, as oil will become scarcer, deeper wells located into ever-more remote areas or even offshore in deep water locations will be needed so as to satisfy the raising global demand in the years to come. Together, these results lead us to prefer a production function with diminishing returns to scale.

<sup>5</sup>The price of capital  $p_K$  is assumed to be 1.

$P_t$ . When at  $t$  the producer decides how much capital to purchase, he takes the current capital stock,  $K_t$ , current availability  $X_t$ , the current and future expected realizations of the demand shocks  $\{Y_s\}_{s=0}^{\infty}$  so as to maximize his expected present-value net profit

$$\mathbb{E}_t \sum_{k=0}^{\infty} \beta^k \left\{ P_{t+k} A K_{t+k}^{\alpha_Q} \eta_{t+k}^Q - I_{t+k} - \phi(I_{t+k}, K_{t+k}) \right\}, \quad (3.3)$$

subject to

$$\begin{aligned} K_{t+1} &= (1 - \delta_K) K_t + I_t, \\ I_t &\geq 0. \end{aligned} \quad (3.4)$$

**The Storage Demand** In addition to producers and consumers, the commodity market comprises storers also assumed rational, risk-neutral and price-takers. Through the storage technology, the commodity is transferred from one period to another at a constant marginal cost  $k$ . Storers maximize the expected net profit from purchasing  $S_t$  of the commodity and selling it next period,

$$\max_{S_t \geq 0} [(1 - \delta_S) \beta \mathbb{E}_t P_{t+1} - P_t - k] S_t, \quad (3.5)$$

with  $\delta_S$  the decay rate of inventories. The total availability of the commodity  $X_t$  is determined by the sum of the current supply of the commodity,  $Q_t$ , and the inventories inherited from the previous period net of the share lost due to decay, that is

$$X_t = Q_t + (1 - \delta_S) S_{t-1}. \quad (3.6)$$

**Market clearing** The market demand for the commodity constitutes the consumption demand  $D(P_t)$  and the speculative demand for storage  $S_t$ . In each period, the market clears for a spot price  $P_t$  when the availability equals total demand according to the equilibrium condition:

$$X_t = D(P_t) + S_t, \quad (3.7)$$

with a linear demand function  $D(P_t)$ , assumed downward-sloping in  $P_t$  and subject to a multiplicative stochastic disturbance  $Y_t$  described by an autoregressive process.<sup>6</sup> Hence, the linear demand function takes the following form:

$$D(P_t) = \bar{D} \left( 1 + \frac{\alpha_D}{\bar{P}} (P_t - \bar{P}) \right) Y_t, \quad (3.8)$$

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<sup>6</sup>The demand shock is an AR(1) process:  $Y_t = \rho Y_{t-1} + \eta_t^Q$ . Hence, the demand uncertainty is modeled as a persistent stochastic process akin to the cyclical fluctuations of the international business cycle.

where  $\bar{D}$  and  $\bar{P}$  represent the steady-state values of final demand and the spot price respectively and  $\alpha_D$  is the elasticity of demand.

### 3.3.2 The competitive equilibrium

**Definition 1.** A rational competitive equilibrium is given by the path of capital investment  $\{I_t\}_{t=0}^{\infty}$ , storage  $\{S_t\}_{t=0}^{\infty}$  and prices  $\{P_t\}_{t=0}^{\infty}$  such that: (i) the representative producer maximizes the present value of his expected net profits subject to the sequence of capital accumulation constraints in (3.4); (ii) storers maximize the present value of their net profits subject to the nonnegativity constraint on storage; and (iii) the market clears in every period.

The producer's maximization problem given by the equations (3.3) and (3.4) delivers the following Euler equation:

$$\beta \text{E}_t \left\{ P_{t+1} \alpha_Q \left( A K_{t+1}^{\alpha_Q - 1} \eta_{t+1}^Q \right) + (1 - \delta_K) \right\} \leq 1, = 1 \text{ if } I_t > 0. \quad (3.9)$$

The investment decision rests on the present value of the expected marginal return on capital, the left hand side of equation (3.9), being equal to its marginal cost. Should the right-hand side exceed the left, there is a large enough opportunity cost of investing today which makes the investment in the current period non-viable.

Likewise, regarding the speculative demand for storage, differentiating (3.5) with respect to  $S_t \geq 0$  yields the following storer's optimality condition:

$$\beta (1 - \delta_S) \text{E}_t P_{t+1} - P_t - k \leq 0, = 0 \text{ if } S_t > 0. \quad (3.10)$$

The storage decision hinges on whether the commodity price net of carrying costs grows at the rate of interest. It is profitable to store only if the expected price grows at the interest rate adjusted for the decay of inventories. Therefore, a market in contango is one in which the expected price would rise at the decay adjusted interest rate. Finally, as a result of the rational expectations assumption, both the investment and storage are forward-looking decisions depending on the expectations agents have regarding the one-period-ahead price  $F_1$  without any consideration for  $F_2$  and subsequent forward prices.

### 3.3.3 Numerical Solution

The nonlinear nature of the decisions rules warrants the use of global numerical solution methods. We choose to employ a projection method to approximate the solution of our model. There are two endogenous state variables  $K_t, X_t$ , and one stochastic state variable  $Y_t$ . The decision variables are  $S_t$  and  $I_t$ , while  $P_t$  falls from the market clearing condition.  $P$ , in this set up, is regarded as an additional

control variable and so are future prices. To solve the model, the state space is discretized and the bounds are defined around the steady state values of the state variables. It thus consists in  $[\underline{X}, \overline{X}] \times [\underline{K}, \overline{K}] \times [\underline{Y}, \overline{Y}]$ . The solution to the time iteration problem delivers three time-invariant policy functions  $P = \mathcal{P}(X, K, Y)$ ,  $I = \mathcal{I}(X, K, Y)$ ,  $S = \mathcal{S}(X, K, Y)$ . These policy functions solve the constrained system of equations (3.7) and (3.9)-(3.10), using the transition equations in (3.4) and (3.6) to bring the model forward.<sup>7</sup> The model solution yields nonlinear decision rules that are governed by endogenous thresholds, which in turn depend on the state variables. In order to assess the extent to which storage interacts with the irreversibility constraint on investment, we proceed by studying two models, identically calibrated and which differ only by whether there is the possibility for storage.

## 3.4 Simulations and results

In this section, we will analyze the theoretical relationships between storage, investment and the term structure of prices based on the simulation results of four models: a baseline investment model with and without an irreversibility constraint on investment. Both of them are, in turn, augmented or not with storage capacity. The former is no different from the model set out in the previous section except that we remove the possibility of stockpiling.

### 3.4.1 Calibration

In calibrating the models, the parameter choices have been largely guided by empirical analysis summarized in Table 3.3. Particular attention has been paid to their internal consistency as it is a connection between two strands of literature mostly developed independently of one another. The annualized calibrated parameter values are reported in table 3.1 and are selected so as to follow the standard calibration and, when available, estimation results found in the investment and storage literature.

The share of capital  $\alpha^K$  is set to 0.33 which is equivalent to a long-run supply elasticity of  $\alpha^K / (1 - \alpha^K) \approx 0.5$ . Since no distinction is drawn between short and long-run demand elasticities,  $\alpha^D$  is set to  $-0.1$ , a value in the range of estimates provided in Dahl (1993) and Cooper (2003) and also reflecting the lack of substitutes for such a primary product. It has to be said that these low values of supply and demand responsiveness have been further suggested by the

<sup>7</sup>The model is solved by implementing policy function iteration on an equally-spaced 3-D grid of state variables with  $20 \times 10 \times 5$  nodes. Between the points the policy functions are approximated using the cubic spline functions relying on the "Rational Expectations Complementarity Solver" (RECS) developed by Gouel (2013) and available from the following website <http://www.recs-solver.org//>. More details about the model resolution are available from the authors upon request.

Table 3.1: Model Parameters

Parameter	Description	Value
$\alpha_K$	Capital share	0.33
$\delta_K$	Capital depreciation rate	0.1
$p_K$	Purchase price of capital	1
$\alpha_D$	Demand elasticity	-0.1
$k$	Physical storage cost	0.05
$\delta_S$	Storage decay rate	0.05
$\beta$	Discount factor	0.95
$A$	Scale parameter	$\beta^{-1}$
$\bar{D}$	Long-run average demand	24
$\bar{P}$	Long-run average price	0.65
$\rho$	Persistence of demand shock	0.85
$\sigma_{\eta^Q}$	Standard deviation of supply shocks	0.05
$\sigma_{\eta^D}$	Standard deviation of demand shocks	0.17

*Notes:* The table describes all the annualized parameter values characterizing the model and used in the simulations.

substantial gap in volatility between the prices and quantities noted in Table 3.3. The depreciation rate of capital  $\delta_K$  is set to 10% which is in the range of 8 and 12% used in the related literature [Kogan et al. \(2009\)](#); [Kung and Schmid \(2015\)](#). Likewise, the decay rate on storage  $\delta_S$  is fixed at 5% to stay close to the 3% used in [Routledge et al. \(2000\)](#). We decided to also account for a physical storage cost,  $k$ , unlike most of the empirical studies of the storage model, which specify either a proportional cost as in [Deaton and Laroque \(1996\)](#) or a constant marginal storage cost following [Cafiero et al. \(2011\)](#), but never both at the same time. The selected value—i.e.,  $k=5\%$  of the long-run average price—lies within the range of the rather low estimated values on a set of 13 different commodities ( $\approx 5\%$  [Gouel and Legrand \(2017\)](#)) and the 10% value provided by the World Bank and FAO studies in the case of grains storage in the Middle-Eastern and North African countries ([World Bank and FAO, 2012](#), figure 2-4).

The specification of the demand shock  $Y$  is close in spirit to the income shock variable embedded in the storage framework developed in [Routledge et al. \(2000\)](#), [Dvir and Rogoff \(2009, 2014\)](#) and [Bachmann and Ma \(2016\)](#). Hence, for the persistence value of the demand shock  $\rho$ , we choose an intermediate value between those they used which range from 0.65 to 0.95. Lastly, the volatilities of supply and demand shocks are chosen so as to match the observed coefficient of variation of production (table 3.3) and consumption.<sup>8</sup>

<sup>8</sup>The market demand is known to be much more volatile than production as it is both a function of the wild fluctuations of the global real economic activity and the more stable demand for immediate consumption whose coefficient of variation, equal to 0.0521, is very close the production one. This comes as no surprise as it only consists of the difference between the production and the stock variation, which explains why the latter descriptive statistics have not been documented in Table 3.3. The selected value is thus

We verify the performance of the model under this calibration against alternative key parameter values. We perform distance minimizing routine between the simulated moments and empirical moments through a grid search of key parameter values:  $\{\alpha_K, \alpha_D, \rho, \eta^Q, \sigma_{\eta^P}\}$ .

Before discussing the dynamics generated by the model, we highlight the key theoretical implications that can be drawn from the set of restrictions introduced in the modeling. For this, we restrict the discussion to the full irreversible investment model with storage and a partial irreversible investment model with no storage capacity. The comparison of the simulation results from the two models can shed light on the role of storage.

### 3.4.2 Theoretical insights

**States variables and regimes thresholds:** The nonnegativity constraints yield nonlinear decision rules for storage and investment, which are governed by trigger levels for availability and capital, respectively. These thresholds levels are functions of the other state variables and can be written as  $X_t^* = X^*(K_t, Y_t)$  and  $K_t^* = K^*(X_t, Y_t)$ .  $K_t^*$  represents the capital stock above which it is optimal to delay investment and let the capital stock depreciates. For different levels of  $X_t$ , it is determined from the optimality condition (3.9) of the producer's problem when investment is null and the inequality holds. When capital is abundant, i.e. above  $K_t^*$ , the marginal product of capital is too low for investment to be profitable.

At the same time,  $X_t^*$  is the availability level under which the commodity is too scarce to justify holding any inventories. This results in a high the spot price relative to the expected price. When the commodity in the market is abundant, the target level of capital is lower, since the value of a marginal unit of investment is low. This is mainly driven by a persistent low commodity price. Similarly, a large capital stock entails that the price at which storage becomes profitable is low, such that the availability threshold  $X_t^*$  is higher than when the capital stock is low.

Given the properties of the expected price and spot price functions, the relationships between  $K_t^*$  with  $X_t$  and  $Y_t$  as well as between  $X_t^*$  with  $K_t$  and  $Y_t$  are summarized in the two observations from the numerical results below.

**Observation 1.**  $X_t^*$  is a nondecreasing function of  $K_t$ .

First, observation 1 summarizes the relationship between capital stock levels and the availability trigger point  $X^*$ , under which stocks are empty. Since the capital stock does not adjust downward very easily, a high capital stock entails that supply in the current period and the next will be high, the resource will remain abundant, and the future price will not grow enough to justify hold

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a mix between these two extreme values.

inventories. The resource abundance coming from an inelastic supply in the short-run implies that the spot price would have to be much lower. One can see this from the threshold expression  $X^* = D(P)$ . Since  $P$  is decreasing in  $K$ , a high  $K$  implies a low spot price,  $P$ , a high consumption demand, and in turn a high  $X^*$ ,

**Observation 2.** *The desired level of capital  $K_t^*$  is*

1. *strictly decreasing in  $X_t$  and strictly increasing in  $Y_t$  when  $S_t > 0$ ;*
2. *increasing with  $Y_t$  and invariant to  $X_t$  when  $S_t = 0$ .*

To understand the effects of availability on the threshold capital level  $K^*$ , two distinct regimes must be explored. The first statement in observation 2 corresponds to the case when inventory building is profitable, that is  $S_t > 0$ . The interpretation is straightforward recalling from the arbitrage equation (3.10) that

$$E_t P_{t+1} = \beta (1 - \delta_S)^{-1} (\mathcal{P}(X_t, K_t, Y_t) + k)$$

which implies that the spot and expected prices move together in a lock-step variation. Hence, since the spot price is a decreasing function of the availability in the market, when the commodity is abundant and storage is positive the expected price is low. This in turn reduces the net marginal benefit from investment and in the end lowers the desired level of capital.

The result points to the first source of divergence between the two models with and without storage. Storage increases the value of postponing investment by lowering the cut off value above which it is optimal to delay capital expenditures. In addition, and perhaps even more importantly, by linking current prices to future prices, storage induces a time-varying volatility in prices, with increasing expected price volatility when inventories are high because the likelihood of stockouts is pushed into the future as the productive capacity shrinks. Through these two channels, the presence of storage has *delays* investment. The outcome is a gradual wind down of the productive capacity accompanied by withdrawals of inventories eventually making the occurrence of a stockout more and more likely.

Finally, once the supply falls short of the demand, stocks are sold out, i.e.  $S_t = 0$ , and from equation (3.10), the expected price is a function of expected supply and expected demand shock,  $E_t P_{t+1} = E_t [D^{-1}(Q_{t+1}, Y_{t+1})]$ . In other words, the expected price is no longer a function of the spot price. The stockout regime reverts to the model of irreversible investment without inventory building capacity, in which the desired capital level is a function of the realized supply-side shock, and the steady state values of the price and consumption demand of the commodity. The realized shock  $Y_t$  raises the trigger value of capital.

To borrow the terminology from the option pricing literature, the value of waiting to invest is lower when there is a positive demand shock. Indeed, given the

assumed persistence of shocks to the consumption demand for the commodity, the whole conditional distribution  $F(Y_{t+1}|Y_t)$  shifts to the right giving greater probability to larger  $Y_{t+1}$  values, thereby rendering the opportunity to invest and to terminate the option more attractive than waiting. This investment incentive is further strengthened by what can be called the “uncertainty effect”. The reason is that, the high spot price deters inventory speculation and provides a more favorable environment for investing since the expected price, now decoupled from the very volatile spot price, is more stable. The volatility of the expected price is now constant since the expected price itself is a function the capital stock and the expected demand shock.<sup>9</sup> All in all, the combination of persistent demand shocks and time-variations in both the desired level of capital and uncertainty of future price are the key reasons behind the substitutability, albeit imperfect, between storage and investment.

Together, both zero-lower bounds on storage and investment split the state space into four regions demarcated by the capital and availability thresholds. They are described in the following observation based on numerical results:

**Observation 3.** *The competitive equilibrium can be characterized by four regimes:*

1.  $I_t = 0, S_t = 0$ , if  $K_t \geq K_t^*$  and  $X_t \leq X_t^*$ ;
2.  $I_t = 0, S_t > 0$ , if  $K_t \geq K_t^*$  and  $X_t > X_t^*$ ;
3.  $I_t > 0, S_t = 0$ , if  $K_t < K_t^*$  and  $X_t \leq X_t^*$ ;
4.  $I_t > 0, S_t > 0$ , if  $K_t < K_t^*$  and  $X_t > X_t^*$ .

When both  $I = 0$  and  $S = 0$ , the expected price is only a function of expected production, which is constant  $AK_t^\alpha$ . This is a regime where the economy has an overcapacity and it is optimal to defer investment. Furthermore, in spite of a relatively low spot price, it is not profitable to store either because of the large and persistent productive capacity. Indeed, as stated in observation 1, a very high capital level brings down the expected price, preventing the latter from rising sufficiently to cover the purchasing and carrying cost of inventories. If only  $I = 0$ , there is still an excess of capital but not enough to preclude expected price from increasing so that it becomes profitable to stockpile (e.g.,  $S > 0$ ). So long as the expected commodity price grows at a higher rate than the rate of interest (net of decay), it is profitable to store. If now  $S = 0$  but  $I > 0$ , the market is tight resulting in a high spot price. Futures market is backwardated and selling inventories today is optimal. Although the availability is too scarce to allow storage, the associated environment of high prices encourages investment to reach the optimal level of capital  $K^*$ .

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<sup>9</sup>The constant volatility of the expected price in a stockout regime is discussed in Deaton and Laroque (1992, 1996).

Finally, as mentioned previously, the substitutability between the investment storage is only partial and it might be the case that it is optimal to invest and store jointly so that  $I > 0$ ,  $S > 0$ . It has to be noted that, in this regime, both the  $S$  and  $I$  values are much lower than those reached when one of the constraint is binding. The market equilibrium can enter this regime for instance if, despite a capital level lying below the desired  $K^*$ , a high positive value of the supply shock  $\eta^Q$  yields an availability in excess of the threshold  $X^*$ . The latter scenario is even more likely if during persistent low demand state  $Y$  which will lower  $X^*$  while raising  $K^*$ . The outcome is a relatively slack market in which inventories are used to absorb excess supply. Yet, and contrary to the first regime when  $I = 0$  and  $S = 0$ , here the stock of capital is not large that (i) expected price can increase to cover the carrying cost of inventories, and (ii) it is still optimal to invest and bring the capital stock to its desired level  $K^*$ .

**A characterization of the policy functions prevailing in the various market regimes** The  $X^*$  threshold point implies that the price function is nonlinear and follows a two regime equilibrium which, from equation (3.10), can be written as:

$$P_t = \mathcal{P}(X_t, K_t, Y_t) = \begin{cases} \beta(1 - \delta_S) E_t\{P_{t+1}\} - k & \text{if } X_t > X_t^* \\ D^{-1}(X_t) & \text{otherwise.} \end{cases} \quad (3.11)$$

The rule can be summarized in the following functional form:

$$\mathcal{P}(X_t, K_t, Y_t) = \max[\beta(1 - \delta_S) E_t P_{t+1} - k, D^{-1}(X_t)]. \quad (3.12)$$

Figure 3.3 depicts the two regimes of the price policy function with respect to the availability and for two extreme values of  $K$ . When  $X < X^*$  the spot price is only function of the consumption demand that is assumed to be linear. In line with observation 1, a high level of capital is associated with a right shift of  $X^*$ . When there is a large productive capacity, the spot price is lower for all levels of availability and storage becomes optimal at a higher availability level.

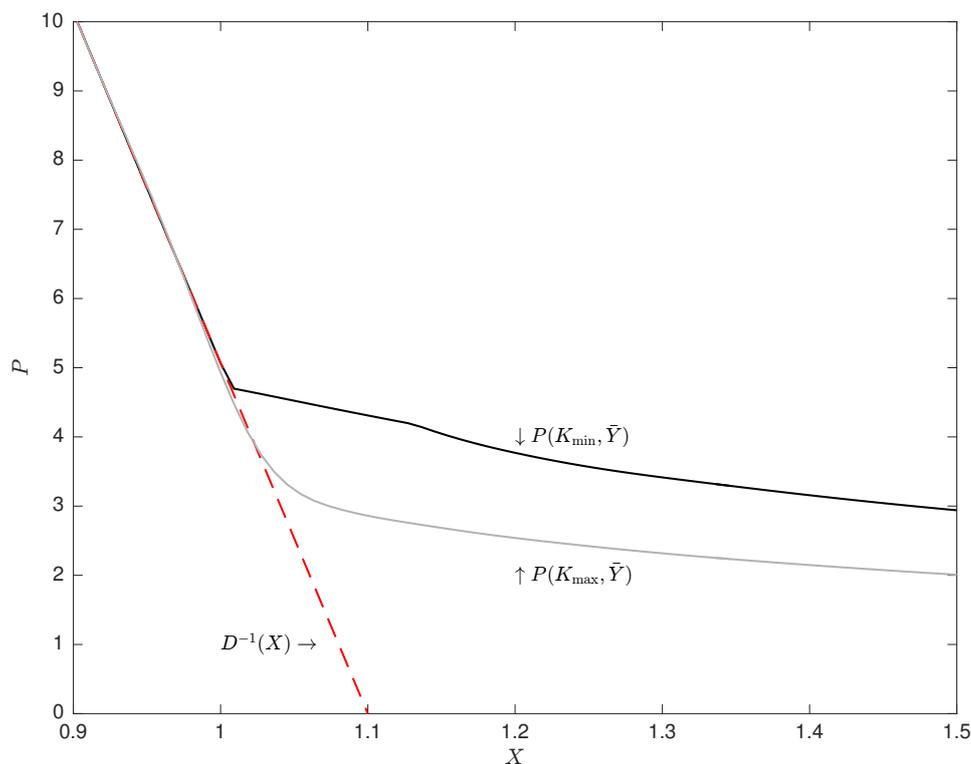
Characterizing  $\mathcal{P}(X_t, K_t, Y_t)$  in terms of the four regimes shaped by  $X_t^*$  and  $K_t^*$  gives the following result:

**Observation 4.** *The equilibrium price function  $\mathcal{P}(X_t, K_t, Y_t)$  relates to different levels of capital and availability in the following manner :*

1.  $\mathcal{P}(X_t, K_t, Y_t)$  is strictly decreasing in  $X_t$ ;
2.  $\mathcal{P}(X_t, K_t, Y_t)$  is nonincreasing in  $K_t$ .

The first part of the observation is straightforward and does not deserve additional comments. Regarding the second point, when inventories are carried over, the price function is linked to the behavior of the expected price. Since

Figure 3.3: Price Policy Function



*Notes:* Two price functions, obtained for the highest and the lowest capital levels, are plotted against different levels of availability  $X$ . Additionally, the inverse demand function that prevails when inventories are null is plotted in the dashed line.

the equilibrium of the model is described in terms of a desired level of capital  $K^*$ , the expected price is also a function of this threshold. Specifically, when the capital stock lies below  $K^*$ , investment is positive and brings back the next period capital stock to its optimal level. In this regime, the expected price is disconnected from the level of capital and so is the current spot price. On the other hand, when the capital stock is above  $K^*$ , there is no investment and the next period capital stock equals the current capital stock less depreciation. Since a high level of capital entails a high expected supply, it turns out that the expected price and the spot price are decreasing in the capital stock whenever its current value exceeds  $K^*$ . Consequently, whether  $K$  is below or above  $K^*$ , the spot price is either independent or a decreasing function of the capital stock.

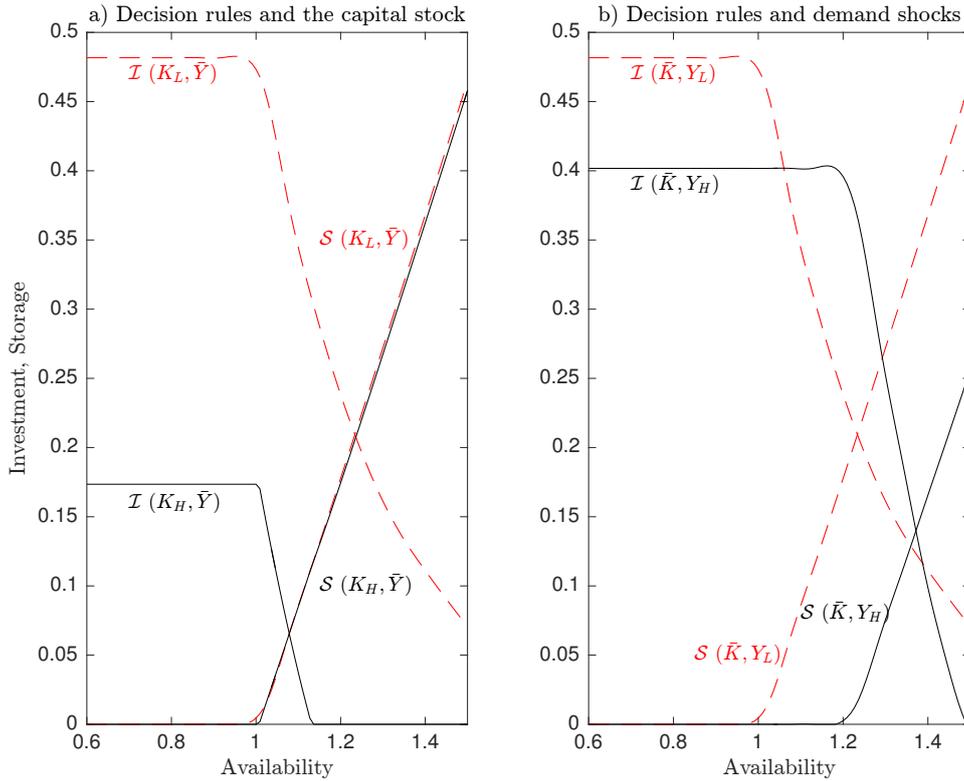
The same characterization can be derived for the other two investment and storage policy functions.

**Observation 5.** *The equilibrium investment and storage functions,  $I_t = \mathcal{I}(X_t, K_t, Y_t)$  and  $S_t = \mathcal{S}(X_t, K_t, Y_t)$ , relate to availability, capital and demand shock in the following manner :*

1.  $\mathcal{I}(X_t, K_t, Y_t)$  is nonincreasing in  $X_t$  and  $K_t$  and increasing in  $Y_t$  ;
2.  $\mathcal{S}(X_t, K_t, Y_t)$  is nondecreasing in  $X_t$ , nonincreasing in  $K_t$ , and decreasing in  $Y_t$ .

The observation is further illustrated in Figure 3.4 exhibiting the investment and storage functions as they relate to the state variables,  $X$ ,  $K$ , and  $Y$ . The

Figure 3.4: Investment and Storage Policy Functions



*Notes:* The investment and storage functions for the highest and lowest value of capital and demand shock are plotted against different levels of availability. Panel a) represents the two nonlinear functions in terms of the two extreme values of capital. Panel b) represents the functions for the two extreme realizations of the demand shock.

substitutability between investment and storage as well as the nonlinearities embedded in this model are well represented by these functions and the different kinks at the thresholds,  $X^*$  and  $K^*$ , can be identified. As can be seen on the left panel, when  $X < X^*$ ,  $I$  is constant with respect to availability and decreasing with  $K$ . The reason is that the investment decision is driven by the expected price. Below  $X^*$ , the relationship between the expected and spot price is severed. In a stockout market, the expected price only depends on the next period stock of capital along with the expected state of the demand governed by the autocorrelated shock  $Y$ . Investment follows suit: for a given fixed capital stock lying below

$K^*$ , optimal investment is constant and equals the gap between  $K$  and its target  $K^*$ . Therefore, the higher  $K$ , the lower  $I$ .

On the other hand, when the commodity is abundant in the market so that  $X$  lies above  $X^*$ ,  $I$  is decreasing in  $X$ . In this regime, as the storage arbitrage condition holds, the expected price is indeed a function of the spot price which is decreasing with the availability.

Moreover, given that in each period market availability equals the sum of past inventories and the realized production, an increase in the productive capacity is sluggish. It must be added that the rise in the option value of waiting stems from the higher uncertainty inherent in the transmission of spot price volatility to the expected price. It turns out that the bigger the quantity in storage, the greater the delaying effect on investment which, consequently, is a nonincreasing function of availability for any given level of capital. For its part, storage is nondecreasing in  $X$  and  $Y$ . Storage is profitable only when the commodity is sufficiently abundant in the market so as to depress the spot price. Investment and storage are negatively correlated, with inventories standing high when the market is flooded. Since excess supply is persistent, as the constant gradual shrinkage of the capital stock is slow, storage becomes more important as an adjustment channel while the productive capacity adjusts. Therefore, storage does not vary much with the capital stock.

As already mentioned and illustrated in the panel b) of Figure 3.4, investment and, interestingly storage too, are really reactive to demand shocks. Investment response is of the same order of magnitude. All that means is that the persistent demand shock entails shifts in the whole demand curve affecting the expected price level and, in turn, the equilibrium investment and storage schedules. As a result, a higher demand pushes upward the expected price and so both the  $X^*$  and  $K^*$  thresholds.

### 3.4.3 Simulation results and model dynamics

All the above observations on the resulting decision rules for  $I$  and  $S$  and the price function have provided a general picture into the inner workings of an irreversible investment model with storage capacity. To go further in the analysis, we simulate at a monthly frequency 1,000 sequences of length 500 for each state and decision variables of the model and, discarding the first hundred and fifty, we end up with a total 350,000 simulations across which to compute the different moments investigated. Regarding the futures prices, for liquidity and availability reasons we consider only the first twelve maturities.<sup>10</sup> As in Bloom (2009),

<sup>10</sup>It has already been shown that future prices tend to converge to a long-run future price. Available the forward contracts beyond a year of maturities are too thinly traded to be really insightful. We can thus consider the 12-month forward contract to be  $F_\infty$  as in Routledge et al. (2000).

the simulated investment variable has been divided by  $0.5(K_t + K_{t-1})$  so as to be directly comparable to the observed investment rate variable  $I$ . The slope of the forward curve is defined as the log of the ratio between the 12-month future price,  $F_{1,2}$ , and the front-month price,  $F_1$ .

$$SL_t = \log \left( \frac{F_{t,12}}{F_{t,1}} \right). \quad (3.13)$$

As of time  $t$ , the forward curve is classified as being in contango (backwardation) when the demeaned slope  $\tilde{S}L = SL_t - \bar{S}L$  is positive (negative).

We will study the influence of storage on the dynamics of prices and investment, when investment is irreversible. We will discuss simulation results of the full model, denoted as *ModelIRREVS*, as well as the three other models where we either remove the irreversibility constraint on investment or we remove the availability of storage, or both. *ModelREVS* is an identical model to our full baseline model except that investment is fully reversible. *ModelIRREV* is an irreversible investment model with no storage capacity. Lastly, *ModelIREV* is a model of reversible investment with no storage capacity. All of them are parametrized according to the calibration table 3.1. Using these four iterations of the model will allow us to isolate the interaction of storage capacity with the irreversibility constraint on investment; the crux of this paper. These results are displayed in Table 3.2.

**Storage capacity** The starting point is the unconstrained investment model with no inventory capacity. In this model, the demand for the commodity is only for consumption purposes and the only source of supply in the commodity market is the quantity produced. There is no capacity to absorb excess supply through storage. The only room for manoeuvre to counter unanticipated transitory supply or demand shocks is through changes in the production capacity. In this model, price and investment dynamics are far from what we observe in the data. When investment is unconstrained (*ModelIREV*), the investment rate is negatively auto-correlated and barely positively skewed, while the spot price is negatively skewed, much more volatile and as half as persistent as its 3-month future counterpart. Looking at the *ModelREVS*'s results, introducing storage without constraining investment does not really improve the dynamic properties of the induced prices and investment rate variables. On the whole, storage capacity smooths out the spot price, renders it positively skewed as well as more persistent and increases the lumpiness of investment along with the volatility of the expected future price. The presence of storage therefore stabilizes current prices at the detriment of the stability of future production and prices.

**Investment irreversibility** Imposing a nonnegative constraint on investment constraints supply from adjusting to demand and supply shocks. It therefore

Table 3.2: Comparison of true with simulated data features

	Price	Future price	Investment	Storage
<b>Volatility</b>				
ModelIRREVS	0.27	0.07	0.02	0.11
ModelREVS	0.16	0.02	0.07	0.05
ModelIRREV	0.41	0.03	0.01	
ModelREV	0.33	0.01	0.04	
Data	0.31	0.31	0.03	0.05
<b>Persistence</b>				
ModelIRREVS	0.76	0.77	0.22	0.93
ModelREVS	0.54	0.75	-0.22	0.61
ModelIRREV	0.60	0.64	0.32	
ModelREV	0.31	0.77	-0.16	
Data	0.94	0.92	0.96	0.82
<b>Skewness</b>				
ModelIRREVS	0.55	-0.81	4.63	1.03
ModelREVS	0.88	-0.04	0.21	0.56
ModelIRREV	-0.07	-0.59	1.71	
ModelREV	-0.07	-0.01	0.19	
Data	0.59	0.66	1.59	0.23
	$\tilde{S}L < 0$		$I = 0$	$S = 0$
ModelIRREVS	0.50		32.16	17.47
ModelREVS	0.53			10.09
ModelIRREV	0.54		24.08	
ModelREV	0.50			
Data	0.49		14.08	12.36

*Notes:* The table shows moments of simulated prices, storage and investment rate time series from four models: ModelIRREVS is the full model with irreversible investment and storage; ModelIREVS is a model with reversible investment and storage; ModelIRREV is a model with irreversible investment and no storage capacity; and ModelRev is a model with reversible investment and no storage capacity. The corresponding models from the oil industry data are included in the last row of each subtable.

heightens both spot and future price volatility (*ModelREV* vs. *ModelIRREV*). Because irreversible investment acts as an adjustment cost to changes in production capacity, it implies that in the short-run, supply can be inelastic, therefore generating greater persistence in spot prices. At the same time, irreversibility reduces volatility and creates greater persistence in investment dynamics compared the ones generated by an unconstrained model. It also accentuates the positive skewness of the investment distribution, which is reflected in the data.

**Storage and investment irreversibility** The impact of storage on the dynamics of the model change substantially with inclusion of a constraint on in-

vestment. The smoothing effect of storage on current price volatility is weakened when investment cannot adjust as easily. Indeed, comparing the dynamics of the spot price from *ModelREVS* with *ModelREV* models, storage halves price volatility and it increases the persistence of the spot price.

When investment becomes irreversible, price volatility drops by a third (*ModelIRREV* vs. *ModelIRREVS*) in the presence of storage, but future price volatility doubles. Investment irreversibility generates more persistence in both spot and futures prices as well as the investment rate. Interestingly, storage capacity strengthens this lingering effect of irreversibility by about 20% on both the spot and future prices, bringing the values of their respective autocorrelation coefficients closer to those observed in the data.<sup>11</sup> Additionally, the investment rate is twice as volatile, which is more in line with the true value, with an inaction rate increasing by a quarter. The inventory accumulation, as a substitute for capital investment increasing future supply, is a less costly source of additional supply when investment is irreversible. In other words, the opportunity cost of investment, on average, increases in the presence of storage. Finally, when investment is irreversible, storage is also more persistent and stockouts are more frequent because it is relied upon more as a source of supply of the commodity than when investment can be costlessly adjusted. Finally, the four models are able to replicate the observed duration of time spent in backwardation.

Overall, as documented in Table 3.2, a model with investment as the sole variable of adjustment to demand and supply fluctuations does not generate the correct spot and futures prices stylized facts in terms of volatility, persistence and skewness. Thus, when it comes to modelling the dynamics of commodity prices, it is important to allow for inventory building in combination with irreversible investment. Fluctuations in commodity prices are mainly driven by both these types of investment; neither storage nor fixed capital investment taken alone is enough. In addition, investment dynamics is also impacted by the presence of inventories as a second channel for transferring the commodity supply intertemporally. In particular, the rate of inaction in capital investment is higher when storage is possible. This can be explained by the presence of two substitutable ways to respond to economic fluctuations.

Storage is used to mitigate the effects of a supply glut on the commodity price and therefore prevents the latter from dropping too quickly. At the same time, while storage is profitable, the production capacity or the targeted level of capital is decreasing in storage. In section 3.4.2, we explained that the storage arbitrage condition creates a tight link between the spot and expected futures prices. One implication of this condition is that storage, which occurs at lower spot prices, ties the next-period prices to this low level of price. As a result of the

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<sup>11</sup>Regarding the storage model literature, accounting for the dynamics of capital accumulation helps answering the puzzling lack of prices autocorrelation the model can explain which has first been noted in Deaton and Laroque (1992, 1996).

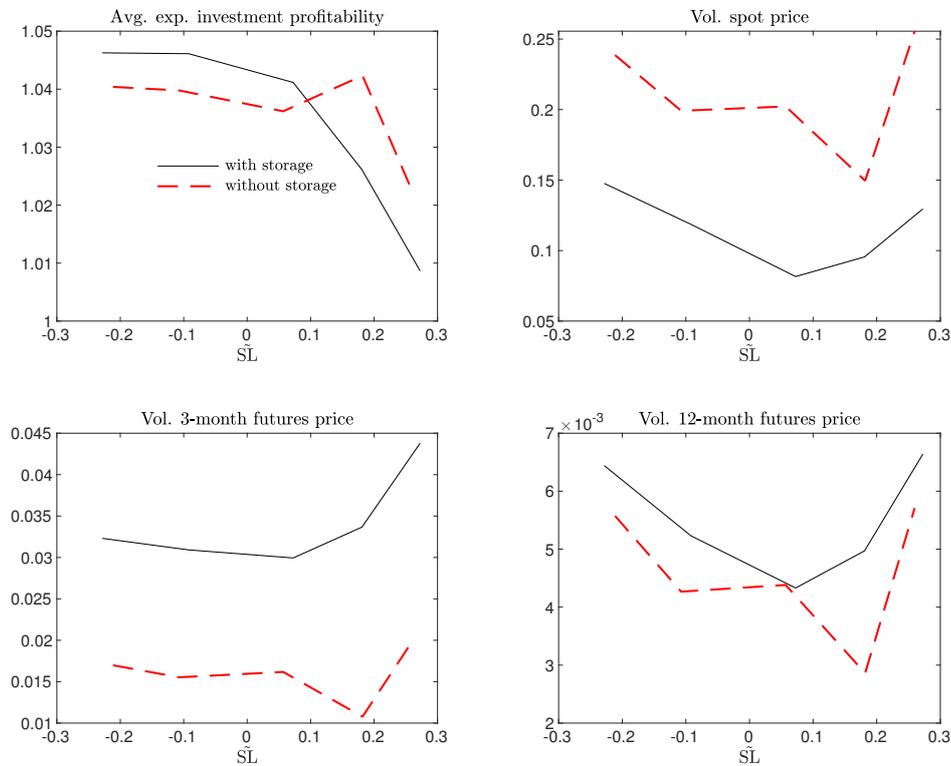
storage arbitrage, the expected futures prices are pinned down to a lower price regime, leading to a lower marginal profitability of investment and ultimately a lower investment rate. Additionally, the speculation through storage renders the expected futures prices more volatile. Because we are in an environment where the decision to invest is impacted by both uncertainty and sunk costs, the presence of storage through this volatility channel increases the value of postponing investment and of waiting to receive more information before committing to an investment project of this sort.

As a result, in response to the higher uncertainty surrounding the expected price whenever inventories are carried over, producers tend to wait, thereby making investment even more intermittent and pronounced. In other words, we invest less often but more aggressively. It turns that both the rate of inaction and the positive spike rate are higher when the possibility to store the commodity does exist. Since investment is irreversible, it is more optimal to wait for more information, defer investment, and instead use storage to smooth fluctuations in the commodity market. In this set up, there is a temporary lack of investment which is caught up by a sharp increase when inventories are run down completely. When outgoing inventories are either running low or empty, the spot price is higher and decoupled from the expected futures prices, the market is thus in backwardation, and it is no longer optimal to delay investment. It is precisely the role of the volatility transmission from the spot to futures prices along the forward curve brought by storage that we would like to emphasize. The upcoming discussion focuses on both the irreversible investment models with and without storage (i.e., *ModelIRREVS* and *ModelIRREV*).

**Conditional volatility and investment rate on storage** As mentioned earlier, the postponing effect is intimately linked to the degree of uncertainty. The storage arbitrage condition, by connecting expected price to spot prices, transfers the volatility of the latter into the former. This very condition results in an increased uncertainty around the expected price. When the expected price volatility rises, the anticipated marginal profitability of investment falls accordingly and the producer prefers to invest less or even nothing as to avoid being constrained in the future. While the presence of storage has a strong smoothing effect on the spot price of the commodity, it is destabilizing for both investment and the expected price. Figure 3.5 illustrates the average expected marginal profitability of investment along with the spot and expected 3 and 12-month futures prices volatilities for both models conditional on the slope of the forward curve.

As discussed at length in Kogan et al. (2009), the conditional volatility of the spot and futures prices is V-shaped: it is higher the more backwardated market, indicative of a supply shortage, dips when the market is moderately satiated and spikes again during a supply glut. Furthermore, introducing storage to an

Figure 3.5: Conditional mean profitability of  $I$  and volatility of  $P$ ,  $F_3$ , and  $F_{12}$



*Notes:* The corresponding conditional average and standard deviations values from both models with and without storage are plotted against the slope of the forward curve,  $\bar{S}L$ . These moments are computed for each of the 20th percentiles of the distribution of the simulated time series  $\{I_t\}_{t=0}^T$  and  $\{P_t\}_{t=0}^T$ .

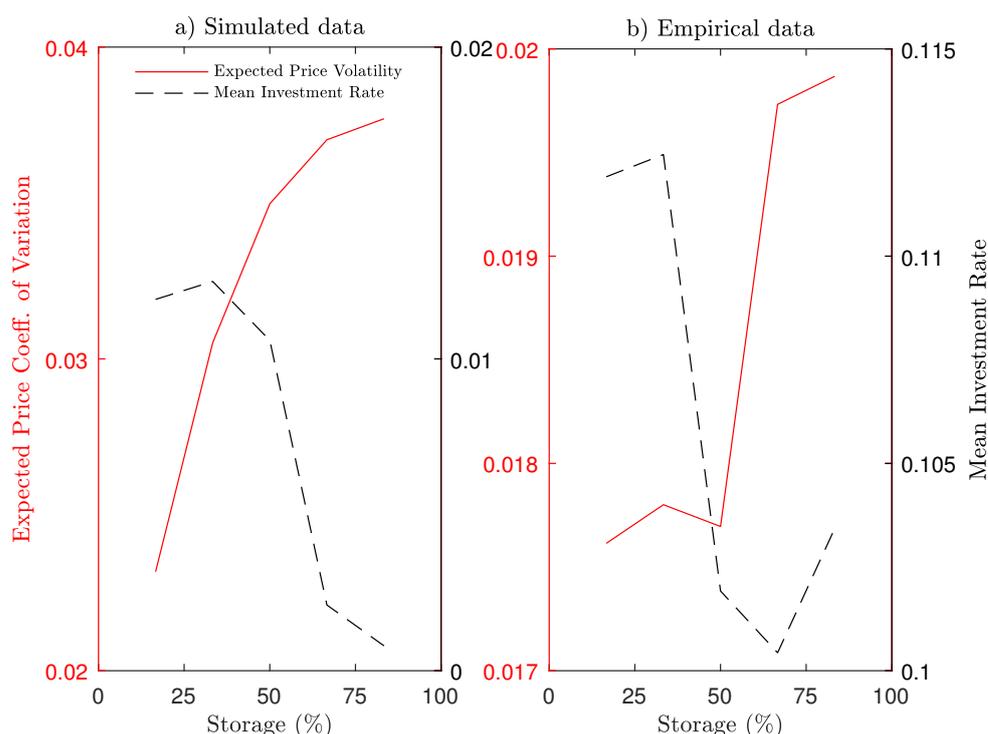
irreversible investment model cuts by almost one third the standard deviation of the spot price as documented in Table 3.2. Also noteworthy is that, on the contrary, with storage, the expected futures prices whether at 3 or 12-month to maturities are always more volatile. This heightened volatility eventually affects the expected marginal return on investment which depends not only on the expected price but also, and given the irreversible nature of the investment, on the degree of future uncertainty. If uncertainty is higher, increasing the variance of expected cash flows, the producers will want to avoid being constrained and thus will invest less today. The presence of storage thus generates higher uncertainty for instances of a market switching from a backwardated to a contango regime. Indeed, since the shape of the futures curve is positively correlated with storage, the higher the slope, i.e. the more inventories there are, the higher the opportunity cost of investment in the current period. This is observed in the top left-hand panel of figure 3.5 with a sharper decline in the mean expected marginal profitability of investment in the presence of storage capacity. More

importantly, this fall almost exactly parallels the strong rise in volatility of the 3-month and 12-month futures prices plotted in the bottom panels.

All in all, the increased endogenous instability of futures prices results in a more volatile investment rate compared with the partial irreversible investment model. Indeed, the low excess capacity of production starts to translate into higher uncertainty because up until now, the producers have delayed investment more than they would have if they were no storage capacities. When outgoing inventories are running low, the spot price becomes more affected by both disturbances in supply and the persistent demand shock. Since the production capacity adjusts sluggishly, coupled with low outgoing inventory levels, the expected futures prices will be more volatile than under the stark model with no storage.

Correspondingly, we draw a comparison of the observed relationships between future uncertainty, investment, and storage with those obtained from our simulated variables in Figure 3.6. The similarities are noteworthy. Indeed, the invest-

Figure 3.6: Conditional volatility of  $F_3$  and mean investment rate



*Notes:* The left scale stands for the mean of the simulated investment rate while the right one represents the coefficient of variation of the simulated time series for the 3-month price,  $F_3$ . They both are computed for each 20th percentile of the storage levels distribution. Panel a) represents represents the conditional volatility of the expected price and the mean investment rate for each percentile of the storage distribution based on the simulated data, whereas Panel b) represents its empirical counterpart.

ment rate is decreasing in the level of inventories, corroborating the relationship between the expected marginal profitability of investment and the slope of the

forward curve in Figure 3.5. Furthermore, storage has a destabilizing effect on the forward price as measured here by the volatility of the 3-month futures price; storage mostly affects the front-end of the forward curve (Kogan et al. (2009)). The elevated levels of uncertainty when the storage mechanism is at play explains also why in this regime the optimal investment rate is lower. Finally, the volatility of the forward price starts to plateau when the supply glut is at its highest meaning that the storage smoothing effect on the front-end of the forward curve dominates its destabilizing effect.

Uncertainty about the future, when the producer is constrained and cannot resell his capital in bad states of the world, makes him more prudent when deciding to invest. This precautionary effect of the nonnegativity constraint on investment is most present when the market is in contango or weakly backwardated. The effect of the irreversibility constraint on investment is strengthened when storage is allowed for. This is a novel insight and certainly extends our understanding of a firm's investment decision when it can decide between two types of investment: fixed capital investment and inventory investment. Additionally, the endogenous time-varying volatility that is brought about by storage through the lock-step variation between the spot and the forward price is key in generating the delaying effect of storage on the investment rate.

### **3.5 Conclusion**

Storage and investment are the two main economic mechanisms serving as the theoretical bedrock of most of the dynamic commodity models. In addition, the recent development of liquid futures market offers a valuable way to test empirically these forward-looking theories by looking at the market's reaction to various shocks and see if they match the model's predictions. Even from the strict perspective of the operators in the global market of crude oil, the two most scrutinized metrics are the inventory levels and drilling counts publicly published on a weekly basis. They are believed to mirror the prevailing supply and demand balance, where a glut is associated with ballooned inventories and diminishing capital expenditures. This is why we believe that it is worth studying investment and storage decisions jointly to account for fluctuations in prices, a point noted but thus far neither explored in the dynamics of capital accumulation nor competitive storage model literature.

This paper aims at filling this gap by building upon three strands of the economics and finance literature (e.g., capital accumulation, storage and futures pricing) to lay out a partial equilibrium-framework placing investment and storage at the forefront of the economic decisions dictating the dynamics of a commodity market. The simulations results obtained on four versions of the model depending whether or not investment is irreversible and storage are present sup-

port the importance of considering both economic mechanisms.

They demonstrate that, at the margin, investment is less profitable whenever storage is possible. Indeed, not only carrying inventories will weigh on the expected price and in turn the marginal benefit of investing today, but also will raise future uncertainty and thus the value of postponing investment. Put another way, operators invest less often but more aggressively. The deferred investment translate into lower capital stock and hence a mitigated production capacity. As a result, the commodity becomes scarcer, storing is more costly, thereby leading to an upward turn in the spot price and a tighter market (i.e., backwardated). The supply and demand tension is eventually alleviated with a renewed increase in the production capacity through capital investment. Such a narrative of the cyclical emergence of booms and busts in the oil industry broadly proves to match the data. The key insight that emerges out of the confluence of inventory and fixed capital investment is the implications of lock-step variations in the spot and forward prices on the investment decision. This tight link between the two prices translates into higher future uncertainty, rendering the nonnegativity constraint even more penalizing. Ultimately, storage reinforces the irreversibility of investment.

In terms of extensions, following [Bachmann and Ma \(2016\)](#) it might be worthwhile to study the effects of capital adjustment costs of various nature—fix, convex and non-convex—in the tradition of [Cooper and Haltiwanger \(2006\)](#) since they are possibly significant in capital intensive sectors like the oil industry. Among the expected effects of interest are a higher persistence in production translated into the volatility levels of forward prices which are dying-off too quickly in our current modeling as compared to the levels observed, although it is a shared drawback among many dynamic economic models of this kind. Perhaps more challenging given the computational issues at stake would be to push the empirical analysis even further in estimating the model key parameters in stead of the current calibration informed by a grid search.

### 3.A The data

Following [Kellogg \(2014\)](#) and for reasons mostly related to timeliness in the publication of data, especially those on inventories, our study focuses on the US oil market. The data are monthly and span from January 1986 to December 2014.<sup>12</sup>

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<sup>12</sup>The starting date is dictated both by the availability of the monthly spot price data given by the Energy International Administration (EIA) and the CFTC data related to the traders' positions in the forward market. Although longer monthly series of oil spot prices are available, for instance from the World Bank pinksheet or the International Monetary Fund (IMF), starting in 1986 should not be very contentious since the oil futures market has been first traded in 1983 and was at the beginning not sufficiently liquid to be really relevant.

**Quantities:** The US production and inventory levels data, noted  $Q$  and  $S$  respectively, are taken from the Energy International Administration (EIA).<sup>13</sup> To remove the trend and seasonality patterns, we divide the production and inventory levels by the moving average over the previous twelve months as in Gorton et al. (2013).<sup>14</sup>

**Prices** Monthly futures prices are constructed using daily observations of the New York Mercantile Exchange (NYMEX) light sweet crude oil contracts.<sup>15</sup> The monthly futures price is equated to the last daily price of a given month. Since futures contracts are traded everyday, prices update accordingly. Consequently, the last day of the month price reflects all the information available that month. Several contracts are traded on each day in our data. To categorize each contract according to the number of months to its maturity, we identify the maturity date for each contract according to its month of delivery; the date of expiry for each contract is preset. Following Kogan et al. (2009), we sort each contract according to months to delivery. We divide the number of days it has left to maturity by 30 and round off the result. For contracts with less than 15 days to maturity, we add a month. The selected contracts are those maturing in the next 1, 6, and 12 (hereafter denoted  $F_1$ ,  $F_6$ , and  $F_{12}$ ). While this market is liquid, especially for the short term maturity contracts, there are still missing values for daily prices. To address the sparsity of the data, we use the spread between two consecutive contracts to fill in the missing daily price.<sup>16</sup> The spot price  $P$  is the West Texas Intermediate (WTI) crude price taken from the EIA. Spot and futures prices are deflated by the US CPI following the common practice in the literature Kilian et al. (2009); Hamilton (2009); Knittel and Pindyck (2016); Baumeister and Kilian (2016a) and expressed in deviation from the same log-linear time trend.

**The slope of the term structure (SL):** it is obtained by taking the logarithm of the ratio between the first and the twelfth months forward contracts ( $SL = \log(F_{12}/F_1)$ ). A negative (positive) value of the demeaned slope  $SL = \tilde{SL} - \bar{SL}$  is indicative of a backwardated (contango) market.

<sup>13</sup><https://www.eia.gov/petroleum/>. As in Knittel and Pindyck (2016), we choose commercial stocks, i.e. excluding the Strategic Petroleum Reserve (SPR).

<sup>14</sup>Following Gorton et al. (2013) again, they have been lagged one month to account for most likely reporting and revision delays.

<sup>15</sup><https://www.quandl.com/collections/futures/cme-wti-crude-oil-futures>.

<sup>16</sup>The spread between two consecutive months,  $\Delta_{1,2} = F_1 - F_2$ , is constructed using daily prices. Then for all the days where the spread is missing, we fill it out with the closest available spread. If, for a given day,  $F_1$  is missing, we fill it in using  $F_2 + \Delta_{1,2}$ . Once we obtained the constructed daily prices, we use the last price as the monthly price. If this price is still missing, we interpolate between the two closest available prices to construct the monthly price; i.e.  $F_{1,t} = \frac{F_{1,t-1} + F_{1,t+1}}{2}$ .

**Expected price volatility:** Our baseline measure will be the one-year historic volatility. As built in Kellogg (2014), it is obtained by taking the standard deviation of the logarithm of the return on the futures price within a 1-year rolling window for the horizon of the forward contract considered.<sup>17</sup>

**Global real economic activity index (GRA):** this indicator capturing cyclical variations in global real economic activity is based on the Dry Cargo Bulk Freight Rates as constructed in Kilian et al. (2009) and available from the author's personal website.<sup>18</sup> It is stationary by construction as the author also opts for a log-linear trend modeling to focus on the cyclical fluctuations solely. Though not free from drawbacks we prefer this measure to the less specific world GDP growth, such as the OECD +6 monthly GDP data used in Dvir and Rogoff (2014), to assess the global demand pressure for industrial commodities often cited as one of the primary driver of prices.

**Investment rate  $I/K$ :** it is built following the perpetual inventory method described in Bloom (2009), that is  $(I/K)_t = I_t/0.5(K_t + K_{t-1})$ . Regarding the investment, we take exactly the same real capital and exploration expenditures in the US oil sector used in Baumeister and Kilian (2016b). These nominal figures are only available at a quarterly frequency from the Bureau of Economic Analysis (BEA), which provides also the Personal Consumption Expenditure (PCE) deflator they used to deflate the series. The data includes mining and oil field machinery along with investment in petroleum and natural gas structures. Then, as in Kellogg (2014), we generate a monthly investment series by assigning each quarterly reported value to the central month of each quarter, while the other month values are obtained through a linear approximation. Finally, to proxy the capital stock  $K$ , we use the Energy Information Administration (EIA) data on the number of development wells built on a monthly basis. Since development wells are drilled in a proven area of oil reservoir, they are investments in future productive capacity, contrary to the exploratory wells, which are omitted from this calculation.<sup>19</sup>

**Speculative pressure (T):** this metric aims at assessing the relative strength between the net short positions—the difference between short and long positions—of hedgers, assumed belonging to the group of “commercial traders”, as compared to the net long ones held by the speculators or else the group of “non-commercial

<sup>17</sup>When computed on the simulated series, the standard deviations are directly on the prices levels instead of the return as the latter are stationary by construction.

<sup>18</sup><http://www-personal.umich.edu/~lkilian/paperlinks.html>.

<sup>19</sup>For the sake of comparison with the empirical studies of Cooper and Haltiwanger (2006) and Kogan et al. (2009), in the rest of the paper the investment rate will be denoted  $I_t$ .

traders”. It is based on the Working (1960)’s T-index according to which speculators are needed to balance the market for hedgers.<sup>20</sup> In other words, the speculative pressure increases with the number of short speculators relative to the total number of hedgers when the latter are net short. We obtain the historical positions of traders from the “Commitments of Traders Reports” published on the CFTC’s website.<sup>21</sup>

Table 3.3: Descriptive statistics of the monthly detrended observables (1986:M1-2014:M12)

Variables	First-Order AC	2nd-Order AC	Coeff. of Variation	Skewness	Excess Kurtosis
Inventory	0.80	0.56	0.05	0.23	0.62
Investment rate	0.96	0.90	0.03	1.59	6.93
Production	0.31	0.45	0.04	-0.55	2.95
SL	0.64	0.42	0.09	-0.14	0.56
T	0.91	0.85	0.04	0.52	-0.70
GRA	0.96	0.89	0.25	0.53	-0.16
Spot price	0.94	0.87	0.31	0.60	0.64
$F_3$	0.93	0.86	0.31	0.55	0.45
$F_6$	0.95	0.89	0.31	0.46	0.14
$F_{12}$	0.93	0.89	0.32	0.47	0.25

Notes: The index of global real activity, the spot and futures prices are log-linearly detrended.

<sup>20</sup>See Alquist and Gervais (2013)’s appendix for more detailed about the index’s construction as well as the rationale behind it.

<sup>21</sup><http://www.cftc.gov/files/dea/history/>. The CFTC contract code of the NYMEX light sweet crude oil product is 67651.

## Chapter 4

# Share Buybacks, Monetary Policy and the Cost of Debt

*This chapter is based on joint work with Riccardo Zago*

### Abstract

Share buybacks have become common practice across U.S. corporations. This paper shows that firms finance these operations mostly through newly issued corporate bonds, and that the exogenous variation in the cost of debt – due to innovations in monetary policy – is key in explaining managers' incentives to repurchase their own shares. Under our identification strategy, we find that firms are more likely to repurchase in periods of accommodative monetary policy when the yield on bond adjusts in the same direction. This behavior has macroeconomic implications as it exacerbates the crowding-out effect of share repurchases on investment and employment, thus reducing the transmission of monetary policy at firm-level.

*Keywords:* share buybacks, monetary policy, corporate yield, EPS targeting.

*JEL classification:* E52, G11, G35, G32.

## 4.1 Introduction

Since 1985, U.S corporations are allowed to buy back their own shares on the stock market. Very quickly buybacks have become common practice used to return cash to particular categories of investors, to send signals of confidence to markets, to concentrate firm's ownership or also to adjust stock prices. Yet, these operations deviate resources from productive investments, such that many raised concerns on the legitimacy of repurchase programs, particularly on the way managers use their financial resources and on the impact of buybacks on the real economy. These arguments became of interests to legislators and economists in the aftermath of the Great Recession, a period in which firms – despite having at their disposal substantial internal and external liquidity – devoted a lot of resources to share buyback programs rather than to new investments.

Much is already known about the negative effect of repurchases on real variables (Almeida et al. (2016)), on the market-timing of repurchases (Stein (1996), Ma (2014), Baker and Wurgler (2002)) and the reason why firms do buyback (Grullon and Michaely (2004), Hribar et al. (2006)). Yet, little is known about how firms finance this operation and to what extent the cost of financing affects managers' decision to buyback their own shares. This paper aims to fill this gap in the literature and shows that buyback programs are mostly financed through new corporate debt issuance and they are most likely launched in periods of accommodative monetary policy. In fact, for an exogenous fall in the Fed fund rate, firms who benefit from a downward adjustment of their corporate yield tend to repurchase more by issuing more debt in the same quarter. Using low-cost debt to finance repurchases takes away resources from capital expenditures and new employment, thus reducing the effectiveness of accommodative monetary policy at firm-level. The contribution of the paper stands on the fact that we are able to properly quantify by how much the diversion of resources to repurchase programs is due to accommodative monetary policy, and to causally assess by how much the transmission of monetary policy on real variables is attenuated by the share buyback channel.

In light of this evidence, this paper not only unveils a new fact that informs on the use of share repurchases and the allocation of firms' financial resources, but it also highlights how macroeconomic dynamics have heterogeneous effects on managers' decisions. Hence, this work is also linked to a growing literature investigating how the joint interaction between macroeconomic variables and firm-level heterogeneity influence corporate dynamics and the transmission of macroeconomic shocks across firms (see for example Armenter and Hnatkowska (2011), Acharya et al. (2013), Bacchetta et al. (forthcoming), Falato et al. (2013) and Bloom et al. (2007)).

The first part of the paper shows few basic facts that motivated our investi-

gation and explain the main problems when measuring the effects of monetary policy on firms' repurchase decision. First, we use corporate balance-sheet data to show the extent to which firms use newly issued debt to finance repurchase programs. Second, we show that repurchase programs are more likely and larger in periods of accommodative monetary policy shocks.

In the second part of the paper we quantify the causal effect of repurchases on real variables, i.e. investment and employment. This is not a trivial task since the relationship between buybacks, monetary policy and real variables is exposed to several sources of endogeneity: a firm can self-select into a repurchase program at any time and for reasons other than an exogenous change in the cost of debt. Similarly, there are factors –monetary policy included– that can simultaneously affect employment and investment such that the decision to repurchase and the size of the buyback program might be an endogenous outcome. To solve the endogeneity issue, quantify the correct effect of monetary policy on repurchase and impute by how much the causal crowding-out of buybacks on real variables is due to an accommodative monetary shock, we need a rigorous identification strategy. More specifically, we need an exogenous factor, i.e. orthogonal to firm characteristics and monetary policy itself, able to explain ex-ante firms' repurchase behavior. Then, we can correctly evaluate how monetary policy influences the capability to buyback by comparing the effect of monetary innovations between firms that are ex-ante supposed to repurchase and those that are not. Thus, we can finally establish the causal effect of repurchase on real variables and study the dispersion of an accommodative monetary policy shock due to buybacks.

To do so, we exploit a discontinuity in the likelihood of repurchasing that is driven by management earnings considerations. As shown in [Hribar et al. \(2006\)](#), firms whose earning-per-share (EPS) ratio is below the analysts' forecast are more prone to launch an accretive buyback program in order to meet markets' expectations, build credibility and avoid markets' future punishment.<sup>1</sup> This maneuver allows us to split the sample of firms into a "treatment" group, i.e. those who need to adjust the EPS to meet the target, and a "control" group, i.e. those who do not need to adjust the EPS to meet the target. Both groups are very similar in terms of leverage, size, cost of debt, return on assets, growth opportunities and financial constraints before the EPS forecast is announced, and exhibit also similar dynamics in investments and employment. Moreover, monetary policy and the implied changes of corporate debt cost are not correlated anyhow with the EPS forecast. Hence, all the identifying assumptions for a regression discontinuity design holds and the distance from the EPS forecast is a valid predictor of repurchase behavior.

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<sup>1</sup>An accretive buyback program is one that raises the EPS by more than the opportunity cost of not saving resources.

Then we study how an exogenous fall in the corporate cost of debt – as explained by a monetary policy shock – affects both groups around the discontinuity at the moment of the EPS forecast announcement and show that it has a significant positive impact only for the “treatment” group. In other words, if a manager needs to repurchase to satisfy EPS market expectations, (s)he is more likely and capable to do so if (s)he benefits from a fall in the cost of debt at the same time, i.e. if (s)he can raise money at a low cost to finance this operation. In particular, we find that a 1% exogenous fall in the 10-years corporate bond spread leads to an increase of 0.44% of repurchase among firms in the “treatment” group. This behavior leads to a severe crowding-out effect on future investments and employment, which respectively fall by 1.4 dollars for every 100\$ of asset and 0.31 units for every million dollars of assets. This effect is particularly strong for those firms with small total factor productivity (TFP).

Such diversion of resources from real variables questions the effectiveness of monetary policy and its transmission at establishment level. By exploiting our identification strategy and the results obtained, we measure the effect a monetary policy shock if the repurchase channel was muted. From this simple back-of-the-envelope calculation we find that share buybacks reduce the transmission of a 1% accommodative monetary shock on investments and employment respectively by 7% and 23%.

In conclusion, this paper highlights the importance of debt and its cost for the financing of repurchase programs, and shows how monetary policy interacts with managers decision to repurchase. Most of all, it sheds light on how the transmission of monetary shocks on real variables is attenuated due to the repurchase channel.

**Related Literature** – This paper is related to three strands of literature. The first is the vast literature on share buybacks. This tells us that repurchase are typically conducted when firms have the private information that their stock price is undervalued (Stein (1996), Ikenberry et al. (1995), Brockman and Chung (2001), Peyer and Vermaelen (2008)), when they lack future growth opportunities (Grullon and Michaely (2004)), to signal confidence to markets and strong future performance (Hribar et al. (2006), Lie (2005)), to increase employees effort (Babenko (2009)), to mitigate the dilutive effect of stock option exercises (Kahle (2002), Bens et al. (2003)), to distribute excess capital (Dittmar (2000)). Moreover, we know that repurchase programs follow market-timing. For example, firms repurchase when the value of equity is relatively low with respect to other sources of financing (Ma (2014), Baker and Wurgler (2002)). Finally, Almeida et al. (2016) tells us that share buybacks crowd-out future capital investments, employment and R&D investments. Also Lazonick (2014) goes into this direction and cites repurchases as a possible explanation for why, in the post-recession era, firms

have high corporate profitability but low growth in employment.

The second strand of literature this paper relates to is on earnings and EPS management. In fact, our identification strategy is based on the fact that managers care about meeting market expectations on earnings, and it is well known that repurchases can help in boosting the EPS index (see among the many [Graham and Harvey \(2005\)](#), [Skinner and Sloan \(2002\)](#) and [Burgstahler and Dichev \(1997\)](#)).

Third, this paper relates to the growing literature studying the role of firm heterogeneity for the transmission of macroeconomic shocks and for the comprehension of macroeconomic dynamics. For example, and consistently with the results of this paper, [Bacchetta et al. \(forthcoming\)](#) shows that firms exploit liquidity shocks to hoard cash for precautionary purposes at the detriment of employment. In the same direction go [Armenter and Hnatkowska \(2011\)](#), [Falato et al. \(2013\)](#), [Acharya et al. \(2013\)](#) and [Bloom et al. \(2007\)](#) that show the effects of firms precautionary behavior when productivity and uncertainty shocks realize. Others, like [Melcangi \(2017\)](#) and [Jeenas \(2018\)](#), show that demand shocks and monetary shocks heterogeneously affect firms employment choice depending on the financial structure of the firm, the degree of financial constraint and the level of liquidity.

This paper develops as follows: Section 4.2 discusses EPS targeting and manipulation, and introduces a simple theoretical model showing the conditions under which a fall in the cost of debt allows for accretive repurchases; Section 4.3 documents the financing and the timing of repurchase programs in the data and the issue of measurement bias; in Section 4.4 we explain the identification strategy to study the causal crowding-out effect of repurchase on real variable and to impute correctly the attenuation of accommodative monetary policy due to buybacks; in Section 4.5 we do robustness checks and investigate other facts such like the effect of repurchase on the stock market, the role of firms' heterogeneity in the crowding-out of real variables. Section 4.6 concludes.

## 4.2 EPS Manipulation and the Cost of Money

The EPS ratio can be manipulated by corporate managers through several channels. In order to understand each of them, consider the following definition for the earning-per-share ratio:

$$EPS = \frac{(1 - \tau)[y - r^s * n * P]}{N - n}$$

where  $y$  is firm's profit at the net of production and financial costs,  $\tau$  is the firm specific taxation rate,  $P$  is the current stock price,  $n$  is the number of own shares repurchased,  $r^s$  is the return on a 3-months government bond and  $N$  is

the number of outstanding shares.

Managers can adjust this index by operating on profits  $y$  in order to avoid a fall in earnings or to beat analysts' forecast on sales or EPS. In fact, as shown in [Burgstahler and Dichev \(1997\)](#), it is unlikely for firms to report losses as a substantial percentage of those with below-target earnings would try to adjust in order to report increases in earnings and income. They do so either through manipulating their cash flow from operations or through reducing their working capital. As shown in [Degeorge et al. \(1999\)](#) and [Burgstahler and Eames \(2006\)](#), distance from the analysts EPS or sales forecast triggers managerial strategic behavior on revenues in order to immediately meet market expectations, even though this often comes at the cost of worse performance in the near future.

The second channel through which firms can manipulate their EPS is share buybacks ( $n$ ) (see [Bens et al. \(2003\)](#)). As in a signaling game, managers tend to repurchase their own shares because it is the most effective tool to beat analyst targets. This enables managers to build credibility and preserve their reputation on capital markets, to increase stock prices and avoid uncertainty and further speculation if the target were to remain out of reach (see [Vermaelen \(1981\)](#) and [Grullon and Ikenberry \(2000\)](#)). In fact, there is a valuation premium in meeting or beating the analysts' forecast. As [Bartov et al. \(2002\)](#), [DeFond and Park \(2000\)](#) and [Kasznik and McNichols \(2002\)](#) document, firms that are able to meet the forecast enjoy (cumulative) abnormal returns in the next quarters. Moreover, if firms' strategic behavior is consistent over time, capital markets tend to give greater valuation on their fundamentals because the capability to meet the target throughout time is a good and reliable indicator for future performance. On the other hand, there is clear evidence that managers are punished when failing to meet the target. As in [Skinner and Sloan \(2002\)](#) and [Kinney et al. \(2002\)](#), missing the target by one cent causes a significant decline in stock prices and the value of the firm.

Besides the cost and benefits of missing or beating the target, share repurchases are not always effective in increasing the EPS ratio, i.e. they are not always accretive. In fact, since  $n$  appears in both the numerator and denominator, a repurchase program is effective in increasing the EPS only if the change in the denominator dominates the change in the numerator. [Hribar et al. \(2006\)](#) states that a repurchase program is accretive, i.e.  $\partial EPS/\partial n > 0$ , if the following condition holds:

$$P < \frac{EPS}{r^s * (1 - \tau)}.$$

We start from this condition to think about how the cost of money matters for managers when conducting an accretive repurchase. As from the derivation above, for a given  $EPS$ ,  $P$  and  $\tau$ , the higher  $r$  the more difficult it is for a firm to launch an accretive repurchase. However, this intuition is not necessarily true, since an exogenous change in the value of money changes managers' incentive to

issue new debt, to buy new capital and to change their leverage position. Therefore, the shift in the capital structure of the firm induced by variations in  $r$  affects profits through the level of debt and choices over capital accumulation. These are key variables that must be taken into account when launching an accretive repurchase program.

For these reasons, we introduce a simple static model to show how negative changes in the cost of debt trigger new debt issuance and allow for accretive repurchases, regardless of the endogenous adjustments of capital. Following the work of Stein (1996), we imagine a firm characterized by a leverage ratio  $d$ , choosing today the level of capital  $K$ , debt  $B$  and the quantity  $n$  of shares to be repurchased.<sup>2</sup> The firm is a price taker on the equity, bond and capital markets such that the stock price  $P$ , the cost on newly issued debt  $r^B$  and the unitary cost of capital are all observed at the beginning of the period and taken as given. Also, we assume that the firm-specific cost of debt is proportional to the minimum return  $r^s$  on a saving account in a linear fashion, i.e.  $r^B = \kappa r^s$ , with  $\kappa > 1$ . Once the factors of production and the capital structure are chosen, the firm starts production with a final output equalling  $f(K) = zK^\alpha$ , with  $\alpha \in (0, 1)$  and  $z$  being the productivity of the firm.

Given this setup, managers who are willing to launch an accretive repurchase face the following problem:

$$\max_{K,B,n} \Omega = \frac{(1 - \tau)[f(K) - (1 + r^B)B - r^s nP]}{N - n} - \frac{\theta}{2}[B - dK]^2$$

In words, they maximize the EPS of the firm (the first element of the objective function  $\Omega$ ), taking into account the quadratic cost that arises due to deviations from the original leverage ratio  $d$  (the second element of the objective function  $\Omega$ ).<sup>3</sup> Under this formulation, earnings are defined as the after-tax income generated from production once the firm pays the interests on debt, capital, repurchased shares, and once it cashes in interest earnings on savings. The maximization problem is subject to the firm's budget constraint  $K = B - nP$ , such that capital is financed through debt at the net of the amount of money allocated to repurchases. Substituting the budget constraint into the objective function reduces the problem by one dimension, so that managers can launch an accretive repurchase program financed through debt if the following proposition is true.

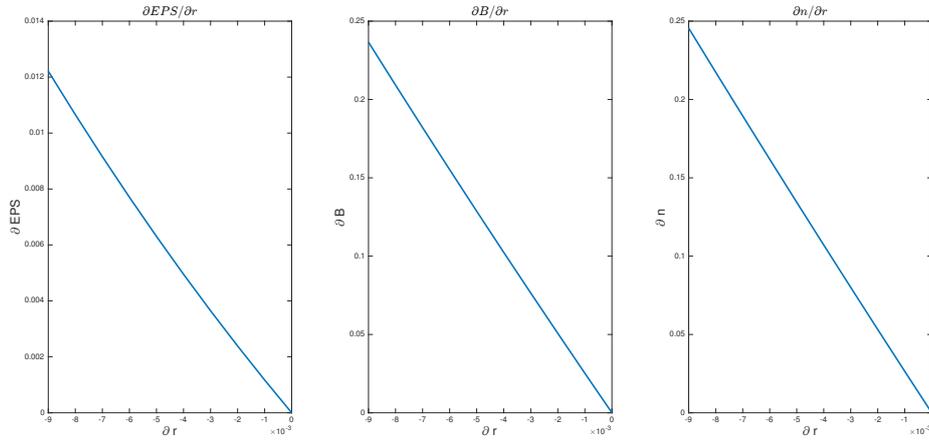
**Lemma 1.** Managers maximize earnings and increase EPS if

- i)  $\frac{\partial \Omega}{\partial B} = 0$ , i.e.  $(1 - \tau)[f' - (1 + r^B)] = \theta(1 - d)[B(1 - d) + dnP](N - n)$
- ii)  $\frac{\partial \Omega}{\partial n} > 0$ , i.e.  $EPS > (1 - \tau)P[f' + r^s] + \theta d[(1 - d)B + dnP]P(N - n)$

<sup>2</sup>If  $n < 0$ , then the firm is a net equity issuer.

<sup>3</sup>Note that, under this formulation,  $d$  is the target leverage of the firm. Hence, for a level of capital  $K$ , the debt issued  $B$  should be equal to  $dk$ . Deviation from the targeted leverage leads to a quadratic cost with weight  $\theta$ , a proxy for capital structure flexibility.

Figure 4.1: Comparative Statics



Notes: The picture plots marginal changes in the model endogenous variables  $B^*$ ,  $n^*$  and implied  $EPS^*$  for negative marginal changes in the interest rate  $r^s$ .

where condition (i) states that the net marginal income from an extra unit of debt must be equal to the marginal cost of changing the capital structure through higher bond issuance, while condition (ii) states that a repurchase is accretive if the EPS is larger than the sum of the marginal loss in net income and the marginal cost of changing the capital structure due to higher buybacks. The solution of the system of equations (i) and (ii) leads to the equilibrium  $B^*$ ,  $n^*$  and therefore  $K^* = B^* - n^*P$ .

In order to understand how changes in the cost of money affect the equilibrium, we perturbate the equilibrium conditions by a marginal change in the interest rate  $r^s$ . This leads to the following.

**Definition 1.** For a marginal decrease in the interest rate, managers always increase debt issuance ( $\partial B^*/\partial r^s < 0$ ), always increase repurchase ( $\partial n^*/\partial r^s < 0$ ) and always increase the EPS ( $\partial EPS^*/\partial r^s < 0$ ). In other words, debt issuance, share buybacks and EPS are correlated with changes in the cost of money.

*Proof.* See Appendix 4.B □

Under Proposition 1, we gain two insights. First, launching a repurchase program affects mechanically more the denominator than the numerator of the EPS ratio: for an extra share repurchased, the fall in net income is smaller than the fall in the number of outstanding shares. Second, for a marginal fall in the interest rate, the capital structure of the firm changes in favor of debt despite the quadratic cost of over-leveraging, and managers buyback more. Figure 4.1 plots the change in the optimal level of the endogenous variables ( $EPS^*$ ,  $B^*$ ,  $n^*$ ) with respect to the interest rate  $r^s$ . Again, a decrease in  $r^s$  leads to an increase in  $EPS^*$ ,  $B^*$ ,  $n^*$ . This is because a lower cost of money allows the firm to increase

its leverage and use debt to buyback its shares in order to increase the EPS ratio. Yet, we still do not know whether this necessarily leads to a fall or increase in investments. In fact, the crowding-out effect on capital investments ( $\partial K^*/\partial n^* < 0$ ;  $\partial K^*/\partial r^s > 0$ ) depends heavily on model parametrization, in particular on the return to scale parameter  $\alpha$ , the firm productivity level  $z$ , and the flexibility of the capital structure  $\theta$ .

In light of this simple model, in the next sections we empirically show (i) how firms finance repurchases and when; (ii) how the change in the cost of debt helps firms launch accretive repurchases; (iii) if the crowding-out effect on investment and employment is stronger for the firms that conduct accretive repurchases, and how much heterogeneity in firm productivity, return to scale and capital-structure flexibility attenuates it.

### 4.3 Repurchases, Debt and Monetary Policy

In this section we describe the data and provide some motivating evidence on how share buybacks, debt issuance and monetary policy are all related. In particular, we show three results. First, firms finance repurchase programs by issuing new debt and cutting their capital expenditures. Second, the timing and magnitude of buybacks programs are correlated with unanticipated changes in monetary policy: they are more probable and larger in periods of accommodative monetary policy, i.e. when the cost of money is lower. Third, monetary shocks have a firm-specific effect on debt issuance through changes in the yield on corporate bonds that would influence the size of repurchase programs.

#### 4.3.1 Data and sample selection

In order to study the impact of an exogenous change in the cost of debt on repurchases and the consequent crowding-out effect on real variables (capital investment and employment), we use two types of data: firm-level data and macroeconomic data on monetary policy shocks.

Firm micro-data comes from different sources. We use Standard and Poor's Compustat to extract firms' fundamentals data at quarterly frequency between 1985 and 2016. Following [Almeida et al. \(2016\)](#), we exclude regulated utility firms (standard Industrial Classification (SIC) codes 4800-4829 and 4910-4949) and financial firms (SIC 6000-6999) as well as firms with missing or negative assets. Thereafter, we merge the Compustat sample with stock-level data from the Center for Research in Security Prices (CRSP) and analysts' forecast data from Institutional Brokers' Estimate System (IBES). Finally, we use data from Trade Reporting and Compliance Engine (TRACE) to extract firm-level yields on newly

Table 4.1: Descriptive Statistics

<b>Repurchase Statistics</b>	<i>Mean</i>	<i>SD</i>	<i>p1</i>	<i>p5</i>	<i>p25</i>	<i>p50</i>	<i>p75</i>	<i>p95</i>	<i>p99</i>	<i>N</i>
$\mathbb{I}(\text{Repurchase} > 0)$	.24	.43	0	0	0	0	0	1	1	831,649
For $\mathbb{I}(\text{Repurchase} > 0) = 1$										
<i>Repurchase/Assets</i>	.03	.06	.00	.00	.00	.01	.03	.12	.30	204,794
<i>Repurchase (\$M)</i>	110.11	587.58	.00	.02	.41	3.93	36.10	459.20	1927	204,794
<b>EPS Distance Statistics</b>	<i>Mean</i>	<i>SD</i>	<i>p1</i>	<i>p5</i>	<i>p25</i>	<i>p50</i>	<i>p75</i>	<i>p95</i>	<i>p99</i>	<i>N</i>
<i>Distance (%)</i>	-.07	1.91	-7.33	-3.34	-.48	.04	.61	2.30	5.91	196,378
$\mathbb{I}(\text{Distance} \geq 0)$	.54	.49	0	0	0	1	1	1	1	196,378
$\mathbb{I}(\text{Distance} < 0)$	.46	.49	0	0	0	0	1	1	1	196,378
<b>Firm Characteristics</b>	<i>Mean</i>	<i>SD</i>	<i>p1</i>	<i>p5</i>	<i>p25</i>	<i>p50</i>	<i>p75</i>	<i>p95</i>	<i>p99</i>	<i>N</i>
<i>Market Cap. (\$M)</i>	2,630	14,901	.33	2.02	22.70	141.86	876.99	9,428	46,011	248,137
<i>Market-to-Book</i>	3.46	4.98	.15	.41	1.11	1.98	3.65	11.46	28.16	211,214
<i>Assets (\$M)</i>	1,946	13,130	.02	.91	14.43	84.68	507.06	6,533	34,235	831,649
<i>Money/Assets</i>	.17	.19	.00	.00	.03	.09	.23	.63	.88	223,742
<i>Profits/Assets</i>	-.01	.19	-.79	-.42	-.03	.02	.06	.17	.33	586,650
<i>Debt/Assets</i>	.23	.20	.00	.00	.05	.18	.34	.65	.87	562,305
<i>Investments/Assets</i>	.04	.07	.00	.00	.00	.02	.05	.17	.40	723,171
<i>Employment/Assets</i>	.13	88.78	.00	.00	.00	.00	.01	.03	.11	668,791
<i>Yield Spread (%)</i>	3.40	24.58	0.05	.20	.85	1.66	3.14	7.67	23.51	12,477
<i>Excess Return (%)</i>	1.02	.32	.41	.62	.86	.99	1.12	1.47	2.05	309,249
<i>Q</i>	2.43	2.61	.35	.65	1.09	1.55	2.58	7.51	14.97	234,911
<i>ROA</i>	-.04	.18	-.93	-.29	-.03	.00	.01	.05	.16	790,956
<i>PE10</i>	21.74	352.78	.03	.15	1.10	3.50	10.65	52.94	212.20	95,314
$\mathbb{I}(\text{Dividend} > 0)$	.16	.37	0	0	0	0	0	1	1	831,649
<i>Fin. Constraint</i>	-2.58	0.72	-3.27	-3.25	-3.11	-2.79	-2.28	-1.27	-.15	351,375
<b>Monetary Innovations</b>	<i>Mean</i>	<i>SD</i>	<i>p1</i>	<i>p5</i>	<i>p25</i>	<i>p50</i>	<i>p75</i>	<i>p95</i>	<i>p99</i>	<i>N</i>
<i>Shock (%)</i>	0.005	1.11								128

Notes: All the variables are build on quarterly data. *Repurchase* is the difference between stock purchases and stock issuances (in \$M). *Distance* is the difference between the reported EPS and the median EPS forecast at the end of the quarter, normalized by the end-of-quarter stock price. *Market-to-Book* is the market value of common equity divided by the book value of common equity. *Money* is the total value of cash holdings (in \$M). *Profits* is defined as net income plus depreciation (in \$M). *Debt* is the value of total debt (in \$M). *Investments* equates capital expenditure (in \$M). *Employment* is the stock of employees (in Ks). *Yield Spread* is the difference between the firm's 10-years-maturity corporate bond and a 10-years-maturity government bond. *Excess Return* is the quarterly excess stock return on the S&P500. *Q* is the book value of liabilities plus the market value of common equity divided by the book value of assets. *ROA* is net income (in \$M) divided by lagged assets (in \$M). The measure of *Fin. Constraint* follows Hadlock and Pierce (2010). *PE10* is the 10-quarter-moving-average of the price-earning ratio. *Shock* is the monetary shock obtained from a SVAR (see Appendix A).

and previously issued corporate bonds.<sup>4</sup> Regarding monetary policy shocks, we follow the literature on structural VAR and recent developments as in Ramey

<sup>4</sup>Firm level yields are calculated using equal weighted average on the different bonds issues of the same maturity.

(2016) and Rossi and Zubairy (2011) to extract innovations on the fund rate.<sup>5</sup>

Table 4.1 shows summary statistics of the variables we use and it describes their construction. In particular, as in Ma (2014), we define repurchase as the firm's net position on the equity market, i.e. difference of the value of the shares repurchased and the value of the newly issued shares normalized by total assets in the previous period. In this way, a negative value would stand for a net equity issuance while a positive value for a net equity repurchase. As the first panel of Table 4.1 reports, 24% of firms are net repurchasers across quarters. Among them, on average 3.1% of assets are repurchased every period with an average cash flow of 110 million dollars.

The second panel reports statistics on firm's ex-post EPS distance from the analysts' target and frequency for a (weakly) positive and negative distance from the target. Such distance is measured as the difference between the EPS forecast and the end-of-the-quarter EPS as reported by the firm. The (price-normalized) average distance is negative and 0.07% off the median analysts' consensus. Across quarters, 54% of the time firms are above target (i.e. they are reporting an end-of-the-quarter EPS bigger than the forecast) while 46% of the time they are below the target.

The third panel reports on other firm characteristics like market capitalization, the market-to-book value of the firm, assets, internal and external financial resource (cash holdings, profits, debt issuance), investments, employments, the cost of debt (measured as the yield spread on a 10-years government bond), the cost of equity (measured as the stock excess return over the S&P500 index), the Q-value, return on assets (ROA), the 10-quarter-moving average of the price-earning ratio (PE10), an indicator on whether the firm has payed dividends in the previous four quarters, and a measure for financial constraint (build after Hadlock and Pierce (2010)). The fourth panel reports the mean and standard deviation of monetary policy innovations as extracted from the SVAR.

### 4.3.2 The financing of share buybacks

How are share buybacks financed? In the spirit of the our model in Section 4.2, we answer this question by considering the following relationship between repurchases, financing sources (external and internal), as well as other uses of resources:

$$Repurchase_{i,t} = \beta_1 \Delta Debt_{i,(t,t-1)} + \beta_2 \Delta Cash_{i,t} + \beta_3 Investments_{i,t} + \beta_4 Dividends_{i,t} + \epsilon_{i,t}.$$

Under this specification, we want to understand how much of each dollar that the firm spends on repurchases is financed through the change in debt ( $\beta_1$ ), the

<sup>5</sup>See Appendix A for details on the SVAR model we use to extract monetary policy shocks and its identifying assumptions.

change in cash holdings including net profits from the current quarter ( $\beta_2$ ), a reduction in capital expenditure ( $\beta_3$ ) or in dividend distribution ( $\beta_4$ ). All variables are normalized by the level of assets in  $t - 4$ . As reported in the first column of Table 4.2, unconditionally on other sources of financing, an increase of 1\$ in repurchases is explained by 0.75\$ of new debt issuance. Controlling for the change in cash holding and quarterly profits (column 2) does not affect the role of debt by much. Moreover, the estimate for  $\Delta Cash$  is insignificant, suggesting that firms do not use their liquidity from cash-holdings or newly generated net profits to finance this operations. This is consistent with the trend across U.S. corporations of hoarding cash for precautionary savings (see Falato et al. (2013) and Acharya et al. (2013)). When controlling for all other variables in the above equation linking repurchases to different sources of funds, as well as time and industry fixed effects, as in column 3 to 5, the contribution of debt drops to around 40 cents whereas now the increase in repurchases is mostly explained by a reduction in capital expenditure (around 62 cents).

Table 4.2: Financing Buybacks

	(1)	(2)	(3)	(4)	(5)
	<i>Repurchase</i>	<i>Repurchase</i>	<i>Repurchase</i>	<i>Repurchase</i>	<i>Repurchase</i>
$\Delta Debt$	0.75*** (0.11)	0.79*** (0.07)	0.40*** (0.05)	0.40*** (0.05)	0.40*** (0.05)
$\Delta Cash$		-0.23 (0.31)	-0.00 (0.03)	-0.00 (0.03)	-0.00 (0.03)
<i>Investments</i>			-0.62*** (0.04)	-0.62*** (0.04)	-0.62*** (0.04)
<i>Dividends</i>				0.06 (0.05)	0.06 (0.05)
Observations	604777	476997	476748	476748	476748
Time FE	No	No	No	No	Yes
Industry FE	No	No	No	No	Yes
Controls	No	No	No	No	No

Notes: Standard errors in parentheses, clustered at firm level. The unit of observation *Repurchase* is the difference between the value of stock purchases and stock issuances from the statement of cash flows.  $\Delta Debt$  is the change in the value of current total debt of the firm.  $\Delta Cash$  is the change in firm money holding plus current net profit. *Investments* is equal to capital expenditure. *Dividends* is equal to the value of the dividends paid. All variables are normalized by the value of total assets in  $t - 4$ . \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

To sum up, debt plays a important role in the financing of repurchases. Also dividend distribution does not affect share buybacks. On the other hand, it seems that repurchases are associated with a reduction in capital investment.<sup>6</sup>

<sup>6</sup>See other specifications in Appendix 4.C.

### 4.3.3 Share buybacks and monetary policy

The fact that debt is an important source for financing buybacks suggests that these corporate operations might be sensitive to changes in the cost of money, i.e. changes in monetary policy. Yet, to measure the exact impact of monetary policy on repurchase is subject to many sources of bias since any exogenous change in the cost of money might influence other firms' decisions, for instance investment and employment. To comprehend better this fact and show what is the main problem when assessing the impact of monetary policy on the repurchase, consider the following regressions:

$$\mathbb{I}(\text{Repurchase}_{i,t+1} > 0) = \alpha + \beta \text{Shock}_t + X'_{i,t} \gamma + Z'_{i,t} \mu + \theta_t + \epsilon_{i,t} \quad (4.1)$$

$$\text{Repurchase}_{i,t+1} = \alpha + \beta \text{Shock}_t + X'_{i,t} \gamma + Z'_{i,t} \mu + \theta_t + \epsilon_{i,t} \quad (4.2)$$

where  $\mathbb{I}(\text{Repurchase}_{i,t+1} > 0)$  takes value one when the firm is a gross repurchaser in quarter  $t + 1$ ,  $\text{Shock}_t$  is the exogenous innovation on the fund rate as predicted by our SVAR,  $X$  controls for firm-level characteristics such as net income, Q-value of investment, a dummy indicating whether the firm has redistributed dividends in the first previous four quarters, a dummy indicating the quintile of asset the firms belong to,<sup>7</sup>  $Z$  controls for capital investments and employment,  $\theta$  is a year-quarter fixed effect.<sup>8</sup>

The first two columns of Table 4.3 report results for model (1) under different set of controls. As from column (1), where we control for  $X$  only, we find that a 1% exogenous fall of the Fed fund rate leads to an increase in the probability of repurchase by 3%. As mentioned above, to interpret the  $\beta$  coefficient in a causal sense and be sure that it is not biased, we need to control also for  $Z$ , i.e. that the relationship between the monetary policy shock and investment and employment decision has no feedback on the probability of launching a repurchase program. As from column (2), the effect of the monetary policy shock does not change, and the  $\beta$  coefficient is not biased by the relationship between the shock and real variables. Therefore, we can conclude that monetary policy causally affects firms in their propensity to buyback their shares. The last two columns of Table 4.3 report results for model (2). As from column (3), where we control for only  $X$ , we find that a 1% exogenous fall in the Fed fund rate leads to a 16% increase in the level of repurchase. However, when we control also for real variables in column (4), we see that the effect falls to 10% and it is significant at the 10% level only. In other words, in column (4) we were overestimating the impact

<sup>7</sup>The set of control variables  $X$  will remain the same throughout the paper, if not else specified.

<sup>8</sup>The year-quarter fixed effect implies controlling for a year dummy and a quarter dummy separately.

of monetary policy on the level of repurchase. This happens since the monetary policy shock also influences the real variables such that repurchasing might be a consequential (endogenous) outcome of investment and employment decisions. Therefore, the presence of the bias does not allow for a precise measure of the effect of monetary policy on the level of share repurchase.

Table 4.3: Net Repurchases and Monetary Policy Shocks

	(1)	(2)	(3)	(4)
	$\mathbb{I}(\text{Repurchase} > 0)$	$\mathbb{I}(\text{Repurchase} > 0)$	<i>Repurchase</i>	<i>Repurchase</i>
<i>Shock</i>	-0.03*** (0.00)	-0.03*** (0.00)	-0.16** (0.07)	-0.10* (0.05)
Observations	213761	171144	203966	169730
Time FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Controls ( <i>X</i> )	Yes	Yes	Yes	Yes
Controls ( <i>Z</i> )	No	Yes	No	Yes

Notes: Standard errors in parentheses, clustered at firm level. In model (1) and (2), the unit of observation is  $\mathbb{I}(\text{Rep.} > 0)$ , an indicator variable taking value one if the firm is a gross repurchaser, i.e. the difference between equity repurchased and new equity issuance is positive. In model (3) and 4, the unit of observation *Repurchase* is the difference between the value of stock purchases and stock issuances from the statement of cash flows, normalized by total asset in  $t - 1$ . *Shock* is an exogenous monetary innovation as from a SVAR (see Appendix A for details). Controls includes net income, normalized by total asset in  $t - 1$ , Q-value of investment, a dummy indicating whether the firm has redistributed dividends in the first previous four quarters, a dummy indicating the quintile of asset the firms belong to. *Z* controls for the level of capital expenditure and the stock of employment, both normalized by total asset in  $t - 1$ . \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

#### 4.3.4 Corporate yield and monetary policy

So far we have shown that repurchase programs are financed mostly with new debt and indeed they are more likely and larger in periods of (exogenous) accommodative monetary policy. However, it is not plausible to assume that these common monetary shocks affect all firms in the same way. In fact, monetary shocks affect firms' capital structure and decision on new debt issuance depending on the responsiveness of the firm's bond yield to the shock. The following regressions investigate the effect of the unanticipated monetary shock on firm-level bond yields and debt issuance:

$$\Delta Yield_{i,(t+1,t)} = \alpha_1 + \beta_1 Shock_t + X'_{i,t} \gamma_1 + Z_{i,t} \mu_1 + \theta_t + \epsilon_{i,t} \quad (4.3)$$

$$\Delta Debt_{i,(t+1,t)} = \alpha_2 + \beta_2 \Delta Yield_{i,(t+1,t)} + X'_{i,t} \gamma_2 + Z_{i,t} \mu_2 + \theta_t + \nu_{i,t} \quad (4.4)$$

where the variable  $Yield_i$  is the yield spread between firm  $i$ 's 10-years-maturity corporate bond and a 10-years-maturity government bond. The first two columns of Table 4.4 are results for regression (4.3). In column (1), where we control for  $X$  only, we find that an exogenous innovation of 10bps over the fund rate leads

to an increase by 6.1bps of the 10-years yield spread. This result is robust when controlling for real variables, as shown in column (2). The results of regression (4) are reported in column (3) and (4) of Table 4.4. As from column (4), where we control for  $X$  only, we find that a 1% fall in the yield spread is associated with an increase of debt issuance by 0.1%. This result is significant at 10% level only. Adding controls for real variables does not change the magnitude of the coefficient of interest, but affects its significance now increased to 95%. Since the relationship between debt issuance and changes in the yield spread is endogenous, we instrument  $\Delta Yield$  of equation (4.4) with the exogenous monetary innovations, i.e. we use equation (4.3) as 1st stage to predict the exogenous change in the yield  $\widehat{\Delta Yield}$ . Then we use the latter to explain the causal effect of an exogenous change of the yield spread on debt issuance. As reported in column (5), the (2SLS) estimator is 4 times larger: if the yield spread exogenously falls by 1%, the firm will issue 0.4% more debt.

Table 4.4: Yield Spread, Debt Issuance and Monetary Shocks

	(1)	(2)	(3)	(4)	(5)
	$\Delta Yield$	$\Delta Yield$	$\Delta Debt$	$\Delta Debt$	$\Delta Debt$
<i>Shock</i>	0.61*** (0.11)	0.62*** (0.11)			
$\Delta Yield$			-0.001 * (0.00)	-0.001** (0.00)	
$\widehat{\Delta Yield}$					-0.004*** (0.01)
Observations	10624	10458	10624	10458	10458
Time FE	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
Controls ( $X$ )	Yes	Yes	Yes	Yes	Yes
Controls ( $Z$ )	No	Yes	No	Yes	Yes

Notes: Standard errors in parentheses, clustered at firm level. In model (1) and (2) the unit of observation  $\Delta Yield$  is the change in the yield spread for a 10-years-maturity corporate bond. In model (3) and (4), the unit of observation  $\Delta Debt$  is the change in the value of current total debt of the firm, normalized by total asset in  $t - 1$ . *Shock* is an exogenous monetary innovation as from a SVAR (see Appendix A for details).  $\widehat{\Delta Yield}$  is the exogenous change in the 10-years corporate yield as predicted by monetary policy shocks, i.e. as from model (3). Column 5 reports 2SLS estimates, when using model (3) to instrument the endogenous variable  $\Delta Yield$  in model (4). Control  $X$  includes net income, normalized by total asset in  $t - 1$ , Q-value of investment, a dummy indicating whether the firm has redistributed dividends in the first previous four quarters, a dummy indicating the quintile of asset the firms belong to. Control  $Z$  includes the level of capital expenditure and the stock of employment, both normalized by total asset in  $t - 1$ . \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

## **4.4 The Effect of Repurchases on Investment and Employment: accounting for the role of monetary policy**

So far we showed that debt is key in explaining repurchases financing and that the timing and size of buyback programs comove with monetary policy shocks. We established also that, when measuring the effect of monetary policy on the level of repurchase, our estimates are biased since monetary policy interact with many other firm's characteristics and time-varying variables (in particular real variables) that might influence indirectly the size of the buyback program at the same time. Here we push the analysis further and use the causal effect of monetary policy on repurchase as the first step necessary to study the causal crowding-out effect of repurchases on real variables and to impute by how much the transmission of an accommodative monetary policy shock on real variables is attenuated due to share repurchases.

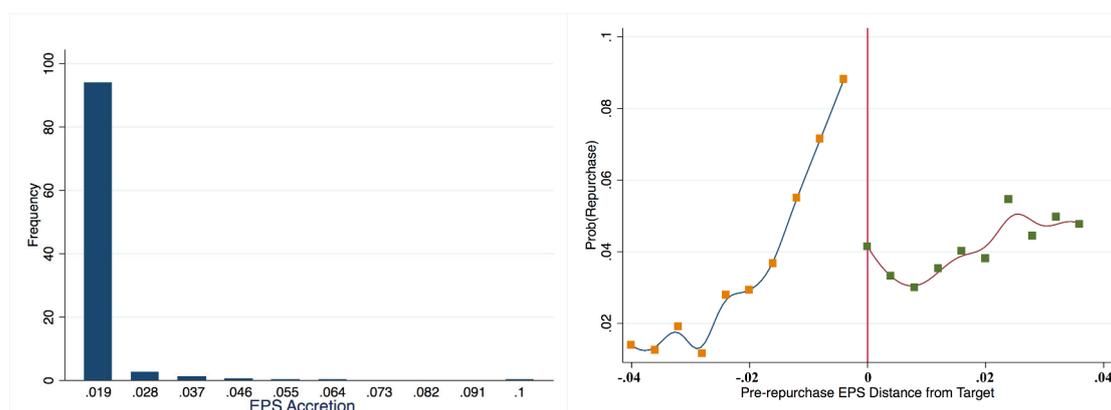
The main problem in our identification is that the option of buying back shares is always at managers' disposal and buybacks can happen for a long list of (endogenous) factors beyond monetary policy: poor growth prospects, lack of investments opportunities, or a need to adjust the balance-sheet structure of capital, among others. These are all factors that can interact with monetary policy. Moreover, monetary policy, in addition to firm-specific factors, can influence managers' choices of investment and employment such that repurchases might be a subsequent endogenous result. In other words, our identification is exposed to endogeneity problems mainly due to omitted variables, endogenous self-selection and reversed causality and monetary policy cannot explain alone repurchase behavior. In order to assess how much monetary policy encourages buybacks, first we must solve this issue: we need a factor, orthogonal to firm-level characteristics and monetary policy, capable to predict ex-ante the repurchase behavior of the firm and to split the sample in two groups: repurchasers and non-repurchasers. This allows us to break the loop between monetary policy, repurchase and real variables, and, more importantly, to assess correctly how exogenous changes in monetary policy affect both groups in their capability to repurchase. Finally, this strategy allows us to study the causal crowding-out effect of repurchase on real variables and evaluate how much of such crowding-out is causally explained by accommodative monetary policy.

#### 4.4.1 Identifying the crowding-out effect of repurchases on investment

In order to overcome the endogeneity problem, we exploit a discontinuity in the level and probability of conducting an accretive repurchase. This discontinuity, first introduced by [Hribar et al. \(2006\)](#) and recently used in [Almeida et al. \(2016\)](#), exploits the misalignment between the firm EPS and the analysts forecast. At the beginning of each quarter, analysts release their forecast for what the EPS of the firm will be at the end of that same quarter. Once the forecast is observed, managers decide whether to launch or not a buyback program to align their EPS at least with the level predicted by analysts. At the end of the quarter, firms announce their (manipulated) EPS along with information on the quantity and buying price of the repurchased shares. Hence, it is possible to reconstruct what the EPS would have been without repurchasing, i.e. the non-manipulated EPS (or the counterfactual) that would have prevailed without repurchase. This allows us to understand which firms were able to run an accretive buyback and by how much they were able to increase their EPS. For example, say that analysts' EPS forecast is \$4 by the end of the quarter for a certain firm. For the same firm, we observe that the realized EPS is \$4.1 as announced at the end of the quarter. Thus, we check the number of shares held at the beginning of the period (say it was  $N = 1000$  millions), the number of shares repurchased (say  $n = 50$  millions) and at what price (say  $P = \$50$ ). Hence we can build the foregone earnings due to buybacks as the opportunity cost of putting the amount  $Pn = 2,500$  millions into a deposit with a monthly rate of  $r^s = 5\%$  at the net of taxes (e.g.  $\tau = 30\%$ ). In our example, the forgone net earnings are equal to  $Pnr(1 - \tau) = 87.5$  millions. Under this manipulation, the realized earnings (as reported at the end of the quarter) are equal to  $4.1 * (1000M - 50M) = 3,895$  millions such that – if managers were not buying back their own shares – the EPS before manipulation would have been equal to  $(3,895M + 87.5M)/1000M = 3.98$  dollars per share. In this case, managers were able to beat the analysts' forecast by 10 cents by increasing the EPS from 3.98\$ to 4.1\$. In this sense, the repurchase program was accretive because managers were able to boost the EPS above the level of inaction by 12 cents.

On the left hand side of [Figure 4.2](#), we plot the frequency of firms conducting a repurchase over bins of EPS accretion, i.e. the difference between announced EPS and pre-repurchase EPS. As it is clear, more than 95% of firms conduct repurchases that allow them to increase the EPS by 0 to 2 cents, and only few boost the EPS by more. This is because, as the numerical example suggests, increasing the EPS by more than 2 cents might be extremely expensive. Therefore, we exploit the distance from the EPS forecast and the pre-repurchase EPS to understand which firms are more likely to repurchase and by how much. The right hand

Figure 4.2: EPS Accretion and Distance from Target



Notes: The graph on the left-hand side plots the frequency of repurchases by EPS accretion bins. The accretion is the difference between the manipulated EPS and the EPS that would have prevailed if no buyback was conducted during the same quarter. The graph on the right-hand side plots the probability for a firm to buyback its own shares as a function of the distance of the pre-repurchase (non manipulated) EPS and the analysts EPS forecast.

side of Figure 4.2 plots the share of repurchasing firms over the pre-repurchase distance from the forecast target. If firms that were already on target exhibit a mean probability of repurchasing around 4%, things are different for those on the left of the cut-off. In fact, those are the firms strategically more willing to repurchase in order to correct the EPS and not disappoint capital markets, as documented in Hribar et al. (2006), Kasznik and McNichols (2002), Bartov et al. (2002). This explains why, on the left-hand side of the cut-off, the probability to repurchase increases the closer a firm is to meeting analysts expectations, i.e. the easier it is to conduct a repurchasing program. This is precisely the discontinuity we are going to exploit to separate repurchasers and non-repurchasers and to assess across both groups how exogenous changes in monetary policy affect repurchase expenditure through variations in the cost of debt.

Yet, before proceeding in this direction, it is important to test whether firms around the discontinuity differ in major characteristics before the repurchase program is launched. This ensures that no other motive leads firms to repurchase their own share, but only the distance from the EPS forecast. Table 4.5 shows the difference in expected leverage, size, yield spread, profitability (ROA), PE10 and a measure of financial constraint (built following Hadlock and Pierce (2010)) between firms below and above the cut-off. The only variable for which firms off target are on average slightly significantly different is ROA. On the other hand, firms on and off target are homogeneous in all other dimensions: they are similarly leveraged, have similar size, cost of debt, growth perspectives and level of financial constraint the period before the repurchase program.<sup>9</sup>

<sup>9</sup>In Appendix D, we show that the EPS forecast is not correlated with monetary policy, neither in the quarter in which the EPS forecast is released and the accretive repurchase occurs, nor in the previous one.

Table 4.5: Pre-repurchase Difference in Firm Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
	<i>Leverage</i>	<i>Size</i>	<i>Yield Spread</i>	<i>ROA</i>	<i>PE10</i>	<i>Fin. Constraint</i>
Difference	-1.360	-0.009	-0.472	0.004***	-0.866	-0.003
	(2.920)	(0.039)	(0.003)	(0.000)	(1.970)	(0.004)

Notes: The table reports the difference in characteristics between firms above and below the cut-off. Each difference is evaluated by regressing the firm characteristic on an indicator variable taking value one if the firm is below the cut-off. For each case, we control for time and firm's industry fixed effects. In model (1), the unit of interest *Leverage* is the ratio between the value of total corporate debt and equity. In model (2), the unit of interest *Size* is the logarithm of the total value of assets. In model (3), the unit of interest  $\Delta Yield$  is the change in the yield spread for a 10-years-maturity corporate bond. In model (4), the unit of interest *ROA* is the ratio of firm net income and assets in  $t - 1$ . In model (5), the unit of interest *PE10* is the 10-quarter-moving-average of the price-earning ratio. In model (6), *Fin. Constraint* is a measure of the financial constraint of the firm built after Hadlock and Pierce (2010). Standard errors in parentheses, clustered at firm level. \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

## 4.4.2 Results

**First Stage: EPS Distance from Forecast and the Cost of Debt** Here we study how variations in the cost of debt due to innovations in monetary policy differently affect repurchasing behavior of firms around the discontinuity. First, for each firm we define the effective distance from the EPS target with the variable  $Distance_{i,t}$ , such that firm  $i$  is off (on) target before the repurchase if  $Distance_{i,t} < 0$  ( $Distance_{i,t} \geq 0$ ). Second, given that most accretive repurchases result in an EPS accretion of 2 cents or less, we keep observations only for firms with  $Distance_{i,t}$  in the  $[-0.02\$, +0.02\$]$  bracket. Third, we regress equation (4.3) for all firms in the bracket to extract the exogenous change in the firm-specific yield, i.e.  $\widehat{\Delta Yield}_{i,t}$ , that is explained by monetary policy innovations. Then, we study how being off-target and receiving an exogenous change in the cost of debt affects the level of repurchase. In order to do so, consider the following:

$$\begin{aligned}
Repurchase_{i,t} = & \alpha_1 + \beta_1 \mathbb{I}(Distance_{i,t} < 0) + \beta_2 \widehat{\Delta Yield}_{i,t} + \beta_3 \mathbb{I}(Distance_{i,t} < 0) * \widehat{\Delta Yield}_{i,t} \\
& + \beta_4 Distance_{i,t} + \beta_5 \mathbb{I}(Distance_{i,t} < 0) * Distance_{i,t} + \beta_6 Distance_{i,t}^2 \\
& + \beta_7 \mathbb{I}(Distance_{i,t} < 0) * Distance_{i,t}^2 + \beta_8 Distance_{i,t}^3 \\
& + \beta_9 \mathbb{I}(Distance_{i,t} < 0) * Distance_{i,t}^3 + \theta_t + \epsilon_{i,t}
\end{aligned} \tag{4.5}$$

where  $Repurchase_{i,t}$  is the level of net repurchase normalized by the level of assets in  $t - 4$ ,  $\mathbb{I}(Distance_{i,t} < 0)$  takes values 1 when the firm  $i$  is off-target with respect to the analysts' EPS forecast,  $Distance_{i,t}$  is the effective distance from the forecast, the square and the cube of this measure and its interaction with  $\mathbb{I}(Distance_{i,t} < 0)$  control for non-linear behavior both at the left and right hand side of the discontinuity cut-off.

Table 4.6 reports results. From column (1), firms that are off-target buyback 0.7% more than those already on target. In column (2), we control for the exogenous variation in the cost of debt due to monetary policy, but the effect is

Table 4.6: 1st Stage

	(1)	(2)	(3)	(4)	(5)
	<i>Rep.</i>	<i>Rep.</i>	<i>Rep.</i>	<i>Rep.</i>	<i>Rep.</i>
$\mathbb{I}(Distance < 0)$	0.007*** (0.002)	0.009*** (0.002)	0.021*** (0.005)	0.015*** (0.004)	0.015*** (0.004)
$\widehat{\Delta Yield}$		0.000 (0.001)	0.003 (0.002)	0.002 (0.002)	0.002 (0.001)
$\mathbb{I}(Distance < 0) * \widehat{\Delta Yield}$			-0.005*** (0.001)	-0.004*** (0.001)	-0.004*** (0.001)
Observations	44856	31263	31263	31263	30494
Time FE	Yes	Yes	Yes	Yes	Yes
Industry FE	No	No	No	Yes	Yes
Controls (polynomial)	No	No	No	Yes	Yes
Controls ( $Z$ )	No	No	No	No	Yes

Notes: Standard errors in parentheses, clustered at firm level. For model (1) to (5), the unit of interest *Repurchase* is the difference between the value of stock purchases and stock issuances from the statement of cash flows, normalized by total asset in  $t - 4$ .  $\mathbb{I}(Distance < 0)$  is an indicator variable that takes value one if the firm is below the EPS forecast before EPS manipulation.  $\widehat{\Delta Yield}$  is the exogenous change in the 10-years corporate yield spread as predicted by monetary policy shocks, i.e. as from equation (4.3) in Section 4.3.4. In column (4), we control for a polynomial of the variable *Distance*, i.e. the difference between the EPS forecast and the pre-manipulated EPS of the firm, interacted with the indicator  $\mathbb{I}(Distance < 0)$ . In column (5), we control for  $Z$ : capital investment and employment, both normalized by total asset in  $t - 4$ . \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

not significant across firms on both sides of the discontinuity, while the level of repurchase for firms off-target increases to 1%. In column (3) we control for the interaction between the dummy variable  $\mathbb{I}(Distance_{i,t} < 0)$  and the change in the cost of debt  $\widehat{\Delta Yield}_{i,t}$ . As a result, the average level of repurchase is now 2% higher for those off-target. More interesting is the effect of the cost of debt across groups: if the change in the yield does not matter for those already on target, it matters a lot for those off-target. In particular, if the cost of debt falls by 1%, repurchases increase by 0.4% only for those that need to repurchase in the same quarter. In other words, if a firm in the position to launch an accretive repurchase faces an exogenous increase of the cost of debt, then its action will be limited and its capability to buyback a larger share of its assets will be reduced. Conversely, if the yield on debt falls for a firm about to launch an accretive repurchase, then the lower cost of debt expands the quantity repurchased. Therefore, we conclude that the cost of debt causally affects the size of a repurchase program and therefore it matters for those managers that need to buyback their own shares to satisfy market expectations. Column (4) shows results when controlling for a polynomial of the variable *Distance*<sub>*i,t*</sub> and the indicator variable  $\mathbb{I}(Distance < 0)$ . Results do not differ by much. Finally, as robustness check, we want to be sure that the estimates of equation (4.5) are not biased by the feedback of the change in the corporate cost of debt on real variables. For this reasons, in column (5) we

control also for the level of capital investment and employment both normalized by total asset in  $t - 4$ . All coefficients remain the same, thus we can conclude that this instrumentation procedure allows us to establish the causal effect of an exogenous change of the corporate cost of debt on the level of repurchase and to provide an unbiased measure of such effect.

To sum up, a "good" shock on the cost of debt boosts the size of the repurchase program for those firms that need to buyback in order to adjust the EPS and bring it to target. Thus, under regression (4.5), we established the causal effect of monetary policy on share buybacks as explained by exogenous variation in the cost of debt. Moreover, we provided an unbiased measure of such effect. The next step is to study the causal crowding-out effect of repurchase on real variables.

**Second Stage: Repurchase and Real Variables** Here we complete our analysis by investigating the causal impact of share buybacks on capital investments and employment. The following regression quantifies this effect:

$$\bar{Y}_{i,(t+1,t+4)} - \bar{Y}_{i,(t-4,t-1)} = \alpha_0 + \beta_0 \text{Repurchase}_{i,t} + X'_{i,t} \gamma + \theta_t + \nu_{i,t} \quad (4.6)$$

where the dependent variable is the difference between the mean value of  $Y$  in the next four quarters and in the previous 4 quarters, with  $Y$  being either capital investments or employment. All variables are normalized by the level of assets in  $t - 4$ .

Table 4.7 reports OLS estimates in column (1) and (4) and two-stage least squares (2SLS) estimates in column (2) and (5). For the latter, the variable *Repurchase* is instrumented under the first stage as in equation (4.5). In column (3) and (6) we repeat the 2SLS estimation under further controls.<sup>10</sup> When not instrumenting the endogenous variable, we find that a 1% of repurchase crowds out investments in physical capital and employment respectively by 4% and 75%. When instrumenting the endogenous variables, the coefficients of the regressors are respectively 5% and 120%. Adding further controls, as in column (3) and (6), does not change the 2SLS estimates by much. To better understand the quantitative implications of these numbers, consider the median firm in the bracket, which repurchases 2% of its assets each quarter and has a corresponding value of asset equal to 1,831M of dollars. Therefore, under the results of Table 4.7, the median firm reduces its capital expenditure by 0.1% of its own assets and the employment stock by 2.3 employee per million of dollars of assets. This is equivalent to saying that the median firm in the bracket diverts financial resources for 36.6M of dollars into repurchase programs and this leads to a reduction of capital expenditure by 1.8M of dollars and of the workforce by 43 units.

<sup>10</sup>We control for net income (normalized by total assets in  $t - 4$ ), Q-value of investment, a dummy indicating whether the firm has redistributed dividends in the first previous four quarters, a dummy indicating the quintile of asset the firms belong to, the joint interaction of  $\mathbb{I}(\text{Distance}_{i,t} < 0)$  with  $\text{Distance}_{i,t}$  and  $\Delta \widehat{Yield}_{i,t}$ .

In light of these results, we conclude that monetary policy do affect the size of buyback programs through changes in the cost of debt for those firms off the EPS target. This leads to a stronger crowding-out effect on real variables.

Yet, some might cast doubts on these results and our identification strategy. In particular, some might ask why we do not use directly monetary policy shocks as instrument. In Appendix 4.E, we show that results do not change much if we directly use monetary policy shocks and its interaction with the the EPS surprise in the 1st stage. Even though marginal, the difference between the results following this alternative identification and the ones from Table 4.7 is explained by firm-level heterogeneity in the cost of debt. We believe that by considering this dimension, we do a better job in measuring the firm-level effect of an exogenous monetary policy innovation on the managerial incentive to buyback.

Finally, one might also ask why we need both the exogenous change in the cost of debt and the EPS surprise together. As explained at the beginning of Section 4.4, monetary policy alone is not able to explain repurchase behavior because it can affect several firms' variables such that repurchase would be and endogenous outcome. In other words, if we consider all firms in the dataset (beyond those with  $Distance_{i,t}$  in the  $[-0.02\$, +0.02\$]$  bracket), either the monetary policy shock or the induced change in the firm-level cost of debt are weak instruments, since repurchase behavior could be explained by several other factors. Appendix 4.E.2 develops this case.

Table 4.7: 2nd Stage

	(1)	(2)	(3)	(4)	(5)	(6)
	$\Delta Inv.$	$\Delta Inv.$	$\Delta Inv.$	$\Delta Emp.$	$\Delta Emp.$	$\Delta Emp.$
	<i>OLS</i>	<i>2SLS</i>	<i>2SLS</i>	<i>OLS</i>	<i>2SLS</i>	<i>2SLS</i>
<i>Repurchase</i>	-0.04** (0.01)	-0.05*** (0.02)	-0.05*** (0.02)	-0.75** (0.31)	-1.19** (0.53)	-1.17** (0.53)
Observations	26588	26588	26588	24046	24046	24046
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls ( $X$ )	Yes	No	Yes	Yes	No	Yes

Notes: Standard errors in parentheses, clustered at firm level. For model (1) to (3), the unit of interest  $\Delta Inv.$  is the difference between the mean value of capital investments in the next four quarters and in the previous four quarters, normalized by total asset in  $t - 4$ . For model (4) to (6), the unit of interest  $\Delta Emp.$  is the difference between the mean level of employment in the next four quarters and in the previous 4 quarters, normalized by total asset in  $t - 4$ . *Repurchase* is the difference between the value of stock purchases and stock issuances from the statement of cash flows, normalized by total asset in  $t - 4$ . When using *2SLS* in model (2), (3), (5) and (6), this variable is instrumented according to equation (4.5), Section 4.4.2. Control  $X$  includes net income (normalized by total assets in  $t - 4$ ), Q-value of investment, a dummy indicating whether the firm has redistributed dividends in the first previous four quarters, a dummy indicating the quintile of asset the firms belong to, the joint interaction of  $\mathbb{I}(Distance_{i,t} < 0)$  with  $Distance_{i,t}$  and  $\Delta Yield_{i,t}$ . \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

### 4.4.3 The Attenuation of Accommodative Monetary Policy on Real Variables due to Repurchase

Should we conclude that accommodative monetary policy crowds out investments? Here we exploit our results from Section 4.3.2 and 4.4.2 to study by how much the transmission of an accommodative monetary policy shock is attenuated through the repurchase channel. From Table 4.4 column (2), we know that a 1% exogenous innovation in the fund rate leads to a 0.62% increase of the 10-years yield spread. As from Table 4.6 column (4), we know that a 0.62% increase in the yield spread leads to a rise in repurchase by  $0.44\% \times 0.62\% = 0.27\%$ . According to the results of Table 4.7, an increase of 0.27% in repurchases leads to a fall in investment and employment respectively by  $5 \times 0.27\% = 1.4\%$  and  $117 \times 0.27\% = 31.6\%$ . In other words, for a 1% exogenous fall of the fund rate, firms that repurchase are decreasing their investments by 1.4 dollar for every 100\$ of assets, and are decreasing their employment stock roughly by 0.31 employees every 1 million dollars of assets.

In order to better understand the magnitude of these results, let's consider the baseline scenario in which firms do not repurchase, and study how a change in monetary policy affects investments and employment for these firms. To do this, we consider the following model:

$$\bar{Y}_{i,(t+1,t+4)} - \bar{Y}_{i,(t-4,t-1)} = \alpha + \beta Shock_t + X'_{i,t} \gamma + \theta_t + \epsilon_{i,t} \quad (4.7)$$

where the dependent variable is again the difference between the mean value of  $Y$  in the next four quarters and in the previous 4 quarters, with  $Y$  being either capital investments or employment. All variables are normalized by the level of assets in  $t - 4$ .  $Shock$  is the monetary policy innovation obtained from a SVAR (see Appendix A).

As from Table 4.8, we find that for a 1% exogenous decrease in the fund rate, there is an increase of investments by 7% and of employment by 54%. Hence, we can now proceed with a back-of-the-envelope calculation of what is the expected transmission of a 1% exogenous fall in the fund rate on real variables. To do so, we calculate a weighted average by using the results computed above and the share of firms-quarter that do and do not repurchase (see Table 4.1) as weights. Formally:

$$\mathbb{E}[\Delta Investments | Shock_t = -1\%] = 0.76 \times (7\%) + 0.24 \times (-1.4\%) = 4.98\%$$

$$\mathbb{E}[\Delta Employment | Shock_t = -1\%] = 0.76 \times (54\%) + 0.24 \times (-31.6\%) = 33.54\%.$$

In words, when the fed fund rate exogenously falls by 1%, investments and employment are expected to grow respectively by 1.95% and 19.01%. Hence, we can say that the repurchase channel attenuates the transmission of monetary

Table 4.8: Assessing the Impact of Monetary Policy

	(1)	(2)
	$\Delta Investments$	$\Delta Employment$
<i>Shock</i>	-0.07** (0.03)	-0.54* (0.28)
Observations	149269	114877
$\mathbb{I}(Rep. > 0) = 0$	Yes	Yes
Time FE	Yes	Yes
Industry FE	Yes	Yes
Controls ( <i>X</i> )	Yes	Yes

Notes: Standard errors in parentheses, clustered at firm level. For model (1), the unit of interest  $\Delta Inv.$  is the difference between the mean value of capital investments in the next four quarters and in the previous four quarters, normalized by total asset in  $t - 4$ . For model (2), the unit of interest  $\Delta Emp.$  is the difference between the mean level of employment in the next four quarters and in the previous 4 quarters, normalized by total asset in  $t - 4$ . *Shock* is the monetary policy innovation extracted from a SVAR (see Appendix A). Control *X* includes net income (normalized by total assets in  $t - 4$ ), Q-value of investment, a dummy indicating whether the firm has redistributed dividends in the first previous four quarters, a dummy indicating the quintile of asset the firms belong to. \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

policy on investments and employment roughly by  $[0.24 \times (1.4\%)/4.98\%] = 6.74\%$  and  $[0.24 \times (31.6\%)/33.54\%] = 22.66\%$ .

## 4.5 Robustness Checks and Extensions

### 4.5.1 Pre-existing differences across firms above and below the EPS target

In order to validate our identification strategy, we need to check that there are no other discontinuous differences in firms' dynamics around the pre-repurchase EPS cut-off. A common way to confirm this assumption is to test whether firms around the cut-off exhibit pre-existing differences in capital investments and employment choices, i.e. if changes in the dependent variables for periods prior to the repurchase differ across firms below or above target. We carryout this exercise for the four preceding quarters,  $j$ , by running the following regression:

$$\Delta Y_{i,(t-1,t-j)} = \alpha + \beta \mathbb{I}(Distance_{i,t} < 0) + \theta_t + \epsilon_{i,t} \quad (4.8)$$

where  $\Delta Y_{i,(t-1,t-j)}$  is the dependent variable simple difference between  $t - 1$  and  $t - j$ , with  $j = \{1, 2, 3, 4\}$ . As from Table 4.9, there are no systematic pre-existing differences between firms at the left and at the right of the discontinuity in terms of outcome variables: the pre-repurchase common trend assumption holds and

our identification strategy is valid.

Table 4.9: Pre-repurchase Trend in Outcome Variables

	(1)	(2)
	$\Delta Investment$	$\Delta Employment$
<b>Changes (<math>t - 2</math> to <math>t - 1</math>)</b>		
$\mathbb{I}(Distance < 0)$	-0.000 (0.000)	0.000* (0.000)
<b>Changes (<math>t - 3</math> to <math>t - 1</math>)</b>		
$\mathbb{I}(Distance < 0)$	-0.001* (0.000)	0.000 (0.000)
<b>Changes (<math>t - 4</math> to <math>t - 1</math>)</b>		
$\mathbb{I}(Distance < 0)$	-0.001 (0.001)	0.000 (0.000)
<b>Changes (<math>t - 5</math> to <math>t - 1</math>)</b>		
$\mathbb{I}(Distance < 0)$	-0.000 (0.003)	0.000 (0.000)
Time FE	Yes	Yes
Industry FE	Yes	Yes
Controls ( $X$ )	No	No

Notes: Standard errors in parentheses, clustered at firm level. For model (1), the unit of interest  $\Delta Inv.$  is the difference between the mean value of capital investments in the four quarters previous to the repurchase and four quarters  $j = \{2, 3, 4, 5\}$  periods before the repurchase. Each Difference is normalized by total asset in  $t - 4$ . For model (2) the unit of interest  $\Delta Inv.$  is the difference between the mean level of employment in the four quarters previous to the repurchase and four quarters  $j = \{2, 3, 4, 5\}$  periods before the repurchase. Each Difference is normalized by total asset in  $t - 4$ .  $\mathbb{I}(Distance < 0)$  is an indicator variable taking value one if the firm is currently below the EPS target. \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

## 4.5.2 The financing of share buybacks around the EPS target

In this section, we check if indeed firms off-target use debt to repurchase compared with firms on target. In order to do so, we propose the same equation as in Section 4.3.2 that shows how repurchases are funded. Columns 1 and 2 of Table 4.10 show the contribution of debt to repurchase for the sample of firms off-target (whose distance from target is in the  $[-0.02\$, 0\$]$  bracket) while column 3 and 4 show results for firms on target (whose distance from target is in the  $[0\$, +0.02\$]$ ). For firms off-target, every dollar of assets repurchased is financed with 20 cents coming from new debt (column 1); when controlling for other sources of financing and expenditures (column 2), the result does not change. For firms already on

target (column 3 and 4), the contribution of debt is not significant. This validates our analysis, confirming that debt is an important source for firms that need to launch an accretive repurchase to bring the EPS on target.

Table 4.10: Financing Buybacks

	(1)	(2)	(3)	(4)
	<i>Repurchase</i>	<i>Repurchase</i>	<i>Repurchase</i>	<i>Repurchase</i>
$\Delta Debt$	0.20*	0.20**	0.00	0.01
	(0.12)	(0.10)	(0.00)	(0.03)
Observations	21422	15851	20348	17392
Off Target Sample	Yes	Yes	No	No
Time FE	No	No	No	No
Industry FE	No	No	No	No
Controls (Other sources)	No	Yes	No	Yes

Notes: Standard errors in parentheses, clustered at firm level. For model (1) to (4), the unit of interest *Repurchase* is the difference between the value of stock purchases and stock issuances from the statement of cash flows, normalized by total asset in  $t - 4$ .  $\Delta Debt$  is the change in the value of current total debt of the firm, normalized by total asset in  $t - 4$ . When used, the control variables are all main other sources of the budget constraint of the firm: the change in firm money holding plus current net profit, capital expenditure and the value of the dividends paid. \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

### 4.5.3 Debt issuance and its persistency

Firms off target rely on debt and new debt issuance to finance repurchases, and the size of their buyback programs depends heavily on the cost of debt. Here we push the analysis further and investigate whether the same firms exhibit a persistent change in debt issuance from the period of the repurchase onwards. In fact, as documented in [Baker and Wurgler \(2002\)](#), the market-timing of firms' operation has persistent effects on the capital structure of the firms themselves. In our case, we want to test if, whenever a EPS surprises realizes, firms that need to buyback persistently issue more debt over time.

To study the persistence of changes in debt, we use the following specification for firms with  $Distance_{i,t}$  in the  $[-0.02\$, +0.02\$]$  bracket:

$$\Delta Debt_{i,(t+j,t+j-1)} = \alpha + \beta \mathbb{I}(Distance_{i,t} < 0) + X'_{i,t} \gamma + \theta_t + \epsilon_{i,t} \quad (4.9)$$

where the dependent variable is the change in the stock of corporate debt between  $t + j$  and  $t + j - 1$  for  $j = \{1, 2, 3, 4\}$ . All changes are normalized by asset in  $t + j - 4$ .  $X$  controls for 4 forward values of the indicator  $\mathbb{I}(Distance_{i,t} < 0)$ . This allows us to be sure that the change in debt issuance in the future is not due to other EPS forecast surprises, but only due to the current EPS surprise.

As from [Table 4.11](#), in the quarter in which firms discover whether they need to adjust their EPS, firms off target issue more debt with respect to those on target (model (1)). Yet, no matter future EPS surprises, debt issuance continues

for one more quarter (model (2)). The effect of the current EPS surprise on debt issuance vanishes in the 2<sup>nd</sup> quarter after the initial surprise (model(3)). In the 3<sup>rd</sup> quarter, debt issuance is negative and slightly significant for firms who were initially off target (model (4)).

Table 4.11: Debt Issuance over Time

	(1)	(2)	(3)	(4)
	$\Delta Debt_{(t+1,t)}$	$\Delta Debt_{(t+2,t+1)}$	$\Delta Debt_{(t+3,t+2)}$	$\Delta Debt_{(t+4,t+3)}$
$\mathbb{I}(Distance < 0)$	0.004*** (0.001)	0.003** (0.001)	0.000 (0.001)	-0.002* (0.001)
Observations	25760	25786	25802	25830
Time FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Controls ( $X$ )	Yes	Yes	Yes	Yes

Notes: Standard errors in parentheses, clustered at firm level. For model (1) to (4), the unit of interest  $\Delta Debt_{(t+j,t+j-1)}$  is the change in the value of current total debt between  $t+j$  and  $t+j-1$ , for  $j = \{1, 2, 3, 4\}$ . This changes are normalized by total asset in  $t+j-4$ .  $\mathbb{I}(Distance < 0)$  is an indicator variable taking value one if the firm is currently below the EPS target. Controls include 4 forward values of the indicator  $\mathbb{I}(Distance_{i,t} < 0)$ . This allows us to be sure that the change in debt issuance for  $j > 0$  is not due to future EPS forecast surprises, but only due to the current EPS surprise. \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

#### 4.5.4 Comparing determinants of share buybacks

Here we assess to what extent the change in the cost of debt matters compared with other major determinants of share buyback programs documented in the literature. In particular, we study how the probability of conducting a repurchase program is related to the occurrence of three states: (i) if the firm experiences an exogenous fall in its cost of debt, (ii) if the firm's EPS is off-target, (iii) if the firm has experienced a decline in growth prospective.

Consider the following:

$$\mathbb{I}(Repurchase_{i,t} > 0) = \alpha + \beta_1 I_{i,t}^{\Delta Yield} + \beta_2 I_{i,t}^{EPS} + \beta_3 I_{i,t}^{PE10} \quad (4.10)$$

$$+ X'_{i,t} \gamma + \theta_t + \epsilon_{i,t} \quad (4.11)$$

where  $\mathbb{I}(Repurchase_{i,t} > 0)$  takes value 1 if firm  $i$  is a net repurchaser at time  $t$ ,  $I_{i,t}^{\Delta Yield}$  is a dummy equal to one if the firm has experienced an exogenous increase in the cost of debt between quarter  $t$  and  $t-1$  (as predicted from equation (4.3));  $I_{i,t}^{EPS}$  is equal to one if the EPS of the firm is off-target;  $I_{i,t}^{PE10}$  is equal to one if the firm has experienced a decline in investment opportunities, i.e a decline in the 10-quarter-moving-average of the price-earning ratio (PE10) between quarter  $t$  and  $t-1$ . As column (1) of Table 4.12 shows, the 20% of the (linear) probability of

repurchasing is explained by the debt cost channel, 5% by the EPS channel, whereas the decline in investment opportunities is not a significant channel. When controlling for industry fixed effect (as in column 2) and a measure of financial constraint (as in column 3), the coefficient on the dummy for the cost of debt moves to 8%, while the other estimates do not change.

The cost of debt is indeed crucial in explaining the willingness and capability for firms to launch a buyback program. The other channels matter relatively less.

Table 4.12: Buybacks' Determinants

	(1)	(2)	(3)
	$\mathbb{I}(Rep. > 0)$	$\mathbb{I}(Rep. > 0)$	$\mathbb{I}(Rep. > 0)$
$I^{\Delta Yield}$	-0.19*** (0.02)	-0.08*** (0.02)	-0.08*** (0.02)
$I^{EPS}$	0.05*** (0.02)	0.04*** (0.01)	0.05*** (0.01)
$I^{PE10}$	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)
Observations	6473	6473	6473
Time FE	Yes	Yes	Yes
Industry FE	No	Yes	Yes
Controls ( $X$ )	No	No	Yes

Notes: Standard errors in parentheses, clustered at firm level. For model (1) to (3), the unit of interest is  $\mathbb{I}(Rep. > 0)$ , an indicator variable taking value one if the firm is a net repurchaser, i.e. the difference between equity repurchased and new equity issuance is positive.  $I^{\Delta Yield}$  is a dummy equal to one if the firm has experienced an exogenous increase in the 10-years corporate bond spread between quarter  $t$  and  $t - 1$  (as predicted from equation (4.3), Section 4.3.4).  $I^{PE10}$  is equal to one if the firm has experienced a decline in investment opportunities, i.e a decline in the 10-quarter-moving-average of the price-earning ratio (PE10) between quarter  $t$  and  $t - 1$ . Control  $X$  includes net income, normalized by total asset in  $t - 4$ , Q-value of investment, a dummy indicating whether the firm has redistributed dividends in the first previous four quarters, a dummy indicating the quintile of asset the firms belong to. \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

### 4.5.5 Repurchases and excess returns on the stock market

In this section we conclude our analysis by investigating the effect of share buybacks on firm's excess returns on the stock market. In particular, we run again the second stage as from equation 6:

$$R_{(i,t+j)} - R_{(i,t-1)} = \alpha + \beta Repurchase_{i,t} + X'_{i,t} \gamma + \theta_t + \epsilon_{i,t} \quad (4.12)$$

where the dependent variable is now the change between quarter  $t + j$  and  $t - 1$  (with  $j = \{0, 1, 2, \dots\}$ ) of the excess stock return of firm  $i$  over the Standard & Poor's index (SP500), and the endogenous variable  $Repurchase_{i,t}$  is instrumented under equation (4.5). Table 4.13 reports 2SLS results for values of  $j$  from 0 to 3. As from column (1), a 1 percent increase in repurchase today causes an increase in the excess return by 7.1 base points. However, the effect is not persistent over time. As from column (2)-(4), higher repurchasing today does not imply higher returns afterwards. The effect vanishes after the quarter in which the repurchase occurred.

Table 4.13: Buybacks and Stock Market Returns

	(1)	(2)	(3)	(4)
	$R_t - R_{t-1}$	$R_{t+1} - R_{t-1}$	$R_{t+2} - R_{t-1}$	$R_{t+3} - R_{t-1}$
	2SLS	2SLS	2SLS	2SLS
<i>Repurchase</i>	0.07*** (0.02)	-0.03 (0.04)	-0.05 (0.03)	0.03 (0.04)
Observations	30223	29343	28310	27303
Time FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Controls ( $X$ )	Yes	Yes	Yes	Yes

Notes: Standard errors in parentheses, clustered at firm level. For model (1) to (4), the unit of interest is  $R_{t+j} - R_{t-1}$  with  $j = \{0, 1, 2, 3\}$ .  $R$  is the firm's excess stock return over the Standard & Poor's index (SP500).  $Repurchase$  is the difference between the value of stock purchases and stock issuances from the statement of cash flows, normalized by total asset in  $t - 4$ . This variable is here instrumented according to equation (4.5), Section 4.4.2. Control  $X$  includes net income (normalized by total assets in  $t - 4$ ), Q-value of investment, a dummy indicating whether the firm has redistributed dividends in the first previous four quarters, a dummy indicating the quintile of asset the firms belong to, the joint interaction of  $\mathbb{I}(Distance_{i,t} < 0)$  with  $Distance_{i,t}$  and  $\widehat{\Delta Yield}_{i,t}$ . \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

#### 4.5.6 Production function, financial constraints and the crowding-out effect

In this part, we link again the data to the stylized model of Section 4.2. In particular, we want to study whether firm heterogeneity in production function parameters (TFP and returns to scale), leverage and the level of financial constraint affect the crowding-out effect of repurchases on real variables. In order to check this, first we need to estimate for each firm the parameters of a generic Cobb-Douglas production function of the form  $Y = zK^{\alpha_K}L^{\alpha_L}$ , where  $Y$  is the firm output,  $z$  is the firm productivity,  $K$  and  $L$  are the level of capital and labor used for production. By following İmrohoroğlu and Tüzel (2014), this translates into estimation of the following model for each firm  $i$ :

$$\log(Profits_{i,t}) = \alpha_{0,i} + \alpha_{K,i}\log(Capital_{i,t}) + \alpha_{L,i}\log(Labor_{i,t}) + \epsilon_i$$

where the left hand side is the logarithm of net profits, while the right hand side is the logarithm of the value of physical capital and the number of employees. All variables are normalized by assets in  $t - 1$ . Then, we estimate the production function with OLS and we store the estimated parameter  $\hat{\alpha}_{0,i}$ ,  $\hat{\alpha}_{K,i}$ ,  $\hat{\alpha}_{L,i}$  and the series of residuals  $\hat{e}_{i,t}$  for each firm. Thereafter, we build  $\hat{z}_{i,t} = \alpha_{0,i} + \hat{e}_{i,t}$ , a measure for total factor productivity (TFP) at establishment level.

Now, we can test how heterogeneity in the production function parameters  $\hat{z}_{i,t}$ ,  $\hat{\alpha}_{K,i}$ ,  $\hat{\alpha}_{L,i}$ , and different measures of the proxy parameter  $\theta$  of the theoretical model (for example the level of financial constraint and leverage) affect the relationship between repurchase and real variables.

Thus, for each firm characteristic  $W_{i,t} = \{\hat{z}_{i,t}, \hat{\alpha}_{K,i}, \hat{\alpha}_{L,i}, Fin. Constraint, Leverage\}$ , we run the following model:

$$\bar{Y}_{i,(t+1,t+4)} - \bar{Y}_{i,(t-4,t-1)} = \eta + \beta_1 W_{i,t} + \beta_2 Repurchase_{i,t} + \beta_3 [W_{i,t} * Repurchase_{i,t}] + X'_{i,t} \gamma + \theta_t + \epsilon_{i,t} \quad (4.13)$$

where the dependent variable is the difference between the mean value of  $Y$  in the next four quarters and in the previous 4 quarters, with  $Y$  being either capital investments or employment. All variables are normalized by the level of assets in  $t - 4$ . The independent variable *Repurchase* is again instrumented under the specification of equation (4.5).

From Table 4.14 panel a), the only variable that weakens the crowding-out effect of repurchase on capital expenditure is firm total factor productivity ( $\hat{z}$ ). In fact, when looking to the interaction term between  $\hat{z}$  and *Repurchase*, we find that the effect on investment is positive. In other words, firms with a higher TFP are capable to conduct buybacks without necessarily crowding-out investments. When looking at the change in employment stock as from Table 4.14 panel b), the interaction term is always not significant and heterogeneity in firms characteristics do not matter in reducing the effect of repurchase on this real variable.

## 4.6 Conclusion

This paper documents how debt and the cost of debt are key deciding factors for a manager when launching a repurchase program. In particular, we show that if a firm benefits from an exogenous fall in the corporate yield – caused by an accommodative monetary policy shock – and needs to buyback its shares, the amount of shares repurchased from the stock market is going to be larger. This proves that the cost of debt determines the size of repurchase programs and that firms mostly rely on new and low-cost debt to finance this market operation. Moreover, when conducting a repurchase, the same firms tend to reduce investment and employment since they devote their resources to these programs at the detriment of new capital or employees. Such crowding-out is particularly strong

Table 4.14: Firm's Heterogeneity and the Crowding-out Effect

	(1)	(2)	(3)	(4)	(5)
	$\hat{z}$	$\hat{\alpha}_K$	$\hat{\alpha}_L$	<i>Fin. Constr.</i>	<i>Leverage</i>
<b>a) Depend Var. <math>\Delta Inv.</math></b>					
<i>W</i>	-0.00** (0.00)	0.00 (0.00)	-0.00 (0.00)	0.01* (0.00)	0.00 (0.00)
<i>Repurchase</i>	-0.18*** (0.07)	-0.07 (0.04)	-0.17** (0.07)	-0.03 (0.19)	-0.15*** (0.05)
<i>W</i> × <i>Repurchase</i>	0.03** (0.01)	-0.12 (0.08)	0.07 (0.06)	0.04 (0.07)	-0.00 (0.00)
Observations	22857	22857	22857	22857	22856
<b>b) Depend Var. <math>\Delta Emp.</math></b>					
<i>W</i>	-0.00 (0.01)	-0.22 (0.25)	0.21** (0.10)	0.25 (0.53)	0.00 (0.00)
<i>Repurchase</i>	-4.49*** (1.28)	-9.34** (4.50)	-3.50*** (0.98)	-22.24 (14.80)	-4.50*** (1.19)
<i>W</i> × <i>Repurchase</i>	0.00 (0.21)	7.48 (5.72)	-3.07 (2.71)	-5.96 (4.71)	-0.00 (0.00)
Observations	20850	20850	20850	20850	20850
Time FE	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
Controls ( <i>X</i> )	Yes	Yes	Yes	Yes	Yes
2SLS	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors in parentheses, clustered at firm level. For Panel a), the unit of interest is  $\Delta Inv.$ , i.e. the difference between the mean value of capital investments in the next four quarters and in the previous four quarters, normalized by total asset in  $t-4$ . For Panel b), the unit of interest is  $\Delta Emp.$ , i.e. the difference between the mean level of employment in the next four quarters and in the previous four quarters, normalized by total asset in  $t-4$ . Each columns consider a different independent variable  $W = \{\hat{z}, \hat{\alpha}_K, \hat{\alpha}_L, Fin. Constr., Leverage\}$ , where  $\hat{z}$ ,  $\hat{\alpha}_K$ , and  $\hat{\alpha}_L$  are respectively the firm productivity, return to scale for capital and return to scale for labor. These values are obtained from the estimation of the following model for each firm:  $\log(Profits_{i,t}) = \alpha_0 + \alpha_{K,i} \log(Capital_{i,t}) + \alpha_{L,i} \log(Labor_{i,t}) + \epsilon_i$ , where the left hand side is the logarithm of net profits, while the right hand side is the logarithm of the value of physical capital and the number of employees. All variables are normalized by assets in  $t-1$ .  $\hat{z} = \alpha_0 + \hat{\epsilon}$ , where  $\hat{\epsilon}$  is the residual from the estimated production function. *Fin. Constraint* is a measure of the financial constraint of the firm built after Hadlock and Pierce (2010). *Leverage* is the ratio between the value of total corporate debt and equity. *Repurchase* is the difference between the value of stock purchases and stock issuances from the statement of cash flows, normalized by total asset in  $t-4$ . This variable is here instrumented according to equation (4.5), Section 4.4.2. Control *X* includes net income (normalized by total assets in  $t-4$ ), Q-value of investment, a dummy indicating whether the firm has redistributed dividends in the first previous four quarters, a dummy indicating the quintile of asset the firms belong to, the joint interaction of  $\mathbb{I}(Distance_{i,t} < 0)$  with  $Distance_{i,t}$  and  $\widehat{\Delta Yield}_{i,t}$ . \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

for firms with low TFP. On the other hand, equity market tends to react positively to repurchase with an increase in stock returns in the same quarter in which the repurchase program is launched. Finally, we show that share-buybacks mitigate the transmission of monetary policy on investment and employment respectively by 2.9% and 0.28%.

## 4.A A SVAR for Monetary Shocks

We extract monetary policy shocks from a SVAR. In particular, we consider this model:

$$Z_t = \Gamma + A(L)Z_{t-1} + \epsilon_t$$

where  $Z_t = [G_t, Y_t, h_t, C_t, I_t, w_t, \pi_t, r_t]$ , i.e. a vector containing series for government spending, real Gdp, hours worked, consumption, investments, wages, inflation rate and the 3-months rate on government bonds. All variables are detrended with a fourth-degree polynomial. The monetary shocks are identified using a Cholesky decomposition. Figure 4.3 reports the time series for the exogenous monetary policy shocks as identified by the SVAR.

## 4.B Proof of Proposition 1

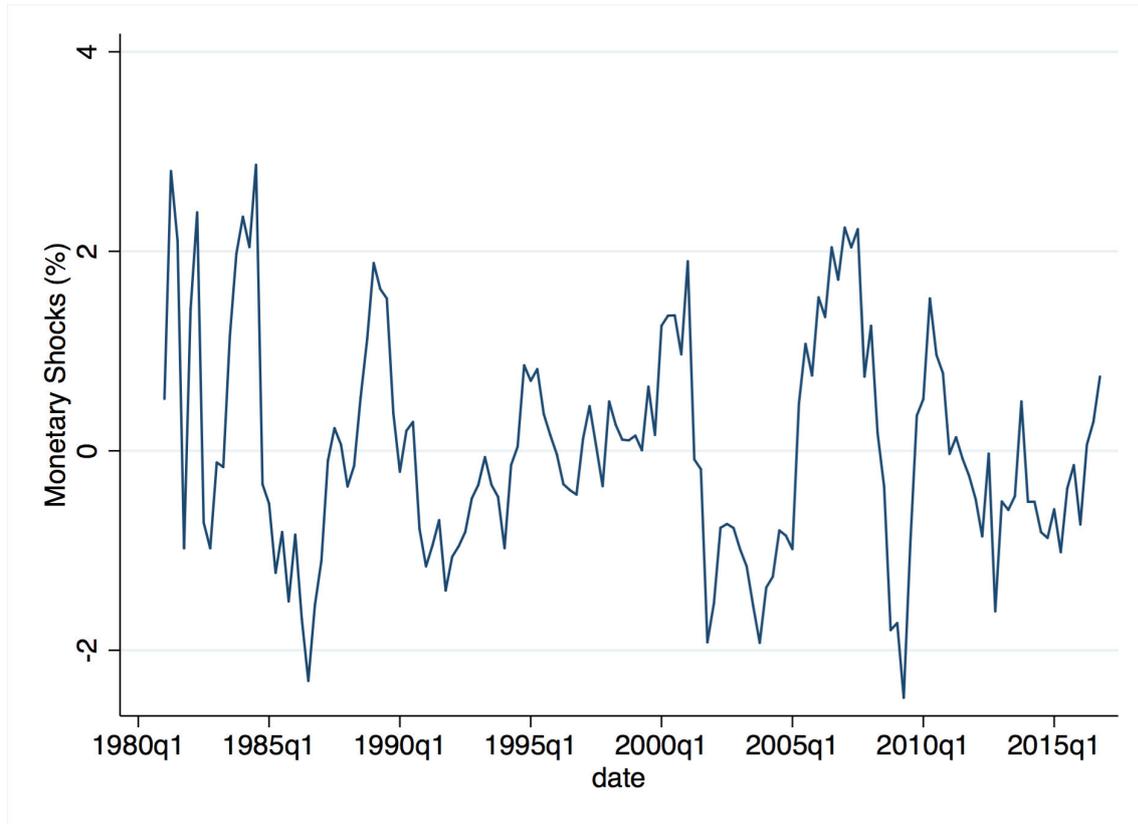
Assume for simplicity that the tax rate is zero (i.e.  $\tau = 0$ ). Then, consider the system of equation pinned down by condition (i) and (ii) of Proposition 1 and evaluate it at the equilibrium:

$$\begin{cases} [f'(B^* - n^*P) - (1 + r^B)] = \theta(1 - d)[B^*(1 - d) + dn^*P](N - n^*) \\ EPS(B^*, n^*) = P[f' + r^S] + \theta d[(1 - d)B^* + dn^*P]P(N - n^*) \end{cases}$$

Perturbate the latter for a small change in the interest rate  $r^S$ . Then we obtain the following

$$\begin{cases} a \frac{\partial B^*}{\partial r^S} + b \frac{\partial n^*}{\partial r^S} = \kappa \\ c \frac{\partial B^*}{\partial r^S} + d \frac{\partial n^*}{\partial r^S} = \frac{\kappa B^* + NP}{N - n^*} \end{cases} \quad (4.14)$$

Figure 4.3: Exogenous Monetary Shocks



Notes: This graph plots the time series of monetary policy innovations extracted -under Cholesky decomposition- from this SVAR:  $Z_t = \Gamma + A(L)Z_{t-1} + \epsilon_t$ , where  $Z_t = [G_t, Y_t, h_t, C_t, I_t, w_t, \pi_t, r_t]$  is a vector containing series for government spending, real Gdp, hours worked, consumption, investments, wages, inflation rate and the 3-months rate on government bonds.

where

$$\begin{aligned}
 a &= [f'' - \theta(1-d)^2(N-n^*)] \\
 b &= \theta(1-d)[B^*(1-d) - dP(N-2n^*)] - Pf'' \\
 c &= -\frac{Pf''}{N-n^*} - \theta dP(1-d)(N-n^*) \\
 d &= f''P^2 - \theta dP[dP(N-2n^*) - (1-d)B^*].
 \end{aligned}$$

Then, by using Cramer Rule, we can find the solution of system (12):

$$\begin{aligned}
 \frac{\partial B^*}{\partial r^s} &= \frac{\kappa d - b \frac{\kappa B^* + NP}{N-n^*}}{ad - cb} \\
 \frac{\partial n^*}{\partial r^s} &= \frac{a \frac{\kappa B^* + NP}{N-n^*} - \kappa c}{ad - cb}
 \end{aligned}$$

To understand the sign of  $\frac{\partial B^*}{\partial r^s}$  and  $\frac{\partial n^*}{\partial r^s}$ , analyze first the sign of the denominator.

For simplicity, we consider the case in which  $\theta = 0$ . Therefore we can write:

$$ad - cb = \frac{(f'')^2 P^2 [N - n^* - 1]}{N - n^*}.$$

Assuming concavity of the production function ( $\alpha \in (0, 1)$ ),  $N - n^* > 1$  and  $\theta$  small is sufficient for  $ad - cb$  to be positive. Under these normative assumptions, which respectively imply decreasing returns to capital, an amount of outstanding shares bigger than 1, and low cost in leverage change, we can write

$$\kappa d - b \frac{\kappa B^* + NP}{N - n^*} < 0$$

and

$$a \frac{\kappa B^* + NP}{N - n^*} - \kappa c < 0.$$

Therefore, under these normative assumptions, we conclude that

$$\begin{aligned} \frac{\partial B^*}{\partial r^s} &< 0 \\ \frac{\partial n^*}{\partial r^s} &< 0. \square \end{aligned}$$

## 4.C The Financing of Share Buybacks

In Section 4.3.2, we show that newly issued debt is mostly used to finance buy-back programs. Here we corroborate this idea by considering this specification:

$$\begin{aligned} \Delta Debt_{i,(t,t-1)} &= \beta_1 Repurchase_{i,t} + \beta_2 \Delta Money_{i,t} + \beta_3 Profits_{i,t} \\ &+ \beta_3 Investments_{i,t} + \beta_4 Dividends_{i,t} + \epsilon_{i,t} \end{aligned}$$

Differently, from the specification used in Section 4.4.2, here variables are in level and the dependent variable is the change in the amount of debt ( $\Delta Debt$ ). Moreover, instead of considering changes in cash-holdings and newly generated profits under the same variable, here we consider this two sub-voices separately:  $\Delta Money$  captures the change in cash holdings between two consecutive periods, whereas  $Profits$  captures the amount of net profits generated in the current quarter. All variables are normalized by total assets in  $t - 4$ . Results are shown in Table 4.15. As from column 1, for every dollar of newly issued debt 26 cents are used to finance a repurchase, 49 cents to finance new investments, and 3 cents to finance dividend payments. This result does not change when controlling for

time fixed effects (column 2). When considering only firms with  $Repurchase > 0$  -i.e. they are always buying back more shares than the number of shares issued- as in column 3 and 4, the result is almost the same. To sum up, debt is used mostly to finance investment and repurchase.

Table 4.15: Financing Buybacks 1

	(1)	(2)	(3)	(4)
	$\Delta Debt$	$\Delta Debt$	$\Delta Debt$	$\Delta Debt$
<i>Repurchase</i>	0.26*** (0.04)	0.25*** (0.04)	0.22*** (0.04)	0.22*** (0.04)
$\Delta Money$	0.07 (0.05)	0.07 (0.05)	0.12** (0.05)	0.12** (0.05)
<i>Profits</i>	-0.16*** (0.03)	-0.15*** (0.03)	-0.11*** (0.04)	-0.11*** (0.04)
<i>Investments</i>	0.49*** (0.06)	0.49*** (0.06)	0.44*** (0.06)	0.44*** (0.06)
<i>Dividends</i>	0.03*** (0.01)	0.03*** (0.01)	0.03** (0.01)	0.03** (0.01)
Observations	116600	116600	34162	34162
Time FE	No	Yes	No	Yes
Industry FE	No	No	No	No
Controls	No	No	No	No
Reduced Sample	No	No	Yes	Yes

Notes: Standard errors in parentheses, clustered at firm level. The unit of observation  $\Delta Debt$  is the change in the value of current total debt of the firm. *Repurchase* is the difference between the value of stock purchases and stock issuances from the statement of cash flows.  $\Delta Money$  is the change in firm cash holding. *Profits* is the value of firm profit at the net of taxes. *Investments* is equal to capital expenditure. *Dividends* is equal to the value of the dividends paid. All variables are normalized by the value of total assets in  $t - 4$ . Column (3) and (4) report results for the sample of firms that are net repurchasers, i.e. firms for which  $Repurchase > 0$ . \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

To conclude our analysis, we now consider again the same specification of Section 4.3.2, but variables in levels and both cash-holdings and profits on the right-hand side:

$$Repurchase_{i,t} = \beta_1 \Delta Debt_{i,(t,t-1)} + \beta_2 \Delta Money_{i,t} + \beta_3 Profits_{i,t} \\ + \beta_4 Investments_{i,t} + \beta_5 Dividends_{i,t} + \epsilon_{i,t}.$$

Table 4.16 reports results. As from column 1, each dollar spent in repurchase is financed with 34 cents of newly issued debt, 12 cents from cash holdings, 35

cents from profits, 23 cents from a reduction of investments. These magnitudes does not change when controlling for time fixed effects (column 2). When considering only "net-repurchasers" (column 3 and 4), the contribution of debt does not change whereas the contribution of profits in the financing of repurchase increases significantly.

Table 4.16: Financing Buybacks 2

	(1)	(2)	(3)	(4)
	<i>Repurchase</i>	<i>Repurchase</i>	<i>Repurchase</i>	<i>Repurchase</i>
$\Delta Debt$	0.34*** (0.07)	0.33*** (0.07)	0.35*** (0.08)	0.35*** (0.08)
$\Delta Money$	-0.12** (0.06)	-0.12** (0.06)	-0.09*** (0.03)	-0.09*** (0.03)
<i>Profits</i>	0.34*** (0.06)	0.35*** (0.06)	0.48*** (0.06)	0.48*** (0.06)
<i>Investments</i>	-0.23*** (0.05)	-0.22*** (0.04)	-0.19*** (0.06)	-0.19*** (0.06)
<i>Dividends</i>	0.05* (0.03)	0.05* (0.02)	0.00 (0.03)	0.00 (0.03)
Observations	116600	116600	34162	34162
Time FE	No	Yes	No	Yes
Industry FE	No	No	No	No
Controls	No	No	No	No
Reduced Sample	No	No	Yes	Yes

Notes: Standard errors in parentheses, clustered at firm level. The unit of observation *Repurchase* is the difference between the value of stock purchases and stock issuances from the statement of cash flows.  $\Delta Debt$  is the change in the value of current total debt of the firm.  $\Delta Cash$  is the change in firm money holding. *Profits* is the value of firm profit at the net of taxes. *Investments* is equal to capital expenditure. *Dividends* is equal to the value of the dividends payed. All variables are in levels, and expressed in US dollars. Column (3) and (4) report results for the sample of firms that are net repurchasers, i.e. firms for which *Repurchase* > 0. \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

## 4.D Monetary Policy Shocks and EPS Surprise

Here, we check that the probability of being below the EPS forecast is not influenced anyhow by both the monetary policy shock and the exogenous change in the firm' cost of debt due to the monetary policy shock itself. In practice, we consider the following specifications:

$$\mathbb{I}(Distance_{i,t} < 0) = \alpha + \beta Shock_t + X'_{i,t-j} \gamma + \theta_t + \epsilon_{i,t} \quad (4.15)$$

$$\mathbb{I}(Distance_{i,t} < 0) = \alpha + \beta \Delta \widehat{Yield}_{i,(t-j,t-j-1)} + X'_{i,t} \gamma + \theta_t + \epsilon_{i,t} \quad (4.16)$$

where  $\mathbb{I}(Distance < 0)$  is the indicator variable that takes value one if the firm is currently below the EPS forecast, *Shock* is the monetary policy innovation out of a SVAR (see Appendix 4.A for details),  $\Delta \widehat{Yield}$  is the exogenous change in the 10-years corporate yield spread as predicted by monetary policy shocks, i.e. as from equation (4.3) in Section 4.3.4. *X* controls for firm-level characteristics such as net income, Q-value of investment, a dummy indicating whether the firm has redistributed dividends in the first previous four quarters, a dummy indicating the quintile of asset the firms belong to,  $\theta$  is a year-quarter fixed effect.

Since we want to be sure that monetary policy does not affect anyhow the realization of the EPS surprise, we check both the contemporaneous and one-period-lag effect of the shock and the implied change in the cost of debt on the indicator for the EPS surprise. Hence we ran these models for  $j = \{0, 1\}$ .

Table 4.17 shows results. From column (1) and (2) we find that the monetary policy shock has no contemporaneous or lagged effect on the probability for the firm to be off target. From column (3) and (4), we find the same when considering the exogenous change in the cost of debt (as explained by a monetary policy shock). These results validate our identification strategy: the two instruments used in the first stage analysis of Section 4.4.2 are orthogonal to each-other.

Table 4.17: Monetary Policy Shocks and EPS Surprise

	(1)	(2)	(3)	(4)
	$\mathbb{I}(Distance < 0)$	$\mathbb{I}(Distance < 0)$	$\mathbb{I}(Distance < 0)$	$\mathbb{I}(Distance < 0)$
<i>Shock</i> <sub><i>t</i></sub>	0.00 (0.00)			
<i>Shock</i> <sub><i>t-1</i></sub>		-0.00 (0.00)		
$\Delta \widehat{Yield}_{(t,t-1)}$			0.42 (0.36)	
$\Delta \widehat{Yield}_{(t-1,t-2)}$				0.55 (0.35)
Observations	42606	42606	33075	33075
Time FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Controls ( <i>X</i> )	Yes	Yes	Yes	Yes

Notes: Standard errors in parentheses, clustered at firm level. The unit of observation  $\mathbb{I}(Distance < 0)$  is an indicator variable that takes value one if the firm is currently below the EPS forecast. *Shock* is an exogenous monetary innovation as from a SVAR (see Appendix 4.A for details).  $\Delta \widehat{Yield}$  is the exogenous change in the 10-years corporate yield spread as predicted by monetary policy shocks, i.e. as from equation (4.3) in Section 4.3.4. Control *X* includes net income (normalized by total assets in  $t - 4$ ), Q-value of investment, a dummy indicating whether the firm has redistributed dividends in the first previous four quarters, a dummy indicating the quintile of asset the firms belong to. \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

## 4.E Challenging our Identification Strategy

Here we want to challenge what done in Section 4.4 in order to understand to which extent our identification strategy is rigorous. First, we want to check whether using the monetary policy shocks (*Shock*) instead of the exogenous change in the cost of debt ( $\widehat{\Delta Yield}$ ) in the 1st stage regression leads to similar results to those from Table 4.7 of Section 4.4.2. Second, we want to check whether monetary policy innovations can be used as instruments alone, i.e. independently from the EPS surprise, to explain the repurchase behavior across all firms in the sample and, consequently, to solve the endogenous relationship between repurchases and real variables.

### 4.E.1 Monetary Policy Shocks and EPS surprise as IV

#### First Stage: EPS Distance from Forecast and Monetary Policy Shocks

Here we study how monetary policy innovations affect repurchasing behavior of firms around the discontinuity. Similarly to what we do in Section 4.4, we consider only for firms with  $Distance_{i,t}$  in the  $[-0.02\$, +0.02\$]$  bracket, and ran the following 1st stage regression

$$\begin{aligned}
 Repurchase_{i,t} = & \alpha_1 + \beta_1 \mathbb{I}(Distance_{i,t} < 0) + \beta_2 Shock_t + \beta_3 \mathbb{I}(Distance_{i,t} < 0) * Shock_t \\
 & + \beta_4 Distance_{i,t} + \beta_5 \mathbb{I}(Distance_{i,t} < 0) * Distance_{i,t} + \beta_6 Distance_{i,t}^2 \\
 & + \beta_7 \mathbb{I}(Distance_{i,t} < 0) * Distance_{i,t}^2 + \beta_8 Distance_{i,t}^3 \\
 & + \beta_9 \mathbb{I}(Distance_{i,t} < 0) * Distance_{i,t}^3 + \theta_t + \epsilon_{i,t}
 \end{aligned} \tag{4.17}$$

where  $Repurchase_{i,t}$  is the level of net repurchase normalized by the level of assets in  $t - 4$ ,  $\mathbb{I}(Distance_{i,t} < 0)$  takes values 1 when the firm  $i$  is off-target with respect to the analysts' EPS forecast,  $Shock$  is the monetary policy innovation as from a SVAR (see Appendix 4.A),  $Distance_{i,t}$  is the effective distance from the EPS forecast, the square and the cube of this measure and its interaction with  $\mathbb{I}(Distance_{i,t} < 0)$  control for non-linear behavior both at the left and right hand side of the discontinuity cut-off.

Table 4.18 shows results. Very closely to what obtained in Section 4.4.1, firms off-target repurchase 1% more (column (1)). When we control for the monetary policy shock, we find no significant impact on the size of the repurchase program (column (2)). When we control for the interaction term  $\mathbb{I}(Distance_{i,t} < 0) * Shock_t$  and further controls, we find a negative and significant impact of monetary policy among firms off-target. In words, if a firm needs to buyback to adjust the EPS in the same quarter in which a negative shock realizes, then the firm will be able to repurchase more. How much more? For a 10bps negative innovation on the Fed fund rate, firms off-target buy back 3.8% more. Is this result comparable with the one from Table 4.6? There we found that 10bps decrease in the corporate

Table 4.18: Monetary Policy Shocks and EPS Surprise as IV

	(1)	(2)	(3)	(4)	(5)
	<i>Repurchase</i>	<i>Repurchase</i>	<i>Repurchase</i>	$\Delta Inv.$	$\Delta Emp.$
$\mathbb{I}(Distance < 0)$	0.01*** (0.00)	0.01*** (0.00)	0.01** (0.00)		
<i>Shock</i>		-0.002 (0.002)	-0.001 (0.001)		
$\mathbb{I}(Distance < 0) * Shock$			-0.004*** (0.001)		
<i>Repurchase</i>				-0.04*** (0.01)	-1.44* (0.74)
Observations	44856	44856	43389	34437	31237
Time FE	Yes	Yes	Yes	Yes	Yes
Industry FE	No	No	Yes	Yes	Yes
Controls ( <i>X</i> )	No	No	Yes	Yes	Yes
1st Stage	Yes	Yes	Yes	No	No
2nd Stage	No	No	No	Yes	Yes

Notes: Standard errors in parentheses, clustered at firm level. In columns (1) to (3), the unit of observation *Repurchase* is the difference between the value of stock purchases and stock issuances from the statement of cash flows.  $\mathbb{I}(Distance < 0)$  is an indicator variable that takes value one if the firm is currently below the EPS forecast. *Shock* is an exogenous monetary innovation as from a SVAR (see Appendix 4.A for details). In columns (4), the unit of observation  $\Delta Inv.$  is the difference between the mean value of capital investments in the next four quarters and in the previous four quarters, normalized by total asset in  $t - 4$ . In columns (5), the unit of interest  $\Delta Emp.$  is the difference between the mean level of employment in the next four quarters and in the previous 4 quarters, normalized by total asset in  $t - 4$ . Column (3) is the 1st stage regression where the endogenous variable *Repurchase* is instruments with  $\mathbb{I}(Distance < 0)$ , *Shock* and their interaction. Column (4) and (5) report the 2nd stage regression when the dependent variable is respectively the change in investments and employment. Control *X* includes a polynomial of the variable *Distance*, i.e. the the difference between the EPS forecast and the pre-manipulated EPS of the firm, interacted with the indicator *Shock* when considering the 1st stage (column (3)). When considering the 2nd stage, *X* control also for net income (normalized by total assets in  $t - 4$ ),  $\mathcal{Q}$ -value of investment, a dummy indicating whether the firm has redistributed dividends in the first previous four quarters, a dummy indicating the quintile of asset the firms belong to, the joint interaction of  $\mathbb{I}(Distance_{i,t} < 0)$  with  $Distance_{i,t}$  and  $\Delta Yield_{i,t}$ . \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

cost of debt among firms off-target leads to an increase of repurchases by 4.4%. The difference is only 0.6% and it is explained by two facts. One is the firm-level cost of debt, which responds heterogeneously to monetary policy. The second is the term-structure of cost of debt: if one one side monetary policy shocks are innovations on top a 3-Months Bill, throughout the paper we measured the firm-level cost of debt by considering 10-year-maturity corporate bonds. A monetary policy shock that can changes the term structure of the corporate bond yield in the long-run has typically higher effects at firm level. As from Table 4.3 of Section 4.3, we know that for a 10bps positive innovation on the 3-Months Bill, the firm-level cost of debt on a 10-year-maturity corporate bond rises roughly by 0.075% , i.e. by 7.5bps as well.<sup>11</sup> The difference between the results from Table

<sup>11</sup>With rounding, a 10bps positive innovation on the 3-Months Bill leads to an increase of the firm-level cost of debt on a 10-year-maturity bond by 0.10%, as actually reported in Table 4.3.

4.6 of Section 4.4.2 and the ones obtained here is due to these two facts together.

**Second Stage: Repurchase and Real Variables** Here we complete our analysis by investigating the impact of share buybacks on capital investments and employment. The following regression quantifies this effect:

$$\bar{Y}_{i,(t+1,t+4)} - \bar{Y}_{i,(t-4,t-1)} = \alpha_0 + \beta_0 \text{Repurchase}_{i,t} + X'_{i,t} \gamma + \theta_t + \nu_{i,t} \quad (4.18)$$

where the dependent variable is the difference between the mean value of  $Y$  in the next four quarters and in the previous 4 quarters, with  $Y$  being either capital investments or employment. All variables are normalized by the level of assets in  $t - 4$ .

Column (4) and (5) of Table 4.19 reports two-stage least squares estimates with the variable *Repurchase* instrumented under the first stage as in equation (4.13).<sup>12</sup> From this estimation we find that the crowding-out effect of 1% increase in repurchase on investment is 4% (5% from Table 4.7 of Section 4.4.2), while on employment is 144% (120% from Table 4.7 of Section refsec:4.2).

Hence, we conclude that our identification strategy is robust since the direct effect of monetary policy on firms off-target and the implied crowding-out effect on real variables is very close to the one obtained when considering the firm-level adjustments of the corporate yield to monetary policy.

## 4.E.2 Monetary Policy Shocks as unique IV

Here we consider all firms in the dataset and not only those with  $Distance_{i,t}$  in the  $[-0.02\$, +0.02\$]$  bracket. Our goal is test with a 2SLS regression whether monetary policy shocks alone could be a good instrument for *Repurchase*. Hence, we consider this first stage regression:

$$\text{Repurchase}_{i,t} = \alpha + \beta_1 \text{Shock}_t + X'_{i,t} \gamma + \theta_t + \epsilon_{i,t} \quad (4.19)$$

Thereafter, we are going to use equation (4.19) to instrument the variable *Repurchase* in the following:

$$\bar{Y}_{i,(t+1,t+4)} - \bar{Y}_{i,(t-4,t-1)} = \alpha_2 + \beta_0 \text{Repurchase}_{i,t} + X'_{i,t} \gamma + \theta_t + \nu_{i,t}. \quad (4.20)$$

Table 4.19 report results. Column (1) shows results from the the first stage: the variable *Shocks* is not significant, i.e. it cannot predict alone repurchase behavior and therefore monetary policy shocks cannot be used as instruments when considering the entire dataset of firms. Column (2) and (3) report the 2SLS estimates respectively for the change in investments and employment. Although

<sup>12</sup>In column (4) and (5) we control for the joint interaction of  $\mathbb{I}(Distance_{i,t} < 0)$  with  $Distance_{i,t}$  and  $Shock_t$ .

negative, the coefficients are not significant. The same results hold if we do not use time fixed-effects in equation (4.19) and (4.20), i.e. if we let monetary policy to explain alone the time variation of the variable *Repurchase*. To conclude, this

Table 4.19: Monetary Policy Shocks as unique IV

	(1)	(2)	(3)
	<i>Repurchase</i>	$\Delta Inv.$	$\Delta Emp.$
<i>Shock</i>	-0.24 (0.25)		
<i>Repurchase</i>		-0.003 (0.11)	-2.87 (10.34)
Observations	520975	520975	31237
Time FE	Yes	Yes	Yes
Industry FE	No	Yes	Yes
Controls ( <i>X</i> )	Yes	Yes	Yes
1st Stage	Yes	No	No
2nd Stage	No	Yes	Yes

Notes: Standard errors in parentheses, clustered at firm level. In columns (1), the unit of observation *Repurchase* is the difference between the value of stock purchases and stock issuances from the statement of cash flows. *Shock* is an exogenous monetary innovation as from a SVAR (see Appendix 4.A for details). In columns (2), the unit of observation  $\Delta Inv.$  is the difference between the mean value of capital investments in the next four quarters and in the previous four quarters, normalized by total asset in  $t-4$ . In columns (3), the unit of interest  $\Delta Emp.$  is the difference between the mean level of employment in the next four quarters and in the previous 4 quarters, normalized by total asset in  $t-4$ . Column (1) is the 1st stage regression where the endogenous variable *Repurchase* is instrumented with *Shock*. Column (2) and (3) report the 2nd stage regression when the dependent variable is respectively the change in investments and employment. Control *X* includes net income (normalized by total assets in  $t-4$ ), Q-value of investment, a dummy indicating whether the firm has redistributed dividends in the first previous four quarters, a dummy indicating the quintile of asset the firms belong to. \*, \*\*, \*\*\* indicate significance at 1%, 5% and 10% level.

analysis was aimed to to show two facts. First, we wanted to show that the monetary policy shocks, or the implied exogenous changes in the cost of debt at firm-level, are valid instrumental variables when used in combination with the EPS surprise. In fact, by using the EPS surprise, orthogonal to all firm characteristics and as well to the exogenous change in the cost of debt, and its interaction with monetary policy shocks (or the exogenous change of the cost of debt) solve the problem and predict well both the propensity to repurchase and the capability of repurchase. Hence, they are good instruments. Second, we wanted to show that the two instruments are good only when used together. In fact, that monetary policy alone cannot predict repurchase behavior since, it interacts with too many other factors and firm characteristics. By using the EPS surprise, we eliminate this problem and we can study the effect of monetary

policy across firms that are ex-ante very homogeneous.

# Chapter 5

## Conclusion

The three chapters comprising this thesis deliver insights on drivers for investment and saving decisions for a resource-rich economy, for the oil industry, and for a firm. The research program undertaken has paid particular attention to the role of uncertainty and its interaction with different features in the economy, such as irreversibility of investment and the exhaustibility of a resource, to instill greater caution for decisions makers.

The first chapter shows that for resource rich countries, faced with highly uncertain income streams, their best strategy is to diversify away their risk by depleting their risky *in situ* asset and saving it abroad. The analytical framework used shows that the interplay between the saving and extraction decision is an important feature that should be taken into consideration when understanding the saving behaviour of such economies. The saving-extraction nexus, shows a heightened need to save that induces a faster upfront extraction, until the *in situ* wealth is of a lesser importance for the economy. The work quantifies the contribution of endogenizing the extraction to the external saving position of exhaustible-resource rich countries. It also does well in capturing income, consumption, and extraction dynamics for the countries with moderate endowments in oil and gas resources.

More generally, this work feeds into the work informing resource-rich countries on the management of their resources endowments. It brings to the fore the importance of considering the underground wealth as an additional asset when constructing a portfolio for diversifying oil risk. Physical constraints associated with extraction of the resource are just as important as financial frictions facing these countries, which can determine the degree invested in long-term assets and placed into stabilization funds.

In a similar way, the second chapter tells us that uncertainty delays investments when investment decisions are irreversible, and even more so when storage capacity is available. This result shows that in the medium run, the interaction of storage with the irreversibility of investment is an important feature for un-

derstanding price and supply dynamics in storable commodity markets, with empirical evidence from the oil market. The delaying effect of storage on investment is intimately linked to the degree of future uncertainty induced. The storage arbitrage condition, by connecting the expected price to the spot price transfers the volatility of the latter into the former. This very condition results in an increased uncertainty around the expected price. When expected price volatility rises, the anticipated marginal profitability of investment falls accordingly and the producer prefers to invest less or even nothing as to avoid being constrained in the future.

This chapter therefore shows that monitoring both capital stock levels and inventory levels are important for understanding current and future supply conditions in the oil and other commodity markets. The persistence of overcapacity can have important implications for investment decisions and prices. As low prices discourage investment, ballooning inventories reinforce the prudent behaviour of oil producers by providing an additional cushion to counter unanticipated shocks. In this sense, an investment lull can be extended, thus subjecting the market to greater levels of uncertainty.

Lastly, the third chapter helps us understand that the slow pick up of investment after the Great Recession could be attributed to some extent to the way firms decide to use low-cost debt. The presence of repurchase opportunities weakens the transmission of accommodative monetary policy, especially for firms that decide to repurchase their shares.

With public concerns over firms diverting resources away from their employees and future growth prospects, this chapter brings an important piece of information to light about which funds firms use to reward their shareholders. What remains unclear from this analysis and could be an avenue for further research, is to investigate whether indeed the use of low-cost debt for repurchases is the more optimal option and under what conditions. Repurchase programs do not necessarily need to be at the detriment of growth opportunity. Therefore assessing their efficiency in allocating firm resources could shed some clarity on this question.

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