Essays on Macroeconomics: Macroeconomic Policy and Economic Performance

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Declaration

I certify that this thesis is solely my own work other than where I have clearly indicated that it is the work of others (in which case the extent of any work carried out jointly by me and any other person is clearly identified in it).

I warrant that this authorization does not, to the best of my belief, infringe the rights of any third party.

Michael Francis McMahon

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Abstract

This thesis discusses the three issues that are important to macroeconomic policymakers. First, I examine the role of inventories over the business cycle. Despite accounting for less that 1% of the level of GDP, inventory changes have made up almost 50% of the post-war volatility of US GDP growth, and yet most models of the business cycle exclude inventories. I develop a dynamic business cycle model that incorporates distribution inventories as well as simple storage inventories. I find that the behaviour of inventories in this model matches the aggregate data well. However, there is little evidence that improved inventory management contributed to the decline in macroeconomic volatility over the last quarter of a century.

Second, the optimal design of a monetary policy committee (MPC) is examined as to whether such committees should include a mix of members from outside (external) as well as inside central banks (internal). Using a new theoretical model of voting behaviour on a mixed committee, it is shown that, under certain circumstance and behaviour, the presence of external committee members may be beneficial. However, using the voting record of the Bank of England's MPC, reveals a problem; there is evidence of an agency problem which may eliminate any benefit to the appointment of external members. These results undermine the current intuition as to why such mixed committees should be employed by policymaking institutions.

Finally, I investigate the effect of policy uncertainty on household saving using a quasi-natural experiment from Germany in the late 1990s. Around the 1998 election, there was a marked increase in uncertainty; using the fact that civil servants were largely unaffected by this policy uncertainty, we show that households reacted to the increase in uncertainty by saving more and, where possible, by working more via the margin offered by part-time employment.

Statement Concerning Conjoint Work

In my thesis I draw on projects undertaken with other researchers for two of the chapters. Chapter 3, on voting behaviour of Monetary Policy Committee (MPC) members, is based on unpublished research with Stephen Hansen (LSE). We both contributed to the entire paper. Nonetheless, Stephen led the project in terms of the building and solution of the committee voting model, where I have mainly gave input about the appropriateness of the model for describing the MPC decision-making process. This model gives rise to testable implications which we then check against the behaviour of the Bank of England's MPC. I was responsible for constructing the dataset, implementing the regressions, and I devised the bulk of the empirical methodology.

Secondly, the chapter on precautionary saving draws on joint research undertaken with Francesco Giavazzi (Universita Bocconi, Milan, Italy). We began working together on the question of why German household saving rates remain high in retirement; this initial collaboration led us to start working together with a German household panel in order to explore the saving behaviour more deeply. The work used in the thesis is unpublished and is related to this project in that it uses the same household dataset. I have been mainly responsible for all the empirical analysis used, including the development of the specific identification technique used. Francesco has served mainly to ensure that the paper is directed at the question in the most appropriate way and he took the lead in motivating the analysis. Of course, we have both had inputs into every section as the project has developed.

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I owe many people thanks for their support and help over the course my PhD studies.

Firstly I must thank Francesco Caselli who, for the last four years, acted as my supervisor. He allowed me to make my own mistakes, and was quick to make sure that I knew whenever I had. This approach has ensured that I leave the LSE with a much greater appreciation of how good research is completed, and more importantly how to recognise poor research. I am very grateful that whenever it came for him to defend, or to promote me, he was always behind me 100%.

Many other faculty members at LSE have also been a significant influence and help; my advisor, Silvana Tenreyro, was a source of research advice, comments and kind words. Chris Pissarides, in particular, supported me in my teaching and in my applications for jobs. I must also thank Alwyn Young for many helpful conversations in the third floor hallway. Other members of the macro programme have also been happy to comment on and encourage my research, which I have appreciated and has been very useful.

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I have been fortunate to be a member of many great research environments; at LSE and the CEP, more recently at the University of Warwick, and, for many years, in the Bank of England. I have many colleagues who have helped me along the way and there are too many of them to mention specifically here. They know who they are, and I know how important they have been to me.

Two colleagues deserve to be singled out. Francesco Giavazzi is a co-author, an advisor and friend. He is always kind and showed great patience with my initial contributions to our research projects. He has also welcomed me into the research fraternity and exposed me to a world of "frontier researchers" that would otherwise have been much more difficult to infiltrate. I will always owe him a debt of gratitude for everything he has done for me. My other co-author, Stephen Hansen, has managed to make micro-theory models fun. He is a great person to speak to about new ideas or to interpret results. Furthermore, he has always been there to share a laugh, a moan or just a cold beer. He is a great friend and a fantastic coauthor.

I am also blessed with many other great friends who, at various times, have supported me through my decision to become a student again. The "Flatties", and in particular Vinay and Garret, thought they were living with a Bank of England economist when he suddenly became a poor student again! The "Panel" who have always provided a welcome outlet for thoughts, ideas and a great place to argue about anything and everything - but mostly football. The Basketball team who gave me a great sporting outlet, a chance to win at the National Championship, and awarded me full sporting colours at LSE. Thanks to all of them for helping me stay sane through all this.

My family, including the whole Murfett clan, have supported and encouraged me throughout my time at LSE. In particular, my parents have provided support, encouragement and guidance. Like a perfect good cop/bad cop double act, my mum cares only about my welfare, while my dad has always pushed me to get my research done. Both were needed in equal quantities, even though I generally received the former more gratefully than the latter. Nonetheless, I am grateful to my Dad for his helpful comments on my papers and for the advice he has given me along the way.

The final thanks are reserved for Marianne. My decision to stay in the UK for PhD study has proved to be one of the best decisions of my life. My beautiful wife has done more for me than a few words here can ever express. Not only does she willingly read my papers and apply her excellent drafting skills, but, most importantly, she is a constant source of support, love and encouragement. Thank you Marianne; you are my gift.

Contents

List of Figures

List of Tables

Introduction

These are extremely challenging times for the macroeconomy, and, as a result, these are also very challenging times for macroeconomic policy.

This is not a thesis about current events, but this is a thesis about macroeconomic policy and economic performance. Over the four chapters, I examine a number of topics that, as I will illustrate below, are at the heart of some of the important debates about macroeconomic policy. In each chapter, I try to isolate, and examine, a particular phenomenon in a way that is new, or innovative, relative to our current understanding.

In doing this, I use many different tools. The thesis contains both theoretical contributions, as well as more applied work. Even within the applied work, I make use of calibration techniques, household micro data, and a panel of voting records from the Bank of England's MPC. The reason for this variety is simple; I try to use whichever method is most suitable to answer the questions that interest me. I, therefore, view the heterogeneity of the approaches used in this paper as a strength.

Inventories, the business cycle and the Great Moderation

Prior to the current "credit crunch", it was increasingly thought that the business cycle was dead. We were living in a period that was known as the Great Stability, or Great Moderation, or even the NICE years[1]. In the US, the decline in macro volatility, since at least the 1980s, had been pointed out by McConnell and Perez-Quiros (2000), Stock and Watson (2002), and Blanchard and Simon (2001). Benati (2004) provides evidence that the UK economy also experienced a period of great stability. Recent developments have led to a marked increase in business cycle volatility, and many people now question whether the Great Moderation is over. In order to be able to answer this, and potentially to know whether, or how, we will return to the more stable times experienced recently, we first need to understand what caused the Great Moderation period. There are many

[1]NICE stands for Non-Inflationary, Consistently Expansionary.

suspects including better monetary policy ("good policy hypothesis") and simply less volatile shocks hitting the economy (the "good luck" hypothesis).

I investigate the role of inventories over the business cycle in Chapter 1, and their role, if any, in the Great Moderation in Chapter 2. It has long been recognised that inventories are a major component of business cycle volatility: "At the macro level, economists have known (but periodically forgotten) since Abramovitz (1950) that inventory movements are dominant features of business cycles" (Blinder and Maccini 1991).

In order to explore the implications of inventory management techniques on macroeconomic volatility in Chapter 2, we first require a model of the inventory behaviour that captures those motives for inventories that we believe have changed. In Chapter 1, I develop such a model within a Dynamic Stochastic General Equilibrium (DSGE) environment. I focus on inventories in motion; that is, those inventories that are associated with the time delay between production and consumption of a good.

In Chapter 1, I lay out my model and explain the Parameterised Expectations Algorithm (PEA) that I use to solve it. This in itself is a significant contribution. Although it has long been recognised that inventories play an important role in the business cycle, modelling inventory behaviour in a general equilibrium context has not fared so well in terms of matching the key features of inventories at the macroeconomic level. Though highly stylised, it is able to successfully match (at least qualitatively) a number of key facts about the behaviour of inventories, including (i) generating an inventory adjustment component that, though small, contributes a great deal to GDP growth volatility; (ii) sales are less volatile than production; and (iii) a counter-cyclical inventory-sales ratio.

In the wider context of Real Business Cycle (RBC) models, I find that my inventory channel also generates a substantial amount of internal propagation of TFP shocks. My model requires less exogenous volatility in order to match the volatility of GDP compared to a standard RBC model.

In Chapter 2, I first explore the evidence that supports the belief that inventory management has played a role in the Great Moderation. This includes the fact that in terms of the decline in the variance of quarterly GDP growth, we can attribute approximately 30% to the reduction in the volatility of the inventories adjustment component. One suggestion is that improvements in inventory management techniques, made possible by advances in information and communications technology, have driven these changes McConnell and Perez-Quiros (2000). While I am not the first person to consider the role of inventories in the Great Moderation, I make use of the model I developed in Chapter 1 to explore how reductions in the costs associated with inventory-in-motion map into what we observe from macroeconomic aggregates during the Great Moderation.

Mapping the salient features of the improvements in inventory management into the parameters of my model, I find that although the inventory management changes are useful to match aspects of the changes in inventory behaviour over the period, they play no role in the reduction of the variance of GDP growth. In my model, the "good luck" hypothesis is a more likely explanation for the Great Moderation decline in volatility of GDP growth. However, the "good luck" hypothesis alone fails to match other developments in the aggregate data. These other developments are more closely matched by the inventory-management explanation. I therefore conclude that the two explanations have played a role in shaping macroeconomic behaviour since the mid-1980s.

Monetary Policy Committee Behaviour

There are many aspects to the "good policy hypothesis" posited above. Traditionally, the macroeconomics literature has focused on the extent the Central Bank follows an 'active' versus a 'passive' monetary policy rule. While more activist monetary policy may or may not have contributed to the Great Moderation, Chapter 3 looks much more specifically at an institutional change which has coincided with (part of) the drop in macroeconomic volatility in the UK; the implementation of monetary policy by an independent mixed committee of experts. Acemoglu, Johnson, Robinson, and Thaicharoen (2003) argue that reduce macroeconomic volatility is driven by improvements in the institutional framework, which then leads to improvements in macro-policy.

Figure 1 shows the decline in the volatility of UK inflation and GDP growth using a 3-year rolling standard deviation. It also identifies distinct periods of different monetary regimes in the UK using grey shading. Since 1997, an independent, nine-person Monetary Policy Committee (MPC) has determined monetary policy within an inflation-targeting framework. This has been the most stable time in UK macroeconomic history (Benati 2004). Using a committee to determine the policy interest rate is not unusual - Pollard (2004) finds 92% of surveyed central banks now use such comittees. What is relatively unusual about the Bank of England MPC is that it consists of both internal members (certain Bank of England staff who also have management responsibilities within the Bank) and external members (economic experts who are employed on a part-time basis in a monetary policy role). A similar set-up is used in South Korea and the Reserve Bank of Australia.

In order to explore the role of external MPC members, this chapter first develops a model in which MPC members communicate their views about the current state of the world. The members each also hold views about the economic structure; in particular, they may differ in the opinion of the natural rate of interest. This model provides two justifications for appointing both internal and external members:

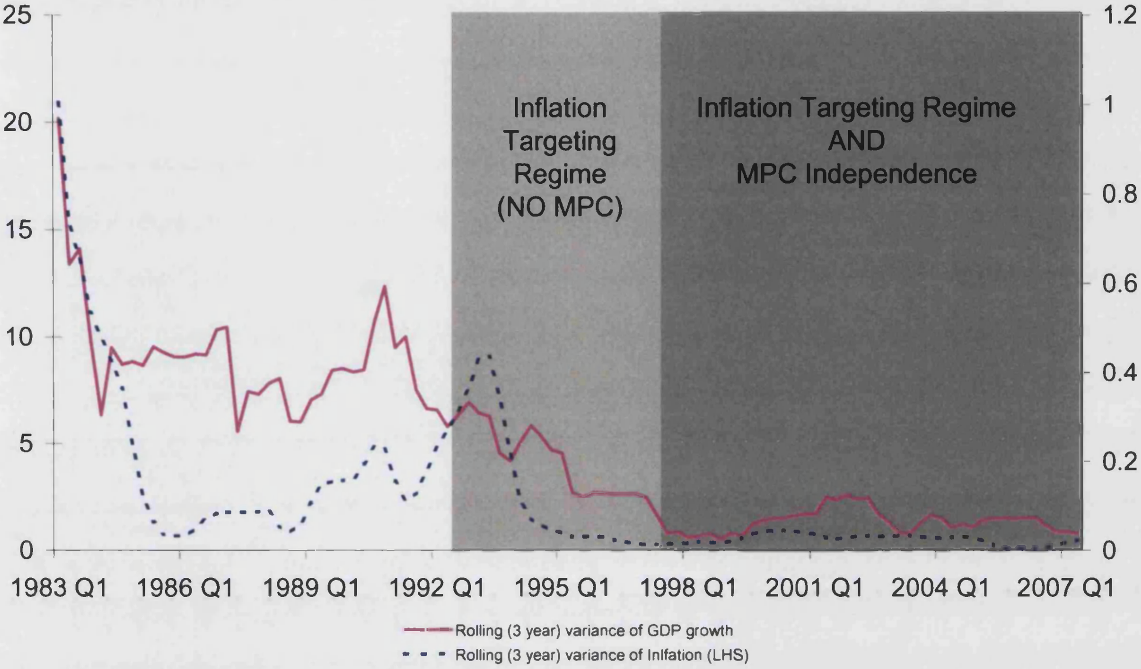


Figure 1: Volatility and the Monetary Policy Environment

1. If different members have different dimensions of expertise, then mixing them together can improve the outcome for the committee designer; and

2. Where the committee designer cannot observe member beliefs about the economic structure, drawing members from two distributions which are likely to lie at extremes of the distribution of possible views of the economy is more likely to generate a moderate median voter.

The first benefit can be attained through a simple advisory role, whereas the second relies on external members having a vote.

The second half of the paper carries out an empirical test of the model's predictions using the voting records of the Bank of England's MPC. Using a large panel, the results of estimated fixed-effects regression models indicate that members' behaviour is not consistent with our ideal voting behaviour model. Members initially fail to moderate each others view; there is evidence of a bedding in period during which the external members seem to always agree with internal members.

Then, using a quasi-natural experiment - an approach that is extremely popular in applied microeconomics - we find evidence that career concerns may drive this behaviour. This is interesting as previous evidence by Meade and Stasavage (2008) found evidence of career concerns on a non-mixed committee in the context of the US Federal Reserve's Federal Open Market Committee.

Though interesting in their own right, these findings are much more powerful in the context of our model. The first finding tells us that the appointment of external members in a voting capacity cannot be justified from a welfare point of view. Instead, as much benefit would be derived from external advisors. The second result, the importance of career concerns, means that not only is the benefit of appointing members with different views about the economic structure reduced, but, if there is less learning about the economic shocks, then any benefits from information sharing may also be impeded.

The policy implications of this analysis is striking. In terms of monetary policy, although the mixed committee has been designed in order to try to make better decisions, our analysis suggests that it may make no difference at all, and, at its extreme, it may make decision-making worse. This is clearly not what the Treasury had in mind in 1997 when the MPC was first established. However, our results also indicate that a policy of no external reappointments might offset the career concern associated with seeking reappointment.

In a more general context, if members on the MPC do not appear to vote in line with the predictions of our model, despite the institutional set-up being designed to be a close to optimal as possible, it is even more likely that voting on other committees, such as political committees, is even less likely to be optimal. These results place a question mark over the general move toward mixed committees in monetary policy and other forms of decision-making.

Policy Uncertainty and Precautionary Saving

The final chapter explores the effects of policy inaction rather than the effects of policy actions. Prolonged political debates about many policies are common. Underlying these debates, which postpone the adoption of reforms, is often a "war of attrition" among various groups in society, each trying to protect itself and to shift the burden of the reforms on someone else. A typical case is the reform of pay-as-you-go (PAYG) pension systems in countries. There is rarely a disagreement on the need to change the existing rules, but as one reform plan after the other is considered, decisions keep being been postponed because the government is unable to agree on how the burden should be shared between various groups in society and in particular between the young and the old.

People do not simply sit and wait while the debates and the "war of attrition" continue. Rather, households and businesses may respond to an increase in uncertainty.

Chapter 4 studies how German households responded to the uncertainty induced by the 1998 election. While the election was extremely close and difficult to call (James 2000), the policies to be adopted by either of the potential winners differed greatly. This was especially true concerning the two key issues surrounding the election - pension reform and unemployment.

This is an empirical paper which makes use of similar econometric techniques to Chapter 3. Using a quasi-natural experiment of the close German election, we examine the increase in precautionary saving that resulted among affected households. We use the households that are headed by civil servants as the control for the other "treated" households.

The finding is that German families reacted to the uncertainty by saving more. In addition, household members who had been working part-time increased their working hours. The conclusion is that "waiting and seeing", or simply prolonging debates and avoiding making hard decisions, may in fact lead to unexpected reactions by households.

In terms of the current crisis, this may be directly relevant. It took six months after the collapse of Bear Stearns before the US Treasury was able to act on their ideas to inject capital into the rest of the banking system. In that time, the crisis had deepened and Lehman Brothers collapsed.

Implementing macroeconomic policy is not easy. These chapters suggest that (i) policymakers may or may not have done anything in order to generate the stable economic performance of the last quarter century, but, (ii) in trying to do doing something right, choosing an imperfect structure for a Monetary Policy Committee could worsen, rather than improve, decision-making; and (iii), as the final chapter shows, not doing anything, when it is known that something has to be done, can also generate unforeseen outcomes.

Chapter 1

Inventories in Motion: A New Approach To Inventories Over The Business Cycle

> "Over the past decade, we have witnessed profound changes in many aspects of logistics. None of the developments, however, has been as striking as the recent trend toward managing 'inventory in motion' - that is, managing inventory while it is still in transit instead of waiting until it arrives at the warehouse". Copacino, 1988

> "Relative to its importance in business fluctuations, inventory investment must be the most under-researched aspect of macroeconomic activity". Blinder, 1981

1.1 Introduction

A bottle of beer purchased by a consumer in a shop, or at a bar, was produced some time before this consumption. In fact, the standard model followed by beer producers involves four distinct steps in the distribution chain. Beer is produced in the brewery and becomes a finished good (although it often gets transported in large trucks to a separate plant for bottling and labeling). The bottles or cans of beer get shipped to a beer distributor who allocates them to regional wholesalers. These wholesalers break up the shipments into smaller units and pass the beer onto the local retail units (bars and shops). Finally, the retailer provides the goods in smaller quantities for the consumer to enjoy. This process is not instantaneous - there are large lags at each stage of the process. In fact, Budweiser, as an example, having reduced the lags involved in distribution of its beer, now labels bottles according to when the beer was produced - this is their "Born On" date. The lag between the "Born On" date and the date it is available for purchase is usually between four and ten weeks, though it can be up to a year.

This distribution model, or a variant of it, is used in many industries. In fact, the beer distribution model is a key example used in the supply chain management literature to describe the importance of inventories in the distribution chain and has given rise to a supply-chain game used in the teaching of inventory management (see Forrester (1961) and Sterman (1988)). This is because, from the moment it is produced, and as it moves along the distribution chain, the beer is an inventory[1]. As illustrated by the opening quotation by Copacino, it is the management of such distribution inventories, the so-called "inventories-in-motion", that has been a focus of the supply chain field for the last 30 years[2], but has thus far been ignored by macroeconomists. In this paper, I develop a model of inventories based on such distribution chains. I explore how well such a model can give rise to macroeconomic inventory behaviour that matches the aggregate data.

Inventory adjustment has long been recognised as a major source of business cycles[3]; inventories account for almost half of the volatility of GDP growth. Macroeconomists, therefore, have long searched for a convincing explanation for the behaviour of inventories at the aggregate level; Metzler (1941) and Abramovitz (1950) are key early references in this regard. After the second World War, the study of optimal inventory policy at the level of the firm became an active area of research in management science; early papers include Arrow et al (1951), Bellman (1956), and Mills (1957). However, in the late 1960s, and through the 1970s, inventory research slowed. A revival of the research effort in the 1980s, in part prompted by the views expressed in the above quote from Alan Blinder, highlighted the inadequacy of the dominant models of the day (particularly the production smoothing model) to explain the stylised facts of inventory behaviour, but little consensus was reached on a canonical model for aggregate inventory behaviour. In fact, Christiano and Fitzgerald (1989) concluded that successfully modelling aggregate business cycle

[1] In fact, even before it is produced, beer gives rise to inventory holdings. The hops, malt barley, yeast, rice and water that make up the ingredients of the beer are likely to be held as input inventories by the brewery. I do not examine input inventories in this paper, though the analysis in this paper could be extended to consider such inventories.

[2] A more recent quote comes from Art Mescher (CEO of Descartes Systems and winner of the Council of Supply Chain Management Professionals 2008 Distinguished Service Reward). He said: "As supply chain professionals, we are now chartered with managing a global set of resources in motion. Our scope is expanding once again. People, resources, truck drivers, field services workers, merchandisers, warehouse workers. All resources in motion" (Gilmore 2008).

[3] In this paper I shall use the term inventories for what are known more commonly in the UK as stocks of goods. In fact, one of the early references to their importance also draws out this distinction: "Recent American experience has also afforded good examples of the part played by fluctuations in the stocks of finished and unfinished goods - "inventories" as it is becoming usual to call them - in causing the minor oscillations within the main movement of the trade cycle" (Keynes, 1936).

movements could (and should) proceed without trying to model any speculative inventory holding.

The existing models of inventories in use by macroeconomists can generally be classified as either firm-level analyses, or general equilibrium analyses. One of the strengths of the firm-level models is that the motivation for firms to hold inventories are generally quite simple and easy to relate to the real world. The main problem with the firm-level approaches is that they generally use a partial equilibrium analysis; this means that they miss important feedback from decisions about inventory policy to other elements of the model such as sales volatility.

While general equilibrium models overcome these missing links, they do so at a cost. In particular, in order to avoid the added complexity associated with the modelling of these interactions, it is necessary to take short-cuts which limit the models' usefulness for analysing the central role played by inventories in the business cycle. For example, the early general equilibrium models of inventory behaviour ensured that the models generated inventory holding by including inventories as a factor of production (Kydland and Prescott (1982)), while Kahn et al (2002) instead use a model in which inventories are part of the household utility function[4]. While both of these approaches make the solution of the model easier (by admitting an interior solution to the maximization problem), because firms/consumers are forced to hold inventories, neither is a suitable approach from which to evaluate how recent changes in inventory management have affected the holdings of inventories[5].

My first contribution in this paper is, therefore, to solve a general equilibrium model of inventories in which the underlying motives for inventory decisions are important in the real world[6]. The first motivation, related to the opening quote by Copacino, is that a large amount of the inventory stocks in a modern economy are those goods which are finished and in the distribution chain but which have not yet reached their final consumer. Hence, these inventories are not speculative (and so not subject to the finding of Christiano and Fitzgerald), but rather are a natural link in the chain between production and consumption. Two well-known inventory management approaches associated with such inventory-in-motion are the "Just-in-Time production" approach and "The Walmart Approach". The simple approach taken in this paper is that there are natural

[4]Other notable papers in the Real Business Cycle (RBC) and inventories literature are discussed in the Blinder and Maccini survey article (Blinder and Maccini 1991).

[5]For example in Kahn et al (2002), as noted by the authors, the steady-state inventories-sales ratio is determined by a parameter of the utility function (the weight of consumption relative to inventories in utility) and therefore "the improvements in IT do not translate into a lower inventory-sales ratio in the model, even though they appear to do so in the data."

[6]In Chapter 2, I also make use of the fact that these inventories can be directly related to the suggested improvements in inventory management techniques.

delays between consumption and production. However, it is possible to overcome these distribution lags by paying for immediate delivery. Such early delivery is used to smooth consumption. After periods of low productivity, when there is not as much freight coming through the distribution chain from earlier periods, the firm will choose to bring forward delivery of some goods in order to consume them today.

There is limited direct data on the extent of these distribution chain delays. An industry report which is famous for laying the seeds for the movement known as "Efficient Consumer Response (ECR)", estimated that, in the dry grocery industry, the delays between orders being received by suppliers and goods becoming available on retailers shelves (where they may still stay for a period before being consumed) was 104 days on average (Kurt Salmon Associates, 1993). The report also showed that, by adopting more efficient distribution practices, the industry could reduce costs significantly each year. For the apparel industry, the same delays are even longer at one year or longer (see Fisher and Raman (1996), and Blackburn (1991)). But firms can, and do, rush goods through the distribution chain and these decisions affect the level of inventories.

The second reason for holding inventories that I consider is simply to store goods. The intuition is that, under the storage motive, inventories help to smooth positive productivity booms - high productivity today induces the agent to work more and then store more in order to carry the gains from high productivity to later (lower productivity) periods. Only one of the two motives will be used at any given period by a firm. The distribution motive is such that if consumption is very low today (so marginal utility is very high), but tomorrow we expect to have higher consumption, then it might be optimal not to wait for the delivery and instead to pay extra to have some goods delivered immediately. In section 1.3 of this paper, I use a simple 2-period endowment model to present the full intuition of both of these inventory motives before I embed them into an infinite-horizon real business cycle framework and carry out the full general equilibrium analysis in section 1.4.

Although conceptually the two motives explained above are simple, the main problem is that both motives involve frequently binding non-negativity constraints. This makes the model highly non-linear and an unsuitable candidate for log-linearisation (a typical approach used to solve real business cycle models). I overcome these problems by using a version of the Parameterised Expectations Algorithm (PEA) which was pioneered by Wright and Williams (1982, 1984). This involves approximating any expectation terms in the optimality conditions using a polynomial in the state variables and can easily be implemented despite the potentially binding constraints (Christiano and Fisher, 2000). I discuss the numerical solution in more detail in section 4, as well as in an appendix to this paper.

An objection to the simple motivations that I propose is that while the typical unit of time in business cycle analyses is one quarter (driven mainly by data availability), firms rarely have a distribution cycle that is three months long and, moreover, the horizon for the decision to carry extra inventory over (or to run down built-up inventories) is also likely to be shorter than a full quarter. This makes the assumed motives seem unlikely for a quarterly model. In this paper, as discussed with the calibration of the model in section 1.6, I calibrate a higher frequency (monthly) model and then aggregate the data to explore the consequences at quarterly frequency. This paper, therefore, contributes to the literature that examines the effects of time aggregation on macroeconomic modelling, such as Aadland (2001), Heaton (1993) and Lippi and Reichlin (1991).

I then compare the quarterly predictions generated by my model with the equivalent predictions from an equivalently calibrated model in which agents cannot actively manage inventory. I find that the simple and highly stylised model that I have solved is able to match a number of the key facts about inventory behaviour at the macro level. Further, the inventory model actually generates greater amplification of shocks compared with a similar model in which the agent has no control over delivery speed. This means that my inventory model can match the behaviour of aggregate GDP with less assumed volatility of shocks. These comparisons are discussed in Section 1.7.

In section 1.8 I first examine why the use of storage, despite attempting to make it more attractive, remains elusive. I then show that the amplification that I generate with my baseline model is robust to lower assumed labour elasticity and a greater degree of risk aversion. Section 1.9 concludes the paper.

1.2 Inventories and the Macroeconomy

The importance of private inventories, defined as "materials and supplies, work in process, finished goods, and goods held for resale" (Bureau of Economic Analysis 2008), in the behaviour of business cycles, as outlined above, is well known (the survey article by Blinder and Maccini (1991) contains the main the references in this regard). Table 1.1 shows that the conclusions of very early research still apply when looking at data from the post war years; it shows that despite making up, on average, less than 1% of nominal GDP[7] and contributing only about 2% of GDP growth (0.1pp), inventory investment has accounted for 43% of the volatility of real GDP growth.

[7] The maximum share of inventory investment in GDP over the sample is 4%, and the minimum is -2%.

Table 1.1: Contributions to US GDP growth, 1960-2007, S.A.A.R.

Description	Share of	Average contribution to:			
	Nominal GDP	GDP Growth		Variance of GDP growth	
	%	pp	*% of total*		*% of total*
GDP	100	3.4	*100%*	16.3	*100%*
Consumption	64.6	2.3	*68%*	3.0	*24%*
Investment	15.4	0.6	*19%*	2.1	*17%*
Government Expenditure	20.3	0.5	*14%*	0.8	*6%*
Net Trade	-0.9	-0.1	*-2%*	1.4	*11%*
Inventory Investment	0.6	0.1	*2%*	5.2	*43%*
Covariance	-	-	-	-0.2	*-2%*

1.2.1 Stylised Facts of Inventory Behaviour

There are a number of other well-known stylised facts about inventory behaviour over the cycle which numerous empirical studies have documented (see, for example, (Blinder 1986)). The two main facts are:

Fact 1.1 *Production is more volatile than sales;*

Fact 1.2 *Production and inventory investment are positively correlated.*

In fact, it was these facts that undermined the production-smoothing model which was the main focus of research interest initially. Within this framework, first proposed by Holt et al (1960), the accelerator idea of Metzler could be attributed to a firm-level optimisation in which costs were quadratic. This meant that it was in the interests of firms to smooth production (to minimise costs) and so inventories played a buffer role within this context. However, the excess volatility of production relative to sales undermined these models. Blanchard (1983) examines the behaviour of inventories within the automobile sector using a framework of both costs of changing production and costs of deviations from a target level of inventory-sales ratio, and concludes that inventories are, in fact, a destabilising force on output. Although attempts were made to salvage this framework, such as Miron and Zeldes (1988) and Ramey (1991), this approach has received less interest in recent years.

Another approach, used in the general equilibrium analyses, include inventories either as a factor of production (as in Kydland and Prescott (1982) and Ramey (1989)) or as an argument of the utility function (such as in Kahn et al (2002)). The main downside of this approach, especially if one wishes to investigate the volatility of inventories, is that inventory behaviour only changes if we change the parameters of the model or the functional form of the production/utility function.

The two main approaches used in recent analyses are those which assume a stock-out avoidance motive and the (s, S) model of fixed costs of ordering or producing goods. The former, pioneered by Kahn (1987), assumes that firms hold inventories to avoid a (costly) stockout in which demand exceeds products available for sale. Using a partial equilibrium framework, he showed that serially correlated demand shocks could explain the fact that production was more volatile than sales. Although Kahn's original work was a partial equilibrium analysis, Shibayama (2008) embeds this motive in a full general equilibrium business cycle model and finds that his model can help to match the behaviour of inventories at the aggregate level.

The other main approach, the (s, S) model, has been popular for many years and the approach is used in many applications, of which inventory analysis is just one (for example, Blinder (1981) uses the approach to model retail inventories). The basic idea is that there is a fixed cost associated with ordering goods (final or intermediate) and therefore the optimal behaviour for firms is to bunch orders and follow a rule whereby they only reorder once inventories fall to an optimally-determined lower bound (s). The firm reorders an amount that is enough to restore inventories to an upper bound level (S). More recent contributions, such as those of Khan and Thomas (2007b), use complex numerical methods in order to get around the difficulties that arise in extending this analysis to general equilibrium models. Despite the intuitive appeal at the firm level, the problem with these models relates to aggregation; it is not clear that an economy in which a large number of firms behave according to an (s, S) inventory policy would lead to aggregate (macro) behaviour that mimics the (s, S) behaviour once we aggregate across time and/or goods. Khan and Thomas (2007b) need to assume firm-level idiosyncratic shocks each period to the cost of reordering in order to generate aggregate effects - this seems like an unlikely assumption.

In another paper, Khan and Thomas (2007a) compare general equilibrium approaches to the stockout avoidance motive and their (s, S) approach using the idiosyncratic reorder cost shocks. They find that, under reasonable assumptions about shocks hitting the economy, the (s, S) model performs better. They argue that the general equilibrium framework is important; introducing inventories in their model endogenously lowers the volatility of sales and this offsets the increased output volatility of introducing inventories that are positively correlated with sales (Khan and Thomas, 2007b). In this paper I use a general equilibrium framework .

Further research has also highlighted, in addition to the two facts of inventory investment and the characteristic of being a small but volatile component of GDP, two further challenges for any model of inventory behaviour over the business cycle. Firstly, Khan and Thomas (2007b) emphasise that the inventory-sales ratio is counter-cyclical.

Secondly, there has been a resurgence of interest in the relationship between the real interest rate and inventory investment. Most models of inventory behaviour predict a negative relationship between the real interest rate and inventory investment, but the empirical evidence fails to support such a relationship. Maccini et al (2004) argue that the failure of empirical tests to uncover a negative relationship is due to the highly persistent nature of the real interest rate; firms will only be concerned with long-run changes in the real interest rate brought about, for example, by regime changes. Under my model, as I discuss below, changes in the real interest rate are positively related to inventory investment. Where data are generated in a world in which my inventory motive operates alongside other inventory motives traditionally emphasised in the literature, it may be difficult to uncover a clear relationship between the real interest rate and inventory investment.

I find that my model, at least qualitatively, matches all of these main facts.

1.2.2 Which Inventories?

The existing literature has argued over which form of inventory holding is the most important and thus the correct one to model. As pointed out in Blinder and Maccini (1991), and reproduced in Table (1.2) below, retail inventories and inventories of materials and supplies in the manufacturing sector are the most volatile components of inventory investment (although they are also the biggest). This suggests that these two forms of inventory holding are the most useful avenues of research to explain the role of inventories in business cycle volatility. Khan and Thomas (2007b), however, argue that the focus should be on manufacturing inventories rather than retail or wholesale inventories.

In this paper, I focus on finished good inventories, although the motives could be extended to work in progress (over which firms may enjoy greater control to determine when these goods are finished) or to materials and supplies. In terms of the distinction between manufacturing, retail and wholesale inventories, such as that emphasised in Blinder (1981), I have not taken a view in this paper. For simplicity, I model a single good and a single sector; the distribution sector is a black-box in my model. Furthermore, the main motive in this paper, inventories that arise as part of the distribution chain, consist of all retail and wholesale inventories, finished goods in the manufacturing sector, as well as some materials and supplies inventories. It is not economically important whether the final goods are stored in a room at the manufacturing plant, on pallets in a wholesalers, or on a retailer's shelves (Summers 1981). Similarly, the distinction between different types of manufacturing inventories is always economically relevant. For example,

Table 1.2: Volatility of Inventories (Source: Blinder and Maccini, 1991)

Description	% of total inventories	% of variance of inventories
Manufacturing and Trade	100	100
Manufacturing	60.8	46.3
Finished goods	16.6	5.7
Work in Progress	19.4	9.6
Materials & supplies	24.8	20.3
Covariance terms		10.8
Wholesale Trade	17.1	8.9
Retail Trade	22.1	24.3
Covariance terms		20.4

if a steel manufacturer sells steel bars to another firm who holds them as inventory to use later in production, the bars are counted as "Materials & Supplies"; on the other hand, if the steel bar producer had held the metal bars on their premises, they would be listed as "Finished Goods".

To summarise, the success of my model will be judged on how well it can match the behaviour of inventories along the following dimensions:

- Inventory adjustment is a small component of GDP growth, but it contributes a great deal to its volatility;
- Sales are less volatile than production;
- Production and inventory investment are procyclical;
- The inventory-sales ratio is counter-cyclical;
- No clear negative relationship exists between inventories and the real interest rate.

1.3 The Basic Mechanisms of the Model

The model of inventories which I propose in this paper is not meant to be an attempt at a canonical model. Rather, my aim is to develop a reasonably simple model which matches the aggregate data, and particularly one that captures the consequential nature of some of the distribution chain inventories associated with the inventory-in-motion concept. I additionally focus on the use of storage inventories as a complement to firm adjustment of distribution inventories. To illustrate these simple mechanisms, I will first explain the basic modelling devices, one at a time, within the context of a 2-period, stochastic endowment economy[8].

In explaining both inventory motives, the 2-period environment is the same and so I shall first elaborate on this, before explaining the specific modelling devices I employ.

The economy is characterised by a single consumption good from which utility is derived; in each period, there is an endowment of consumption goods given by:

$$y_t = a_t \quad t = 1, 2$$

where a_t is the endowment of goods. The consumption choice is given by c_t and consumer preferences are given by:

$$\begin{aligned} \mathbb{U} &= \mathbb{E}_t \left[U(c_1) + \beta . g_2 . U(c_2) \right] \\ \text{where } U(c_\tau) &= \frac{c_\tau^{1-\gamma}}{1-\gamma} \end{aligned}$$

where g_2 is a shock which affects the marginal utility of consumption (taste shock) in the second period (for expositional purposes, I assume that $g_1 = 1$). I introduce taste shocks at this point as I will draw on them in the Chapter 2. The endowment can take two values - high (a^H) and low (a^L), and is driven by a Markov process:

$$a_2 = \begin{cases} a^H \quad w.p.\ p_H \text{ if } a_1 = a^H \\ a^L \quad w.p.\ (1 - \ p_H) \text{ if } a_1 = a^H \\ a^H \quad w.p.\ p_L \text{ if } a_1 = a^L \\ a^L \quad w.p.\ (1 - \ p_L) \text{ if } a_1 = a^L \end{cases} \tag{1.1}$$

Inventories as Freight

The main inventory motive that I examine is the role of distributional inventories - inventories which are held simply while the goods are distributed[9]. For simplicity, there is no cost of holding inventories in this form; goods, once produced, take one period to be distributed free of charge. The amount of goods in the pipeline in period t and carried into period $t+1$ is given by f_{t+1} (for freight, and using the same time subscript as is common for capital stock in RBC models). However, the agent has the option to distribute the good more quickly at a cost; the agent must, therefore, choose a fraction

[8]For the sake of simplicity, I ignore the role of capital and labour supply decisions; I reintroduce these decisions in the main model in Section 1.4.

[9]Related to the title and the quotation at the beginning of this paper, there is much discussion within the supply chain management literature about the concept of managing "Inventory in Motion" as being synonymous with the function of distribution logistics.

ι_t $(0 \leq \iota_t \leq 1)$ of today's production to deliver immediately at a cost (paid for in period t)[10]. Therefore the stock of consumer goods in freight at the end of period t (and so will be available in period $t+1$) is given by:

$$f_{t+1} = (1 - \iota_t).y_t$$

I assume that some freight is given in the first period (f_1). Consumption in each period is derived from the budget constraint:

$$c_t = \iota_t.y_t + f_t - J(\iota_t).y_t$$

where $J(\iota_t)$ is the per unit cost of immediate delivery, which I assume to be convex[11]. As $\iota_t \geq 0$ (agents are not allowed to use distribution in order to defer consumption), I therefore have a non-negativity constraint and will need to solve the model using Kuhn-Tucker optimisation and considering whether the constraint binds or not.

The optimisation is:

$$\begin{aligned} \max_{\{c_1,c_2,\iota_1,\iota_2\}} \mathbb{U} &= \mathbb{E}_1 [U(c_1) + \beta.g_2.U(c_2)] \\ s.t.\ c_1 &= [\iota_1 - J(\iota_1)].y_1 + f_1 \\ c_2 &= [\iota_2 - J(\iota_2)].y_2 + (1 - \iota_1).y_1 \\ \iota_t &\geq 0 \end{aligned}$$

The equilibrium of this model is:

$$\kappa_1 = \beta\mathbb{E}_1 [g_2.U'_c(c_2)] - U'_c(c_1)[1 - J'(\iota_1)] \quad (1.2)$$

$$J'(\iota_2) = 1 \quad (1.3)$$

$$c_1 = [\iota_1 - J(\iota_1)].y_1 + f_1 \quad (1.4)$$

$$c_2 = [\iota_2 - J(\iota_2)].y_2 + (1 - \iota_1).y_1 \quad (1.5)$$

$$\kappa_1 \geq 0, \quad \iota_1 \geq 0 \quad (1.6)$$

The agent will always choose to deliver as much as possible in period 2 and this

[10] An alternative approach which leads to an equivalent set up assumes that firms choose an amount of the good to deliver early ($\zeta_t = \iota_t y_t$).

[11] I assume that $J(\iota_t) = w.(\iota_t)^2$, where w is a cost function parameters; higher w will increase the cost of immediate delivery. I constrain this parameter such that $w \geq (1-\beta)$ as this ensures that the agent will never choose $\iota_t > 1$.

Under the alternative approach of choosing an amount of the good to deliver early (ζ_t), convex costs imply that the unit cost of early delivery rises where the size is normalised by total output. i.e. cost per unit is $\frac{w.\zeta_t}{y_t}$.

maximum is given by equation (1.3). Solving the model in period 1, with a potentially binding constraint, is relatively simple (see, for example, Christiano and Fisher (2000)). I first solve the model by assuming that the non-negativity constraint on i_1 binds and then check whether κ_1, given by (1.2), is non-negative; if it is, the model is solved. When the non-negativity constraint binds, the agent consumes only the freight brought into the period and chooses to allow all recently produced output to carry into the next period. If the model is not solved ($\kappa_1 = 0$, $0 < \iota_t \leq 1$), then equation (1.2) yields an Euler equation for the optimum amount of output to bring forward:

$$U_c'\left(\left(\iota_1 - J\left(\iota_1\right)\right).y_1 + f_1\right)\left[1 - J'\left(\iota_1\right)\right] = \beta \mathrm{E}_1\left[g_2.U_c'\left(\left(\iota_2 - J\left(\iota_2\right)\right).y_2 + (1-\iota_1).y_1\right)\right]$$

That is, we balance the gain in terms of higher consumption today with the cost in terms of lower freight delivered tomorrow and the higher costs of delivery. There are three main factors which affect the decision to deliver goods early. There are 3 main variables which affect the decision to deliver goods early:

Future productivity In periods of low productivity/endowment (relative to the future), it will be desirable to deliver some of today's output that would otherwise only come available in the next period. As such, the more volatile the swings in productivity are, the more likely that stocks levels will be adjusted by bringing forward delivery. In my simple model, this amounts to a low value for p_H (or a high probability that a period of high productivity is followed by a period of low productivity). In a standard RBC model, the parameters of the TFP process (the AR(1) coefficient and the variance of the shocks) will determine the incidence of stock holding.

Future Taste Shocks The higher we expect the taste parameter (g_2) to be in the future, then we will wish to leave more inventory in freight in order to ensure that we have more to consume in the next period. This means we consume less today (when marginal utility is relatively low) and more tomorrow when the marginal utility is higher. This enables the agent to smooth their marginal utility across the periods.

The cost of early delivery Costs of early delivery measured using the parameter w in $J(\iota_t)$ determine the extent of the loss of output from choosing to delivery goods early. Higher w makes early delivery less likely (and, therefore, freight inventories are more likely to arise).

The time discount rate The less the agent values consumption in the next period, the more likely she is to delivery goods early (and so she is less likely to hold inventories).

This simple motive satisfies the two key facts about inventory behaviour:

1. Early delivery is used to smooth consumption and thus the option to reduce pipeline stocks at a cost, means that consumption will be less volatile even where current or recent production is low (so long as future production is expected to increase);

2. After periods of low productivity, when stock available for consumption is low from earlier periods, the agent will choose to bring forward delivery of some goods in order to smooth consumption. This means that lower productivity, and hence output, will coincide with a decline in pipeline inventories; changes in inventories (inventory investment) are procyclical.

Inventories as Storage

The second motive involves using inventories as a storage device[12]; in times of high productivity, people may choose to produce more than they wish to consume at that time in order to store some of the good for consumption at another time, for instance, at a time of much lower productivity. The effects of this type of inventory behaviour may be purely deterministic. For example, consider a manufacturer who knows that demand for their goods will be especially high in January, but also that productivity may be extremely low over Christmas (as many workers are on holidays at times over Christmas and New Year). The producer uses the relatively high productivity of November and the first weeks of December to build up extra inventories in order to meet demand when productivity is low.

In the model, I now ignore the effects of distributional inventories, and focus on the representative agent's ability to store consumption goods at a cost. The amount of goods stored in period t and carried into period $t+1$ is given by s_{t+1} (for storage). The cost of s_{t+1}, paid in period $t+1$, is given by a simple iceberg cost (υ) which can be thought of as loss, theft or damage resulting from the stock storage[13]. Therefore the evolution of stored consumer goods (storage inventories) is given by:

$$s_{t+1} = y_t + (1 - \upsilon).s_t - c_t$$

Crucially for the solution of the model, storage is required to be non-negative - $s_{t+1} \geq 0$. Storage brought into the first period, which is like a bonus endowment in period 1, is given by $s_1 \geq 0$.

[12]A similar story is briefly discussed at the firm level by Blinder and Maccini (1991).
[13]The basic analysis is unchanged by the inclusion of a convex cost term $\left(q.(s_{t+1})^2\right)$ to capture warehouse expenses and output losses through the use of labour in the physical handling of the storage.

We can solve this model by backward induction. In period 2, no storage will be desired, and everything available for consumption (output and stocks less costs) is consumed. There is no decision to make once the endowment is realised ($s_3 = 0$, and $c_2 = a_2 + (1 - \upsilon).s_2$). In period 1, therefore, the consumer faces the following maximisation problem:

$$\begin{aligned} \max_{\{s_2, c_1\}} \mathbb{U} &= \mathbb{E}_1 \left[U(c_1) + \beta.g_2.U(c_2) \right] \\ s.t. \; s_2 &= a_1 + (1-\upsilon).s_1 - c_1 \\ c_2 &= a_2 + (1-\upsilon).s_2 \\ s_2 &\geq 0 \end{aligned}$$

This model can be solved using standard Kuhn-Tucker optimisation, and the equilibrium of this model is given by:

$$\mu_1 = U_c'(c_1) - \beta(1-\upsilon).\mathbb{E}_1 \left[g_2.U_c'(c_2) \right] \tag{1.7}$$

$$s_2 \begin{cases} = a_1 + (1-\upsilon).s_1 - c_1 & if \; \mu_1 = 0 \\ = 0 & if \; \mu_1 > 0 \end{cases} \tag{1.8}$$

$$s_2 = a_1 + (1-\upsilon).s_1 - c_1 \tag{1.9}$$

$$c_2 = a_2 + (1-\upsilon).s_2 \tag{1.10}$$

$$\mu_1 \geq 0, \quad s_2 \geq 0 \tag{1.11}$$

As with the distribution motive, I first solve the model by assuming that the non-negativity constraint on s_2 binds and then I check whether μ_1, given by (1.7), is non-negative; if it is, the model is solved. If it is not solved ($\mu_1 = 0$), then equation (1.7) becomes the key behavioural relationship:

$$U_c'(a_1 + (1-\upsilon).s_1 - s_2) = \beta(1-\upsilon).\mathbb{E}_1 \left[g_2.U_c'(a_2 + (1-\upsilon).s_2) \right] \tag{1.12}$$

The key factors affecting the decision to store goods early are expected future productivity, expected future tastes, the cost of storage (υ), and the time discount rate. These are very similar to the factors affecting the distribution inventory decision. However, this motive operates in the opposite direction. If we choose to store goods, then we will do so until the marginal utility loss today from not consuming, is equal to the expected marginal utility benefit of having that extra good for consumption in the next period. If consumption is very high today (so marginal utility is very low), but we expect to have lower consumption tomorrow, then we may choose to store some of the goods for consumption in the next period. The constraint on storage binds when we would wish to consume more today because we expect consumption to be higher tomorrow, but we cannot bring forward the endowment. This is the opposite of the early delivery decision.

In the absence of variation in productivity and tastes, there is no storage. This means that in a non-stochastic steady state with constant productivity, no inventories are held for storage. However, even when productivity changes are deterministic (such as seasonal variation), this model generates stock holding behaviour. Moreover, such a storage model also matches two of the key facts about inventory behaviour:

1. As stocks are used to smooth consumption, their introduction will mean that production is more volatile than sales (consumption);

2. The build-up of inventories is strongest in periods of high productivity; hence changes in inventories (inventory investment) are likely to be procyclical.

Discussion of the Main Modelling Choices

Before I develop the full model using both these motives, it is worth pausing and considering what each of my two motives captures. Regarding the distribution motive, there is no reason to think that this simply refers to items in a long transportation. Rather, the process of delivery from factory to consumer includes, in addition to the transportation leg, any finished good inventories in the factory awaiting delivery and, particularly, those goods that are on the shelves of retailers (or on the pallets of wholesalers).

One potential criticism of this motive is that it is effectively equivalent to the approach of Kydland and Prescott (1982) (and others) who have included inventories as a factor of production. In particular, in my model, the amount of goods that are available for consumption today, depends on the inventories brought into the period as freight (and, of course, any storage too). In one respect, this is analogous to the inventories in the production function and therefore I have simply added the complication of not having an internal solution, with little gain in terms of the modelling strategy. However, there is one important difference between the my model and that of Kydland and Prescott; in my model, it is the marginal product of capital (and its expected future path) that will determine the behaviour of inventories, while the causality runs the other way with the inventories in the production function models.

The storage motive can be interpreted more broadly as a speculative motive for firms to hold inventories. Any decision by the firm to store goods will be taken because they expect that there will be a higher return (in terms of utility from consumption) next period. Given the general equilibrium nature of the model, there is no such thing as a stock-out in my model - if the agent wants more goods, they can get them but the cost will be the disutility of longer working hours and the costs of immediate delivery. However, to the extent that being forced into this extra cost situation is analogous to a stock-out, the storage motive captures the costs of not having enough goods available for consumption - a quasi-stock-out.

A final criticism may be that these motives lack a firm level foundation relative to the stock-out avoidance or (s,S) model approaches. I, however, view this as one of the strengths of the modelling strategy. The problem with, for example, the (s,S) approach, is that although the motivation has an intuitive foundation when we consider the behaviour of a single producer of a single good, it is not clear that a large number of agents acting individually in an (s,S) manner would aggregate to (s,S)-type behaviour for the macroeconomy. As mentioned above, Khan and Thomas (2007b) get around this by assuming that each producer gets a random draw for the cost of reorder every period and this random draw ensures that some agents delay ordering in every period (even to the point of shutting down production). Instead, my framework requires only that productivity shocks are highly correlated across firms (a standard assumption in the RBC literature) in order to allow me to proceed with a representative agent framework in which aggregate stocks would mimic the actions of the agent.

I, therefore, believe that although the two motives in my model are very simple, they are capturing two important channels for the holding of inventories. Moreover, the explicit modelling of these two channels provides a direct model analogue to the stories describing the improvement in inventory management that, it is alleged, may have driven the Great Moderation - the decline in macroeconomic volatility observed in most developed countries in the past 30 years. I return to the issue of the Great Moderation in Chapter 2.

1.4 The Real Business Cycle (RBC) Model

Although the simple model above is useful to introduce the ideas of the inventory motives that I wish to explore, it does not take into account the general equilibrium impact of changes in decision variables, and in particular, it ignores how changes in the stochastic variables induce changes in the inventory decision through labour and capital choices. Therefore, the inventory holding motives are embedded into an infinite-horizon RBC model. I shall proceed by assuming that there are only productivity shocks; in Chapter 2 I explore the behaviour of the model under preference (taste) shocks. In this section, I will also describe the non-stochastic steady state of the model and how GDP should be measured in this model. The next section explains how the model is solved using the Parameterised Expectations Algorithm (PEA).

As there are a lot of variables, parameters, and functions to keep track of, Table 1.3 provides a ready-reckoner for all the main symbols used in the model and a brief description of what the symbol represents.

1.4.1 Model Setup

The RBC model economy is characterised by a single sector which produces storable[14] consumption goods from which utility is derived. This single good is produced using capital and labour:

$$y_\tau = a_\tau (n_\tau)^\alpha . k_\tau^{1-\alpha}$$

where a_τ is the productivity of labour. The labour productivity term follows an AR(1) in logs:

$$\ln a_{\tau+1} = \rho \ln a_\tau + \varepsilon_{t+1}$$

where $\varepsilon_t \sim N(0, \sigma_\varepsilon)$.

The consumption choice is given by c_τ and consumer preferences, in the absence of taste shocks, are given by:

$$\begin{aligned} \mathbb{U} &= \mathbb{E}_t \left[\sum_{\tau=t}^{\infty} \beta^\tau . U(c_\tau, 1-n_\tau) \right] \\ \text{where } U(c_\tau, 1-n_\tau) &= U(c_\tau) + bN(1-n_\tau) \\ &= \frac{c_\tau^{1-\gamma}}{1-\gamma} + b\frac{(1-n_\tau)^{1-\eta}}{1-\eta} \end{aligned} \tag{1.13}$$

where b is a parameter which determines the relative weight attached to disutility of labour in the consumer's decision.

Both of the previously discussed inventory motives now apply. The agent has the option to store consumption goods, as well as an option to determine how goods are distributed. The model is such that the each motive operates in a different direction. The agent will either wish to consume more, and thus pay for immediate delivery, or they will wish to defer consumption from today and so pay to store the goods. As before, the amount of goods in the pipeline in period t and carried into period $t+1$ are given by f_{t+1}, the goods stored in period t and carried into period $t+1$ are given by s_{t+1} at a cost v. $J(\iota_t)$ is the per unit cost of immediate delivery.

Capital can, at a cost, be made from the single good. These costs of converting the consumption good into a capital good (capital adjustment costs) are included in order

[14]The distinction between durable and storable is an important one, but not one I address in the model. The goods in my model do not provide a service flow, although I assume that all goods can be stored. In reality, all goods can be stored, although the horizon over which they may be stored differs greatly.

Table 1.3: Parameters and Variables Used in the Model

Variable	Description	Other Information
Exogenous Variables And The Underlying Processes		
a_t	TFP variable in period t	$\ln a_{\tau+1} = \rho \ln a_\tau + \varepsilon_t$
ε_t	TFP shock	$\varepsilon_t \sim N(0, \sigma_\varepsilon)$
Endogenous Variables and Functions		
y_t	Output in period t	$= a_t (n_t)^\alpha .k_t^{1-\alpha}$
k_t	Capital stock for use in period t	
n_t	Labour input in period t	
c_t	consumption in period t	
s_{t+1}	storage carried into period $t+1$	
ι_t	early delivery variable (%) in period t	
$J(\iota_t)$	cost function to bring forward delivery to period t	$= w.\iota^2$
d_{t+1}	inventories carried into period $t+1$	$= (1-\upsilon).s_{t+1} + (1-\iota_\tau).y_\tau$
s_t	stored inventories from period $t-1$	
$f_{\tau+1}$	freight carried into period $t+1$	$= (1-\iota_\tau).y_\tau$
$_{t+1}$	adjustment costs of investment - paid in period t	$\frac{\varkappa}{2}\left(\frac{k_{\tau+1}-(1-\delta)k_\tau}{k_\tau}\right)$
$U(c)$	Utility function in consumption	
$N(1-n)$	Utility function in leisure	
$Sales_t$	Consumption + investment in period t	
$\frac{D_{t+1}}{Sales_t}$	Inventory-sales ratio in period t	
Parameters		
α	Labour share of output	
$\varkappa$	parameter of adjustment costs	
β	time discount rate	
γ	parameter on utility from consumption (c)	
η	parameter on utility from leisure $(1-n)$	
b	Relative weight of disutility of labour in utility	
w	cost of early delivery parameter	
υ	iceberg cost of storing goods	
δ	depreciation rate	
ρ	TFP shock persistence	
Numerical Solution		
¥	Update parameter used in numerical solution	
$\Omega_n(a_t, k_t, D_t; \omega)$	Expectation approximation function	
ω	Expectation approximation coefficients	
$\Theta_n(a_t, k_t, D_t; \theta)$	Expectation approximation function	
θ	Expectation approximation coefficients	
$\Psi_n(a_t, k_t, D_t; \psi)$	Expectation approximation function	
ψ	Expectation approximation coefficients	

to make the option of storing goods attractive. In a standard RBC model, without such adjustment costs, all intertemporal storage is achieved via capital accumulation and subsequent running down of capital; storage of goods as goods (rather than machines) would never be desirable as the return on storage is negative (cost). I therefore assume that it is costly to actively adjust (up or down) the level of capital stock. It is not costly, however, beyond the loss of production capability, to allow depreciation to passively reduce the level of capital stock. Capital adjustment costs are given by:

$$\frac{\varkappa}{2}\left(\frac{k_{t+1}-(1-\delta)k_t}{k_t}\right)^2$$

where $k_{t+1}-(1-\delta)k_t$ is net investment and I shall label the percentage change in the capital stock as $F_{t+1}\left(=\frac{k_{t+1}-(1-\delta)k_t}{k_t}\right)$. The assumed form of adjustment costs mean that in steady-state there is a cost to pay[15]; therefore adjustment costs affect the level of consumption in steady state.

Therefore, within each period, the goods available for consumption, storage or investment are given by: (i) output produced today but delivered immediately (less costs); (ii) stored goods brought forward from the last period; and (iii) normally delivered goods that have been in freight from the last period but, from which, we subtract the lost output due to adjustment costs. Therefore, the budget constraint in each period is:

$$\begin{aligned} c_\tau + s_{\tau+1} + k_{\tau+1} - (1-\delta)k_\tau &= (\iota_\tau - J(\iota_\tau)).y_\tau + (1-\upsilon).s_\tau + f_\tau - \frac{\varkappa}{2}\left(\frac{k_{\tau+1}-(1-\delta)k_\tau}{k_\tau}\right)^2 \\ where\ f_{\tau+1} &= (1-\iota_\tau).y_\tau \\ y_\tau &= a_\tau (n_\tau)^\alpha .k_\tau^{1-\alpha} \end{aligned}$$

In addition, the model is, of course, subject to the following two non-negativity constraints:

$$\begin{aligned} s_{\tau+1} &\geq 0 \\ \iota_\tau &\geq 0 \end{aligned}$$

In order to keep track of total inventories, be they pipeline or storage, I define the state variable "total inventories in period t (beginning of period inventories)" as $D_t = (1-\upsilon).s_t + f_t$; the two control variables that make up beginning of period t are determined

[15] The alternative, such that there is no adjustment costs in steady-state, means that there is an adjustment cost to allowing depreciation to take place. If we consider that the adjustment costs derive from the costs of rearranging or delaying production during new investment installation, then allowing depreciation to take place passively does not seem like it should create costs (beyond loss of production capability).

in the previous period. The full optimisation is laid out in the appendix to this paper; the equations defining the equilibrium in period t, using a few reporting variables to make the interpretation easier, are:

$$U_c'(c_t)\left(1+\frac{\varkappa}{k_t}\cdot_{t+1}\right)=\beta.\mathbb{E}_t\left[U_c'(c_{t+1})\left((\iota_{t+1}-J(\iota_{t+1}))MPK_{t+1}+(1-\delta)+\frac{\varkappa}{k_{t+1}}\left(\frac{k_{t+2}}{k_{t+1}}\right)\cdot_{t+1}\right)\right]$$
$$...+\beta^2.\mathbb{E}_t\left[U_c'(c_{t+2}).(1-\iota_{t+1}).MPK_{t+1}\right] \quad (1.14)$$

$$N_n'(1-n_t)=U_c'(c_t).(\iota_t-J(\iota_t))MPL_t+\mathbb{E}_t\left[\beta.U_c'(c_{t+1}).(1-\iota_t)MPL_t\right] \quad (1.15)$$
$$\kappa_t=\mathbb{E}_t\left[\beta.U_c'(c_{t+1}).y_t\right]-U_c'(c_t).(1-J'(\iota_t))\,y_t \quad (1.16)$$
$$\mu_t=U_c'(c_t)-\beta.(1-v).\mathbb{E}_t\left[U_c'(c_{t+1})\right] \quad (1.17)$$
$$c_t+s_{t+1}+k_{t+1}-(1-\delta)k_t=(\iota_t-J(\iota_t)).y_t+(1-v).s_t+f_t-\frac{\varkappa}{2}(_{t+1})^2 \quad (1.18)$$
$$\ln a_{t+1}=\rho\ln a_t+\varepsilon_t \quad (1.19)$$
$$MPL_t=\alpha a_t(n_t)^{\alpha-1}.k_t^{1-\alpha} \quad (1.20)$$
$$MPK_{t+1}=(1-\alpha)\,a_{t+1}(n_{t+1})^{\alpha}.k_{t+1}^{-\alpha} \quad (1.21)$$
$$_{t+1}=\left(\frac{k_{t+1}-(1-\delta)k_t}{k_t}\right) \quad (1.22)$$
$$\kappa_t\geq 0,\quad \iota_t\geq 0 \quad (1.23)$$
$$\mu_t\geq 0,\quad s_{t+1}\geq 0 \quad (1.24)$$

Though they appear more complicated, these are standard first order conditions. Equation (1.15) is the intratemporal Euler equation which determines the optimal amount of labour taking account of the fact that the benefit to working (the MPL_t, which depends on both the capital stock and the level of productivity) is split between this period and the next period depending on how much early delivery that is used. Equation (1.14) is the intertemporal optimality condition for investment in which the cost of investment today (resulting from lower consumption as a result of the investment and the adjustment cost) is equalised with the benefit of that investment (including the impact on adjustment costs in the future) which again will be spread between period $t+1$ and $t+2$ depending on the choice of how much to deliver next period. Equation (1.18) is the budget constraint, (1.19) is the standard productivity process used in RBC models, while (1.20), (1.21) and (1.22) are designated variables that try to make the conditions more readable.

The key equations in this model are the Kuhn-Tucker multiplier equations associated with the early delivery decision (equation (1.16)) and storage (1.17), and the relevant non-negativity constraints ((1.23) and (1.24)). When it is desirable to deliver goods early ($\iota_t > 0$), $\kappa_t = 0$ and the relevant Euler equation (1.16) becomes $U_c'(c_t).(1 - J'(\iota_t)) = \mathbb{E}_t[\beta.U_c'(c_{t+1})]$. This equation implies that the expected benefit from bringing forward one more unit of consumption at a cost of $(1 - J'(\iota_t))$, should equal the marginal cost in terms of lower expected utility of consumption in the next period. In this case, $\mu_t > 0$ with no storage being used. On the other hand, where storage is desirable and no goods are delivered early, equation (1.17) becomes the relevant Euler equation balancing the cost of giving up one unit of consumption today with the benefit of higher consumption in the next period (after taking into account the costs of storage).

GDP Measurement

In this model economy, output can be decomposed into its expenditure components using the accounting identity which is derived from the budget constraint:

$$\begin{aligned} y_t &= c_t + k_{t+1} - (1-\delta)k_t + (D_{t+1} - D_t) + J(\iota_t).y_t... \\ &\quad ... + \frac{\varkappa}{2}(F_{t+1})^2 + v.s_\tau \end{aligned} \tag{1.25}$$

Output growth is given by the percentage change $(\frac{\Delta y_\tau}{y_{\tau-1}})$.

However, this measurement does correspond to the measurement of GDP in the economy; the business costs (early delivery, storage, and capital adjustment) are intermediate consumption by firms and so need to be subtracted from output. This is true if the costs have to be paid formally (such as business consultancy costs for the installation of new investment) and are hence recorded, but it is also true if the costs were lost output (the use of worker time but without producing the usual physical output)[16]. Therefore:

$$\underbrace{y_t - J(\iota_t).y_t - \frac{\varkappa}{2}(F_{t+1})^2 - v.s_\tau}_{GDP_\tau} = c_t + k_{t+1} - (1-\delta)k_t + (D_{t+1} - D_t) \tag{1.26}$$

In the analysis of the model presented below, I will use this definition of GDP and therefore the GDP growth contributions, which correspond to the Bureau of Economic

[16] In the latter case, firm output would actually be measured as GDP and no intermediate consumption would be recorded. Another case concerns where the firm output is measured perfectly but intermediate consumption is mismeasured because the in-house provision of the services is not properly accounted for. In this case, the statistical authorities might attribute all output (y_t) to final value-added but instead mismeasure the expenditure side of the economy. In this case they will need to add a statistical discrepancy equal to the unmeasured parts of spending $\left(J(\iota_t).y_t + \frac{\varkappa}{2}(F_{t+1})^2 + v.s_{\tau+1}\right)$; the discrepancy is often included in the change in inventories contribution.

Analysis (BEA) data and allow the adding up of variance of GDP growth, are given by:

$$\frac{\Delta GDP_\tau}{GDP_{\tau-1}} = \frac{\Delta c_t}{GDP_{\tau-1}} + \frac{\Delta\left(k_{t+1} - (1-\delta)k_t\right)}{GDP_{\tau-1}} + \frac{\Delta\left(D_{t+1} - D_t\right)}{GDP_{\tau-1}} \tag{1.27}$$

Steady-State

The deterministic steady-state of this model is given by a time when productivity and output are constant and there is no uncertainty[17]. It is characterised by a situation in which:

$$\begin{aligned} c_t &= c^* \ \forall t \\ a_t &= 1 \ \forall t \\ n_t &= n^* \ \forall t \\ k_{t+1} &= k^* \ \forall t \end{aligned}$$

This steady-state is one in which it is optimal to take early delivery of some goods ($\iota^* > 0$, and $s^* = 0$). The reason for this is that leaving goods in the distribution chain has an implicit cost given by time discounting; if we wait until the next period to receive the goods, the utility that we derive from consuming the goods is lower than if we consume the same goods today. Optimal immediate delivery of goods balances the costs of early delivery with the loss of utility through discounting. The optimal condition (derived using $\kappa_t = 0$, and (1.16)) is:

$$1 - J'(\iota^*) = \beta \tag{1.28}$$

The higher the discount rate, the more goods we choose to deliver immediately. Further, the intratemporal Euler equation for labour allocation (equation (1.15)), the intertemporal Euler equation for investment (equation (1.14)), and the budget constraint (equation (1.18)) provide three equations in the three remaining unknown steady-state choice variables (c^*, n^*, k^*). Here, I write these three equations in terms of steady-state variables using the reporting variables of y^*, MPL^*, MPK^*, and D^*:

[17]This deterministic steady state solution is not the same as the zero shock outcome to the model; the slight difference results from the fact that the expectation function will take account of the probability of different shocks and a sustained period without shocks will not cause them to update their views. In other words, there is no learning in the model.

$$\begin{aligned}
N_n'(1-n^*) &= U_c'(c^*).MPL^*(\iota^*(1-\beta) - J(\iota^*) + \beta) && (1.29)\\
1 + \frac{\varkappa\delta}{k^*}(1-\beta) &= \beta^2.(1-\iota^*).MPK^* + \beta(\iota^* - J(\iota^*))MPK^* + \beta(1-\delta) && (1.30)\\
c^* + \delta k^* + \frac{\varkappa}{2}\delta^2 &= (1 - J(\iota^*)).y^* && (1.31)\\
y^* &= (n^*)^\alpha.(k^*)^{1-\alpha} &&\\
MPL^* &= \alpha(n^*)^{\alpha-1}.(k^*)^{1-\alpha} &&\\
MPK^* &= (1-\alpha)(n^*)^\alpha.(k^*)^{-\alpha} &&\\
D^* &= (1-\iota^*).(n^*)^\alpha.(k^*)^{1-\alpha} && (1.32)
\end{aligned}$$

1.5 Numerical Solution

The difficulty, however, with using DSGE models stems the complication of solving the dynamic behaviour in a system which has conditional expectations in the optimality conditions. The expectation terms are usually non-linear functions of both future choice variables and the stochastic realisation of future state variables. Given these difficulties, a typical solution, popularised by King, Plosser and Rebelo (1988), is to linearise the system (either in logs or levels) around its steady state and hence obtain (local) approximate solutions. However, in the face of occasionally/regularly binding constraints, it is unlikely that a linearisation around the steady-state will capture the effect of kinks in the policy function.

An alternative solution approach is the parameterized expectations algorithm (PEA). The PEA, which was first used by Wright and Williams (1982, 1984) and then popularised by Den Haan and Marcet (1990, 1994), replaces the conditional expectation in the Euler equation with an approximation. The approach then iterates until the approximation fits well. This approach is particularly well-suited for the solution of models with occasionally binding constraints, as the parameterized expectation means we do not have to solve separately for the policy and multiplier functions (see Christiano and Fisher (2000)).

PEA can be implemented in either a stochastic or non-stochastic fashion. Stochastic PEA works with simulated data and uses the realised values of the target variable as a measure of the expectation. This approach, therefore, depends on outcomes of the exogenous shocks used in the algorithm and it is in this sense that it is stochastic. When implementing the non-stochastic version, the researcher instead uses a selected grid of the possible values for the state variables and then, at each grid point, calculates the conditional expectation explicitly using Gaussian quadrature methods. These two differences have two major advantages; by using the actual conditional expectation, rather than the stochastic realisation, we can eliminate sampling noise and we can use a linear rather than non-linear regression to estimate the coefficients. Secondly, by carefully choosing the nodes used (in particular by making use of Chebyshev nodes and Chebyshev polynomials), we gain efficiency. Den Haan (2007) discusses these issues in greater depth.

To solve my model, I need to approximate the three expectations that appear in the first order conditions of the model using Ω, Θ, and Ψ as the approximation functions as follows:

$$\mathbb{E}_t\left[U_c'(c_{t+1})\left((\iota_{t+1} - J(\iota_{t+1}))MPK_{t+1} + (1-\delta) + \frac{\varkappa}{k_{t+1}}\left(\frac{k_{t+2}}{k_{t+1}}\right).\mathcal{F}_{t+1}\right)\right] \approx \Omega_n(a_t, k_t, D_t; \omega) \quad (1.33)$$

$$\mathbb{E}_t\left[U_c'(c_{t+2}).(1-\iota_{t+1}).MPK_{t+1}\right] \approx \Theta_n(a_t, k_t, D_t; \theta) \quad (1.34)$$

$$\mathbb{E}_t\left[U_c'(c_{t+1})\right] \approx \Psi_n(a_t, k_t, D_t; \psi) \quad (1.35)$$

To implement the PEA algorithm, I use an exponentiated polynomial in the three state variables - TFP (a_t), capital (k_t), and total inventories (D_t)[18] - as the functional form for the approximation of the conditional expectation. For example, for the expectation in equation (1.35), I estimate the log of the expectation with polynomial of order $L = (l_z+1)\times(l_k+1)\times(l_d+1)$ in the logs of the state variables, with coefficients given by ψ:

$$\Psi_n(a_t, k_t, D_{t,}; \psi) \approx \exp\left(P_L\left(\ln(a_t), \ln(k_t), \ln(D_t); \psi\right)\right)$$

where P_L is a L-th order polynomial. As I use Chebyshev polynomials, the total number of coefficients depends on the multiplication of the order of the basis function for each state variable. Therefore, if I use simple 1st order basis functions for each of the state variables ($l_z = l_k = l_d = 1$), the approximant will have eight coefficients to estimate[19].

Once I have an estimate of these expectations, the model can easily be solved for any set of state variables[20]. The solution, which uses the fact that both non-negativity constraints cannot bind at the same time (although they may both not bind in a given

[18]Because of the nature of the model, total inventories will never be 0; this is helpful in the solution of the model as I can take logs of the state D_t.

[19]Namely, the regressors are a constant, $\ln(a_t)$, $\ln(k_t)$, $\ln(D_t)$, $\ln(a_t)\times\ln(k_t)$, $\ln(a_t)\times\ln(D_t)$, $\ln(D_t)\times\ln(k_t)$, and $\ln(a_t)\times\ln(D_t)\times\ln(k_t)$.

[20]What follows is an overview of the solution method - more complete details are provided in the appendix to the paper (page 61).

period), can be summarised as follows:

1. Assume that the agent does not wish to store any goods but rather wishes to bring forward consumption; $s_{t+1} = 0$ and $\iota_t \geq 0$. Use equations (1.15), (1.14) (1.16), (1.18) and the approximating functions for the expectation terms ((1.33)-(1.34)) to solve for the four remaining control variables $(c_t, n_t, k_{t+1}, \iota_t)$.

   I then calculate κ_t from (1.16); if $\kappa_1 \leq 0$, this is the solution. Otherwise, I move to step 2.

2. If $\kappa_t \geq 0$ then set $\iota_t = 0$, and I check whether the agent wishes to store any extra goods. Equations (1.15), (1.14) (1.17), (1.18) and the approximating functions for the expectation terms solve for $(c_t, n_t, k_{t+1}, s_{t+1})$.

   Calculate μ_t from (1.17); if $\mu_t \leq 0$, the model is solved for that period. Otherwise, I move to step 3.

3. Set $\iota_t = s_{t+1} = 0$. I now solve the intratemporal Euler equation, the intertemporal Euler equation and the budget constraint for (c_t, n_t, k_{t+1}). I then confirm that neither multiplier is less than zero.

However, it is not sufficient simply to have an approximation for the expectation; in order to resemble the rational expectations solution, the approximation should lead to a set of beliefs that are consistent with the approximation. Therefore the necessary algorithm to implement the Non-Stochastic PEA solution is:

1. I create a discrete three-dimensional grid of the state space. To do this, I define bounds within which to restrict the grid in each direction and choose q_z, q_k, and q_d as the number of points in each direction of the grid (for TFP, capital and stocks respectively). Within each direction, the nodes are given by Chebyshev nodes; this means that more points toward the bounds are used and this improves the accuracy of the function approximation (Judd, 1998).

2. Using an initial estimate for the coefficients of the approximations (ω^0, θ^0, and ψ^0), I solve the model at each grid point using the steps outlined above. Once I have the model solved for each grid point, I can also compute the conditional expectation in equations (1.33, 1.34 and 1.35) using Gauss-Hermite quadrature.

3. I now have both state variables, and the corresponding conditional expectations based on the initial expectation function, for each grid point. I now fit the exponentiated polynomial of the logarithm of the state variables on the logarithm of the three expectations separately using a linear regression to obtain new coefficients given by $\omega^{new}, \theta^{new}$, and ψ^{new}.

4. The parameter vector is updated in the direction of the newly estimated vector:

$$\omega^1 = (1 - ¥).\omega^0 + ¥.\omega^{new}$$

where ¥ determines the amount of weight placed on the new estimates.

5. I repeat the procedure until the difference between the old and new estimates is below a chosen tolerance level (I use 0.00001).

Relative to the standard application of PEA, my expectation functions add one extra level of difficulty. Namely, it is problematic calculating the actual value of the $\Theta(a_t, k_t, D_t; \theta)$ approximation as it contains the expectation of a variable from 2 periods ahead (c_{t+2}) :

$$\Theta(a_t, k_t, D_t; \theta) \approx \mathbb{E}_t \left[U_c'(c_{t+2}) . (1 - \iota_{t+1}) . (1 - \alpha) a_{t+1} (n_{t+1})^{\alpha} . k_{t+1}^{-\alpha} \right]$$

This would involve repeating the full Gauss-Hermite quadrature loop a second time within each loop of the first Gauss-Hermite quadrature. To avoid this extra computational burden, I make use of the expected marginal utility of consumption approximation given by equation (1.35). Thus, once I have solved for the optimal decision in period t which gives k_{t+1} and D_{t+1}, it is easy to calculate the possible TFP shocks which yield a_{t+1} values and so the range of possible state variables for period $t+1$. Given the states, I repeat the solution to get the optimal decision under each possible shock and calculate the expectation using Gauss-Hermite quadrature as:

$$\begin{aligned} & \mathbb{E}_t \left[U_c'(c_{t+2}) . (1 - \iota_{t+1}) . (1 - \alpha) a_{t+1} (n_{t+1})^{\alpha} . k_{t+1}^{-\alpha} \right] \\ \approx & \sum_{a_{t+1}^i} \left[\Psi\left(a_{t+1}^i, k_{t+1}, D_{t+1}; \psi\right) . \left((1 - \iota_{t+1}) . (1 - \alpha) a_{t+1}^i (n_{t+1})^{\alpha} . k_{t+1}^{-\alpha} \right) \right] \end{aligned} \tag{1.36}$$

The baseline results are reported for a grid that contains a total of 75 points ($q_z = 5$, $q_k = 5$ and $q_d = 3$). I have also used a finer grid (245 points) with no material impact on the equilibrium. The Gauss-Hermite quadrature is performed using 5 nodes. The tolerance level is set to 10^{-5}. I have experimented with Chebyshev polynomials of varying degrees; the baseline results use $l_z = l_k = l_d = 1$.

1.6 Time Aggregation and Calibration

Before turning to the calibration of the model solved above, I first discuss the issue of time aggregation and how that can impact macroeconomic analysis.

1.6.1 Time Aggregation

Although there are examples given above of industries, such as dry grocery and apparel, in which it can takeover one year from an order being placed to the good becoming available on shelves, not all of this delay is due to inventory-in-motion. Unfortunately, aside from anecdotal industry evidence from consultancy reports, there is no hard data on the extent of inventory-in-motion. Even though the concept includes delays in the distribution chain at different stages of production, it seems unlikely that most goods firms have a distribution cycle of one quarter. Moreover, the decision to carry extra inventory over, or to run down built-up-inventories, likely has a horizon that is shorter than a full quarter. Both of these reasons make the assumed motives seem unlikely for a quarterly model.

Instead I choose to calibrate a monthly model. Of course, without hard data, the choice of one month, rather than one week, or even one day, may seem arbitrary. I chose it for two reasons; firstly, it makes the aggregation to quarterly frequency slightly easier which reduces the computation burden of my analysis. Secondly, using an Euler Equation approach, Maccini et al (2004) estimate that the average inventory level corresponds to four weeks of sales. I therefore calibrate my model such that the inventory-sales ratio will be approximately be 1 at a monthly horizon[21].

There is a strand of research that examines the effects of time aggregation on macroeconomic modelling. There are a number of papers which show that the underlying properties of a time-series can become distorted when subjected to intertemporal aggregation. For example, Granger and Siklos (1995) show that temporal aggregation can lead statistical tests for unit roots to be distorted, and Rossana and Seater (1992) show, using real wage data, that temporal aggregation can wrongly lead the time-series properties of the series to be more simple than they actually are. The key message of Marcellino (1999) is that greater care should be taken with specifying a temporal frequency for theoretical models in order to then compare the predictions of their model to statistical properties of the data.

Also, recent papers have argued that the solution to trying to match data collected at quarterly, or even annual, frequency is not simply to ask for more frequently collected data; this might be unduly expensive, or introduce excessive measure error which may be worse than infrequent data. Instead, Heaton (1993), who focuses on time non-separabilities, and Aadland (2001), looking a labour market behaviour, calibrate higher frequency macroeconomic models and then, following data-sampling methodologies, ag-

[21]Without a role for materials and supplies, and work in progress inventories, both of which are included in the NIPA estimates of inventory holdings, it is not possible for me to match the exact ratio of inventories to sales in the NIPA data. I do, however, use these data to explore the impact of the Great Moderation on inventories in Chapter 2.

gregate the data to quarterly frequency.

Modelling the business cycle at a monthly, rather quarterly, horizon is important in my model for two reasons. Firstly, in the baseline calibration, I make use of microeconomic evidence that labour supply is more elastic at higher frequency than at lower frequencies. This means that, with a high willingness to work longer, the amplification of TFP shocks with inventory control is greater. The second reason is that, as I am interested in the behaviour of a stock (rather than a flow) concept. Stock measures, unless normalised by a flow variable, are invariant to the horizon of the period under consideration. For example, the nominal amount of stocks at the end of the year is the stock level at the end of December; this is the same as the amount of stocks at the end the second half of the year, and simply at the end of December 31st. Therefore, expressing the costs of holding these stocks at a higher frequency encourages their use and, since the stock concept at a lower frequency does not change, generates a greater role for them in the economy.

1.6.2 Calibration

When choosing the parameters for the monthly model, care needs to be taken to ensure that the model does not generate different outcomes as a result of imposing inappropriate parameter values. I therefore calibrate the main parameters so that monthly parameters are equivalent to their quarterly counterparts. Aadland and Huang (2004) outline a method of consistent higher frequency calibration which is designed to ensure that steady-state values of temporally aggregated flows are consistent across high and low frequency calibrations. I follow their approach in this regard as much as possible.

I begin by calibrating the parameters of the utility function, for which calibration is not affected to any great degree by the time aggregation. The additively separable isoelastic utility function given by equation (1.13) requires three calibrated parameters: γ defines the CRRA parameter ($\frac{1}{\gamma}$ = intertemporal elasticity of substitution); b determines the relative weight on the marginal utility of leisure and is chosen to ensure that labour takes up about one third of total time; η is related to the Frisch elasticity of labour supply. Usual choices for the CRRA parameter are between 1 and 8; following King and Rebelo (1999), I begin by choosing $\gamma = 1$ as this makes the model solution slightly easier and is a typical value used in the RBC literature. I will also explore the impact of greater risk aversion on inventory behaviour. Typical quarterly values of η range between 1 and 4 (a smaller η means there is a bigger the impact of wage shocks on labour supply). However, following Aadland and Huang (2004), I choose the monthly value for labour supply elasticity ($\frac{1}{\eta}$) such that the agent is more willing to substitute labour from month to month than from quarter to quarter. Micro-evidence, from studies such as Browning et al. (1999), Macurdy (1983), and Abowd and Card (1989), provide evidence to support this choice. In the baseline parameterisation, I choose $\eta = 0.66$ to match with the midpoint of Macurdy's estimated range of labour supply elasticity at a monthly frequency, and $b = 3$ determines the steady-state labour supply such that the amount of labour supplied in steady-state is 0.25 which corresponds to approximately 40 hours per week.

To calibrate the time discount factor, I relate it to the long-term real interest rate[22] such that:

$$\beta^{annual} = \frac{1}{1+\bar{r}}$$

where $\bar{r}$ is the average long-term interest rate (approximately 3%). Hence the annual value to use is $\beta \approx 0.970$. Thus, calibrating a quarterly or monthly value for β is simply:

$$\beta^{quarterly} = \frac{1}{(1+\bar{r})^{\frac{1}{4}}} \approx 0.993$$
$$\beta^{monthly} = \frac{1}{(1+\bar{r})^{\frac{1}{12}}} \approx 0.998$$

Using data on annual nominal capital stock from the Bureau of Economic Analysis (BEA), the average capital to GDP ratio in the US was 2.8 between 1960 and 2007. As the numerator in this ratio is a stock variable, it is not going to be affected by the decision to use a monthly or a quarterly model. The denominator, however, is affected by this choice; the ratio of capital to monthly GDP that I try to match in my model is around 33. Together with the choice of β, the depreciation rate is set to match this capital-output ratio. Using a depreciation rate of 10% per annum, as in King and Rebelo(1999), δ (monthly depreciation rate) is chosen to be 0.008. Following Chari et al, (2000), I chose the investment adjustment cost parameter (χ) to match the relative volatility of investment (to output volatility) found in the US data (3.2 between 1960 and 2007); the chosen value of χ is 201. I assume that α, the coefficient on labour in the Cobb-Douglas production technology, is set to equal the average labour share in the US between 1960 and 2007 ($\alpha = 0.66$).

The standard approach in RBC models to calibrate the parameters of the productivity process (ρ, σ) is to assume that the series for quarterly productivity follows an AR(1) in logs:

$$\ln a^Q_{T+1} = \rho^Q . \ln a^Q_T + \varepsilon_{T+1}$$

where ρ^Q and σ^Q_ε are obtained by estimating this AR(1) using a quarterly series for TFP in the economy. Lippi and Reichlin (1991) show that the estimate of persistence

[22]Other authors choose β to match a steady-state capital-output ratio.

Table 1.4: Parameters in Baseline Model

	Utility and Production functions					AR(1) process		Cost terms			
Parameter	β	γ	b	η	α	ρ_z	σ_z	χ	υ	δ	w
Monthly Value	0.998	1	3	0.66	0.66	0.83	0.0052	201	0.001875	0.008	0.1

of shocks to GDP is changed by temporal aggregation and, importantly, this change is not necessarily systematic - it may go either way depending on the underlying data. Therefore, in order to calibrate the monthly AR(1) process for TFP in my model, I use a quarterly estimate of US TFP and fit an AR(1) but allow for an MA(1) error term due to the fact that the quarterly level is (approximately) the average of the monthly levels. I then use a Monte-Carlo exercise to find values for the monthly AR(1) that yield similar estimates when we aggregate to the quarterly frequency. The monthly parameters I use are $\rho^M = 0.83$ and $\sigma_\varepsilon^M = 0.0053$. These monthly values correspond to quarterly parameters of $\rho^Q = 0.69$ and $\sigma_\varepsilon^Q = 0.006$[23].

To calibrate the value of υ, I follow Khan and Thomas (2007b) who use the estimates for the carrying costs of inventories provided by Richardson (1995). In order to include only those costs for storage of goods that my model explicitly covers, I concentrate on the costs of deterioration & pilferage; these are estimated to be in the range of $3\% - 6\%$ of inventory value for the year. However, since my model only covers about 50% of total inventories in the economy, I rescale these values and use the range $1.5\% - 3\%$. Using the middle of this range, this corresponds to a monthly cost of 0.1875 as a percentage of inventory value ($\upsilon = 0.001875$). I assume that the cost function for early delivery is quadratic, $J(\iota) = w.\iota^2$ and I choose w such that the average inventory-sales ratio corresponds to approximately 4 weeks as already discussed. This entails using $w = 0.1$.

The baseline parameter values, presented in Table (1.4), are used to solve my Baseline TFP model of inventories. The next section explores the behaviour of inventories in this model.

1.7 Results

In order to examine the role played by active control of inventory-in-motion, as distinct from the image of the (assumed) nature of the inventories, I begin by comparing my baseline inventories model to a model that has been calibrated with the same parameters, but in which inventories cannot be actively adjusted. The two versions correspond to:

[23]These quarterly values are derived from an ARMA(1,1) model estimated using a logged US TFP series for the period 1961 Q1 to 2006 Q4; the series is detrended using an HP-filter with the smoothness parameter set to 1600 as suggested by Ravn and Uhlig (2001) for quarterly data.

1. Baseline TFP model

   The baseline inventories in motion model, described above, in which TFP shocks are the driving process which is calibrated with the parameters given in Table (1.4).

2. Pure Pipeline Model:

   This is a standard RBC model driven by TFP shocks. However, all goods are subject to the one month delay in delivery. In this model, inventories are a natural consequence of the pipeline delay and, therefore, this model differs from the baseline model only in that the economic agent does not exercise any control over inventories. The calibration for all parameters coincides with the Baseline model (Table (1.4)).

Before comparing the two models, I first examine the estimated policy functions for the inventory decision variables in the baseline model. Figure 1.1 plots, in the top and bottom panels respectively, the optimal choice of ι_t and s_{t+1} (the control variables affecting active inventory management in period t) for combinations of the TFP variable over the interval $[0.975, 1.025]$ (corresponding to 2.5 standard deviations in either direction from steady-state) and capital stock over the interval $[41.45, 62.176]$ (which corresponds to $\pm 20\%$ on the steady-state level of capital). In each figure, the beginning-of-period stock of inventories is assumed to be at its steady-state level. In Figure 1.1 there are two important non-linearities which justify the non-linear solution method I use. The first is the kink that is to be expected (and was discussed above) where the capital stock is low, and, at the same time, so is TFP. In such a case, the agent does not wish to bring forward any of the freight and hits the non-negativity constraint. The second is that, for any given TFP, the optimal ι_t is an inverted-U shape function of capital stock (though higher TFP, *ceteris paribus*, leads to more consumption being brought forward today).

Figure 1.2 repeat the analysis but in each case capital is held constant at its steady-state level while start of period inventories are allowed to vary on the interval $[0.91, 2.12]$ which represents steady-state stocks $\pm 40\%$; TFP continues to vary on the interval $[0.975, 1.025]$. In this case, the policy functions have only the kink from hitting the non-negativity constraint. Whenever TFP is at, or below, its steady-state level of 1, and even when it is slightly above, the agent will wish to bring forward consumption using early delivery as described in section 1.4.1. It is only when TFP is particularly high that the agent might consider storing the goods. Otherwise, the effect of different levels of starting inventory could be more reasonably be linearly-approximated compared with the effect of different levels of capital stock discussed above.

Next, I simulate each model using the *same* exogenous shock process for 3000 months; I then aggregate to a quarterly frequency (1000 quarters) as described above and all reported results use the quarterly data. Table 1.5 confirms the achieved calibration in

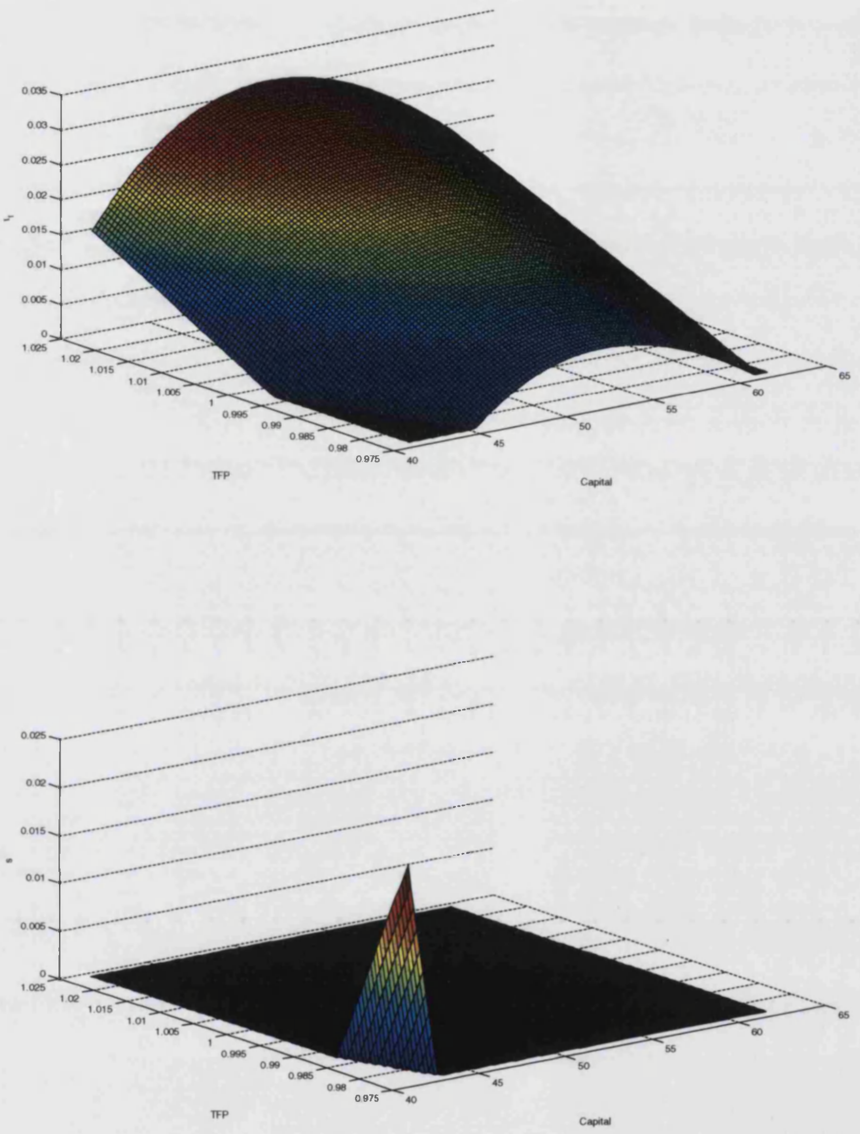


Figure 1.1: Optimal Choice of Inventory Control Variables For Different Values of Initial State Variables: Initial holdings of inventory are assumed to be at their steady-state level

terms of capital and investment to sales ratio. It also shows that the first characteristic of inventories is matched in my model; inventory adjustment is, on average, a negligible component of GDP growth (rounding to zero) and yet accounts for about 28% of the variance of GDP growth in my Baseline Inventories Model. As the effect is also generated by the pipeline RBC model, this suggests that this feature of GDP growth decompositions does not, necessarily, represent an active inventory motive and may, in fact, simply be generated by natural delays between production and consumption. Both models attribute too much variation in GDP growth to investment and not enough to consumption - this

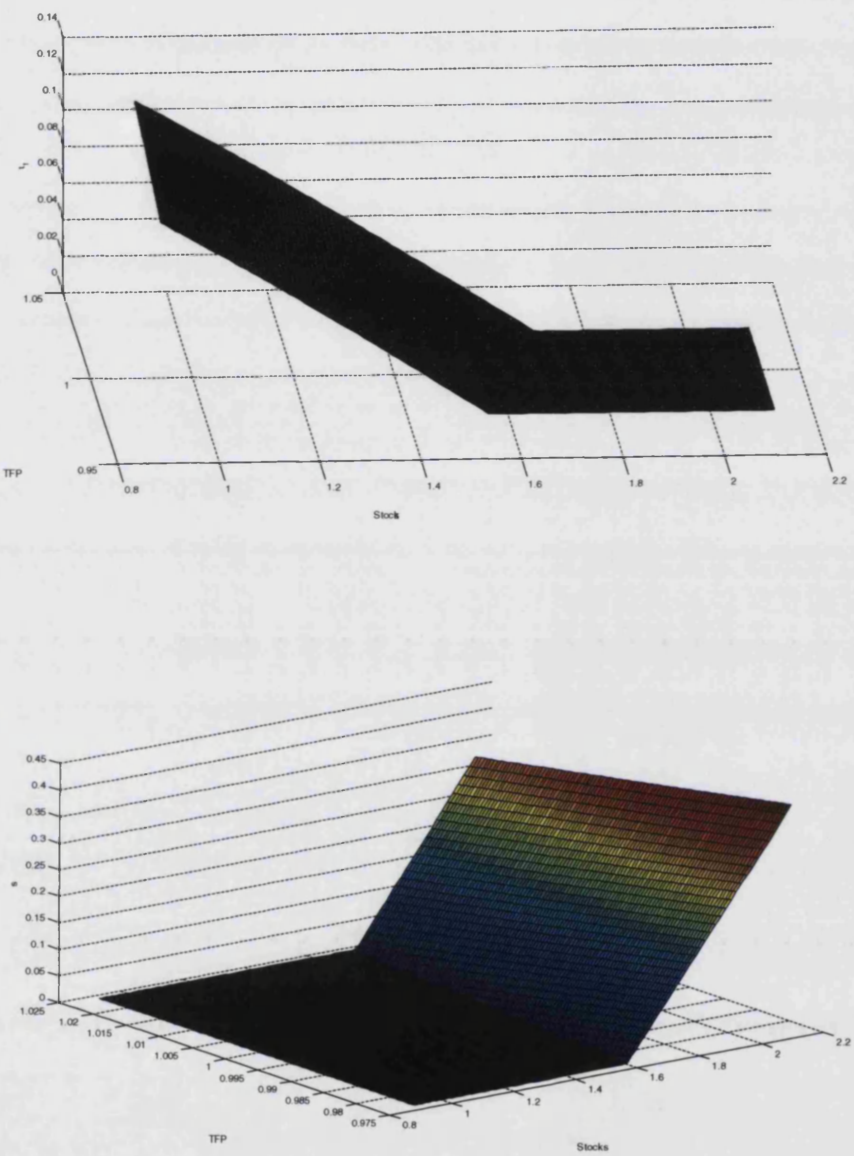


Figure 1.2: Optimal Choice of Inventory Control Variables For Different Values of Initial State Variables: Initial capital stock is assumed to be at their steady-state level

is a typical issue with RBC models.

The standard tool for the matching of RBC models to the data is comparing the relative volatility of the HP-filtered (log) series from the simulated model with the analogous statistics from the data. This analysis is presented in Table 1.6. While the models do reasonably well, as is often the case with RBC models, I cannot fully match the relative volatility of consumption; as mentioned above, both models predict consumption that is

Table 1.5: Result of Simulations: Key ratios, Shares of GDP, and Contributions to the Variance of GDP Growth

	Pipeline RBC		*Baseline Inventories*	
Capital-GDP ratio	2.7		2.7	
Inventory-sales ratio	0.33		0.32	
	GDP share	*% of Variance of GDP growth*	*GDP share*	*% of Variance of GDP growth*
Consumption	75%	1%	74%	1%
Investment	25%	85%	26%	60%
Inventory Adjustment	−0.0%	44%	−0.0%	28%
Covariance		−30%		9%

Table 1.6: Volatility of HP-filtered GDP and Components Relative to GDP, by model

Standard Deviation of HP-filtered Series Relative to GDP			
Model	*Pipeline RBC*	*Baseline Inventories*	*data*
GDP	1	1	1
consumption	0.15	0.18	0.73
investment	3.6	3.2	3.2
labour hours	0.23	0.72	0.99

too smooth relative to GDP. However, the main benefit of the active control of inventories it that we are able to get much closer to the volatility of labour hours as seen in the data; both models have the same assumed labour supply elasticity (which is reasonably elastic), this Table shows that the active inventory management, increases the volatility of hours relative to output by inducing greater labour effort in times of high TFP than is the case where the agent cannot gain from this effort by bringing consumption forward; the representative agent works more (less) in times of high (low) productivity.

This labour result suggests that active inventory control may amplify the effect of TFP shocks. To establish the extent of this amplification, rather than comparing each of the models to the variability of its own GDP series, I now compare the predictions across models, using the Pipeline RBC model as the basis for comparisons. The results are shown in Table 1.7. As expected, the model with inventory management, when subject to precisely the same shocks, has more internal amplification of the shocks; the standard deviation of HP-filtered GDP is more than twice as high as the equivalent model in which the agent cannot adjust their inventory behaviour. The main difference comes through the induced labour effort, which is nearly seven times more volatile relative to its trend in the Baseline model. This results in a more volatile inventory-sales ratio.

Table 1.7: Volatility of HP-filtered GDP and Components, Relative to RBC Model

Standard Deviation of HP-filtered Series Relative to RBC Model		
Model	*Pipeline RBC*	*Baseline Inventories*
GDP	1	2.1
consumption	1	2.4
investment	1	1.9
labour hours	1	6.9
Inventory – sales ratio	1	1.6

In order to better understand the source of this amplification of TFP shocks, I compare the dynamic responses of the key model variables in two models. For a positive (negative) technology shock that takes place in period $t = 1$, Figure 1.3 (1.4) plots the dynamic responses of TFP, Tastes, GDP, the MPK, hours worked, capital, consumption, investment, inventory adjustment, total adjustment costs, inventory levels, the inventory-sales ratio and the two inventory control variables.

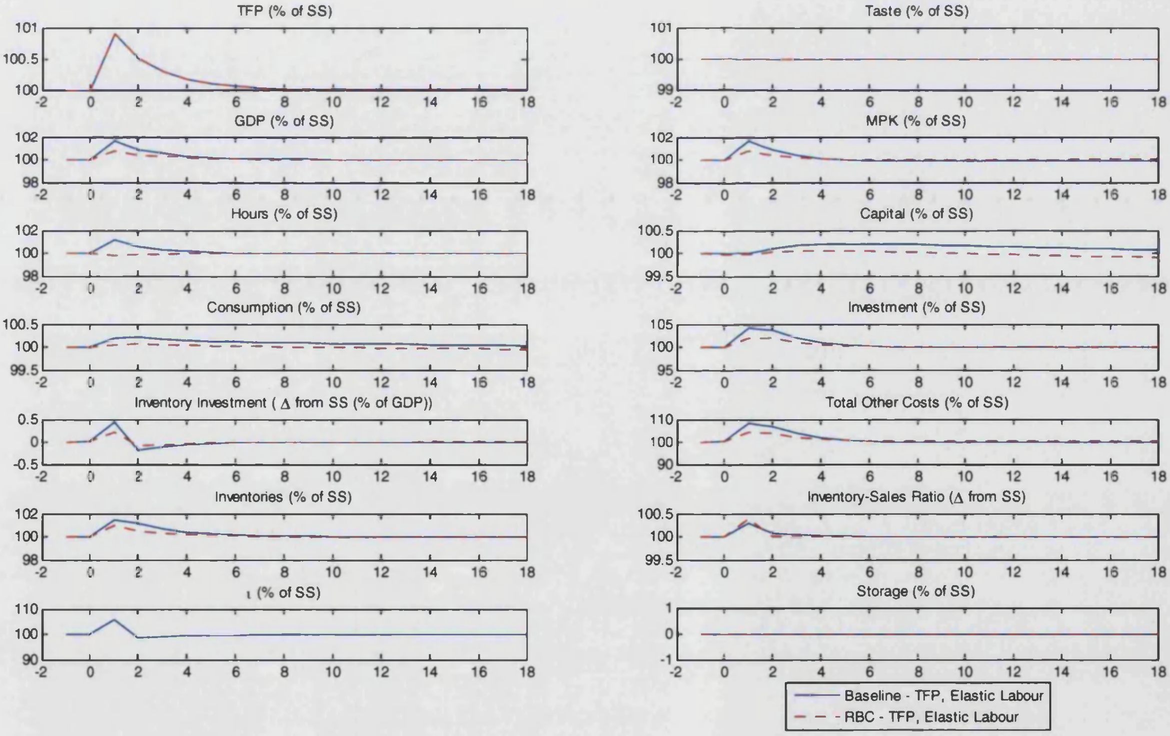


Figure 1.3: Dynamic Model Responses (relative to Steady-State (SS)) to a 2 Standard Deviation Positive TFP Shock Lasting 1 month

The earlier established results are clear from these impulse responses. The increase in TFP, 0.8% in period t, induces a large increase in hours (+1%). The increase in both

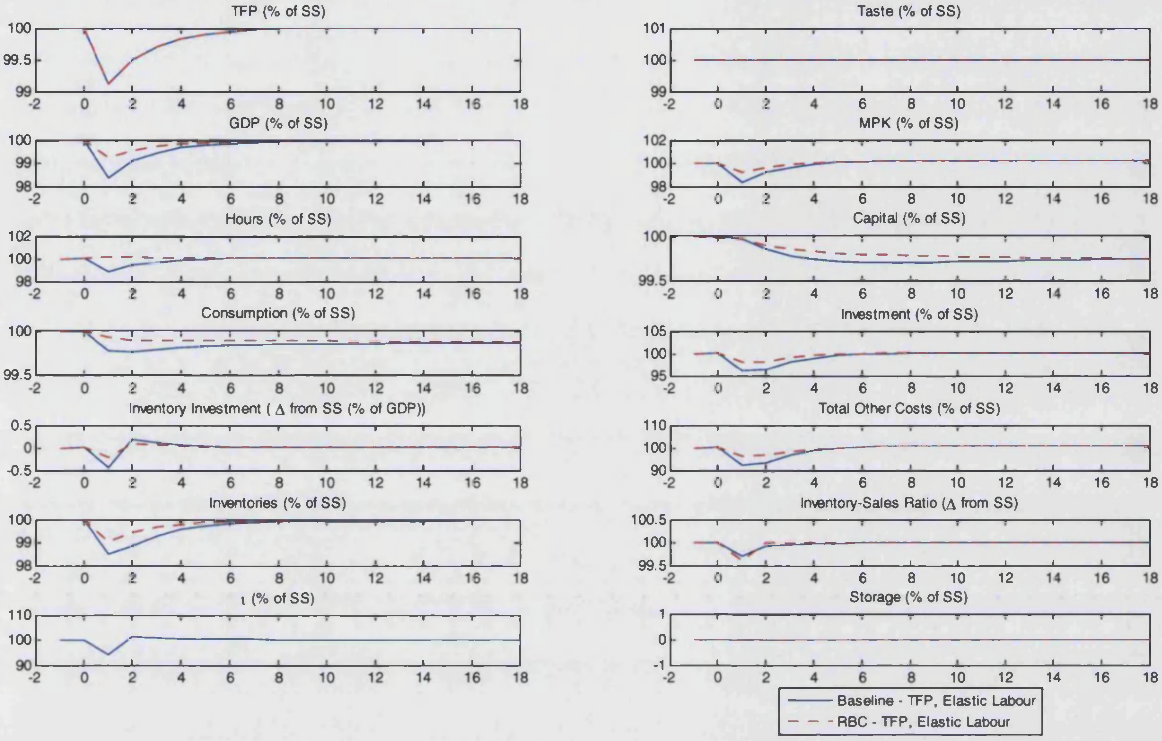


Figure 1.4: Dynamic Model Responses (relative to Steady-State (SS)) to a 2 Standard Deviation Negative TFP Shock Lasting 1 month

TFP and hours push the MPK up markedly which amplifies the increase in investment. Higher TFP and hours input leads to a 1.7% increase in GDP. This increase in GDP leads, via the pipeline inventories effect, to an increase in inventories (and positive inventories investment). However, by being able to actively manage inventories means the agent can take advantage of the higher productivity today - more goods are brought forward for immediate consumption which mitigates the increase in inventories (given the increase in output). This generates the less marked increase in the inventory-sales ratio.

The results of a negative shock are similar (1.4). What is noticeable is that storage is not used in response to either shock in the baseline model. Nor does it appear to be regularly used in the simulations. I discuss this in the next section.

The procyclical response of the inventory-sales ratio in the impulse response functions seems to go against the stylised facts listed above. In Figure 1.5, I examine a small sample of the quarterly data from the model simulation. In quarters 20-25 of the figure, there is an increase in GDP but the inventory-sales ratio falls. The reason for these differential responses is that, as shown above, the response of inventories depends not only on TFP, but also on the other state variables. Below, I show that, overall, the correlation between

GDP and the inventory-sales ratio is negative overall in the simulation.

Inventories are lower in the model where the agent can actively manage them; this is because in the pipeline RBC model we assume that inventories naturally arise whereas the main decision taken in the baseline model is how much to deliver early and, therefore, prevent from becoming an inventory. This Figure also shows that capital is higher in the Baseline Inventory model; this makes GDP higher than in the Pipeline RBC model. Hours, are not any higher on average, but the increased volatility is evident. Higher GDP leads to higher average consumption when inventories are actively managed; welfare will be higher with active inventory control.

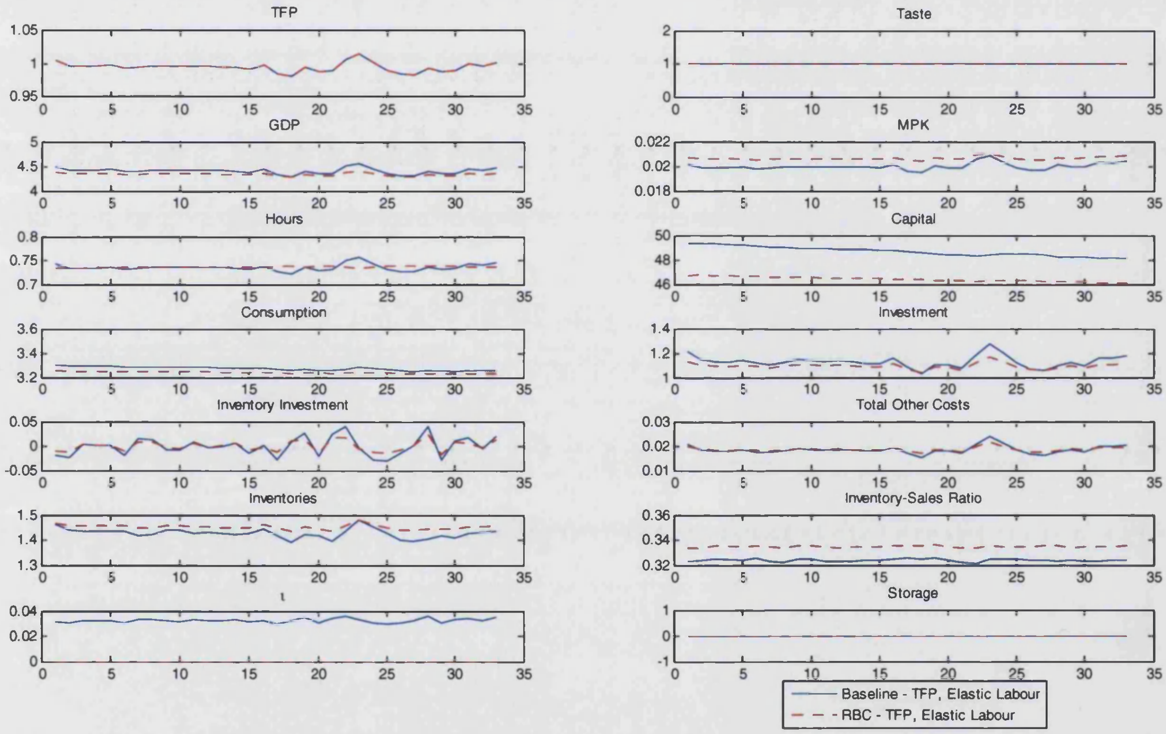


Figure 1.5: Quarterly Levels of Selected Model Variables Over a 34 Quarter Sample.

To conclude, in Table 1.8, I confirm that the key stylised fact about inventories (that sales are less volatile than output) is matched by the Pipeline RBC model and my Baseline Inventory model. I also present some additional correlations from my models in this Table. As in (Khan and Thomas 2007b), my baseline model generates a counter-cyclical inventory-sales ratio. As discussed above, this average correlation is not evident when we look at the impulse response functions. The reason for this difference, as mentioned above, is that the impulse response functions begin at the steady-state and as Figure 1.1 makes clear the response of inventories differs when we start away from the steady-state.

Table 1.8: Correlations between inventories, sales and the I-S ratio

				Pipeline RBC	*Baseline Inventories*
$\frac{Var(Sales)}{Var(Output)}$				0.40	0.67
$Corr\left(\frac{D}{S}, GDP\right)$				-0.58	-0.36
$Corr\left(\Delta D, MPK\right)$				0.2	0.24
Lag – Lead Correlation of GDP and Inventory Adjustment					
	-2	-1	0	$+1$	$+2$
Pipeline RBC	-0.09	$+0.29$	$+0.33$	-0.62	$+0.05$
Baseline Inventories	-0.1	$+0.24$	$+0.48$	-0.70	$+0.01$

To examine the relationship between the real interest rate and inventories, I use the marginal product of capital (MPK) as the relevant real interest rate. Within my framework, inventory investment is positively correlated with the real interest rate. Therefore in a setting in which many different motives for holding inventories operate, including the distributional motive emphasised here, finding a negative effect of interest rates on inventory adjustment (predicted by some of the other motives) may be difficult. Hence, there may be a theoretical explanation, complementary to the econometric reasoning put forward by Maccini, Moore, and Schaller (2004), for why the negative relationship suggested by typical firm-level analyses is difficult to find in the data. Both models perform very similarly in terms of the lag and lead correlations between GDP growth and inventory adjustment; though neither actually matches the positive correlation between GDP and the 1-period lead of inventories that is found in the data.

1.8 The Storage Motive and Alternative Calibrations

1.8.1 The Storage Motive

One of the striking facts of the model is that storage is not used in response to shocks in the baseline model. There are two reasons for this: (1) storage is less desirable than capital investment for carrying excess goods from one period to the next period (because capital investment provides both a positive return in terms of more output the next period), and (2) in steady-state, some goods are brought forward ($\iota^* > 0$) and, therefore, if the agent wishes to defer consumption using inventories, the first response is to reduce ι and leave more goods in the pipeline.

I have tried to generate a greater role for the storage motive by: (1) increasing the costs of adjusting capital ($\chi^{Alt} = 401$); (2) increasing the cost of early delivery ($w = 5$);

and (3) reducing the cost of storage ($\upsilon = 0$). Despite these (large) changes, there remains no use of storage in the simulations.

One alternative suggestion would be to make investment irreversible. If investment cannot be converted back to consumption goods, then it will be less desirable in providing intertemporal storage. The problem with this is that, in the baseline model, total investment never goes negative. Thus, the adjustments that are equivalent to "consuming capital" are in fact achieved by simply investing lower (but still positive) amounts and letting depreciation run capital down. It does not seem desirable to make gross investment irreversible and therefore force firms to replenish depreciating capital stock.

1.8.2 Alternative Calibrations

The most striking implication of the inventories is the induced response of labour and therefore the greater amplification of TFP shocks. In order to examine the robustness of this conclusion, I examine the application in three alternative calibrations of the baseline inventory model[24]:

1. Alternative 1 - less elastic labour supply $\eta = 1.5$;
2. Alternative 2 - higher risk aversion γ;
3. Alternative 3 - both together.

The results in terms of the amplification effect are shown in Table 1.9 which, in the first 2 columns, repeats the analysis of 1.7. Our three alternative models are then subjected to the same series of TFP and the HP-filtered volatilities are compared to the baseline model. As can be seen, although lower labour elasticity (obviously) reduces the volatility of labour hours and therefore mitigates the response of GDP, the amplification effect remains substantial. Risk aversion also lowers the labour supply volatility and, therefore, both together produce the smallest amplification effect from the variants I consider here. Nonetheless, the HP-filtered volatility of GDP is 1.8 times larger when inventory control is possible. Moreover, the close fit of other aspects of the model is not adversely affected by these alternative calibrations.

1.9 Conclusions

In this paper, I focus on the concept of inventories-in-motion - that is, where a firm tries to optimally control inventories that arise naturally between the production and

[24] I do not consider the changes in the cost of inventories here as I explore these in greater detail in Chapter 2.

Table 1.9: Volatility of HP-filtered GDP and Components, Relative to RBC Model under Alternative Calibrations

Standard Deviation of HP-filtered Series Relative to RBC Model					
Model	*Pipeline RBC*	*Baseline Inventories*	*Low Labour Elasticity*	*Higher Risk Aversion*	*Both*
GDP	1	2.1	1.9	2.0	1.8
consumption	1	2.4	2.3	0.8	0.8
investment	1	1.9	1.7	2.0	1.8
labour hours	1	6.9	5.1	6.2	4.6
Inventory – sales ratio	1	1.6	1.4	1.6	1.4

the consumption of the goods. The first contribution is to solve a model of distribution inventories using a version of the PEA numerical solution technique which ensures that I am able to examine the behaviour of the model despite its inherent non-linearities. I then calibrate and simulate a monthly version of this model, and I aggregate the model outcomes following national accounts standards to generate quarterly model predictions.

The second, and main, contribution of the paper that my model, although highly stylised, is able to successfully match (at least qualitatively) a number of key facts about the behaviour of inventories at the macroeconomic level. These include:

- Inventory adjustment is a small component of GDP growth, but it contributes a great deal to its volatility;
- Sales are less volatile than production;
- Production and inventory investment are procyclical;
- The inventory-sales ratio is counter-cyclical;
- No clear negative relationship should exist between inventories and the real interest rate.

Perhaps more importantly, I find that my inventory channel also generates a substantial amount of internal propagation of TFP shocks. The lack of internal propagation is often cited as a major failure of the RBC modelling approach. In my model, the same volatility of GDP could be generated with volatility of the driving TFP process.

1.A Model and Solution Details

Full Model Equations - TFP Shocks

The optimisation problem in period t is then given by:

$$
\begin{aligned}
\max_{\{k_{\tau+1}, c_\tau, n_\tau\}} \mathbb{U} &= \mathbb{E}_t \left[\sum_{\tau=t}^{\infty} \beta^{\tau} . U\left(c_\tau, 1 - n_\tau\right) \right] \\
s.t. \;\; y_\tau &= a_\tau \left(n_\tau\right)^{\alpha} . k_\tau^{1-\alpha} \\
c_\tau + s_{\tau+1} + k_{\tau+1} - (1-\delta) k_\tau &= \left(\iota_\tau - J\left(\iota_\tau\right)\right) . y_\tau + (1-\upsilon) . s_\tau + f_\tau - \frac{\varkappa}{2} \left(\frac{k_{\tau+1} - (1-\delta) k_\tau}{k_\tau} \right)^2 \\
f_{\tau+1} &= \left(1 - \iota_\tau\right) . a_\tau \left(n_\tau\right)^{\alpha} . k_\tau^{1-\alpha} \\
s_{\tau+1} &\geq 0 \\
\iota_\tau &\geq 0
\end{aligned}
$$

which we can treat as a Kuhn-Tucker problem in period t:

$$
\begin{aligned}
\max_{\{c_\tau, n_\tau, k_{\tau+1}, \iota_\tau, s_{\tau+1}\}} \mathcal{L} = \mathbb{E}_t \sum_{\tau=t}^{\infty} \beta^{\tau - t} . U\left(c_\tau, 1 - n_\tau\right) - \mathbb{E}_t \sum_{\tau=t}^{\infty} \mu_\tau \left[s_{\tau+1}\right] - \mathbb{E}_t \sum_{\tau=t}^{\infty} \kappa_\tau \left[\iota_\tau\right] \\
- \mathbb{E}_t \sum_{\tau=t}^{\infty} \lambda_\tau \left[c_\tau + k_{\tau+1} - (1-\delta) k_\tau - \left(\iota_\tau - J\left(\iota_\tau\right)\right) . a_\tau \left(n_\tau\right)^{\alpha} . k_\tau^{1-\alpha} - (1-\upsilon) . s_\tau - \left(1 - \iota_{\tau-1}\right) . a_{\tau-1} \left(n_{\tau-1}\right)^{\alpha} . k_{\tau-1}^{1-\alpha} + \frac{\varkappa}{2} \left(\frac{k_{\tau+1} - (1-\delta) k_\tau}{k_\tau} \right)^2 \right]
\end{aligned}
$$

$$\frac{d\mathcal{L}}{dc_\tau} \quad : \quad \mathbb{E}_t\left[\beta^{\tau-t}.U_c'(c_\tau)\right] = \mathbb{E}_t\left[\lambda_\tau\right] \quad \forall\tau$$

$$\frac{d\mathcal{L}}{dn_\tau} \quad : \quad \mathbb{E}_t\left[\beta^{\tau-t}.N_n'(1-n_\tau)\right] = \mathbb{E}_t\left[\lambda_\tau(\iota_\tau - J(\iota_\tau))\alpha a_\tau (n_\tau)^{\alpha-1}.k_\tau^{1-\alpha}\right] + \mathbb{E}_t\left[\lambda_{\tau+1}(1-\iota_\tau)\alpha a_\tau (n_\tau)^{\alpha-1}.k_\tau^{1-\alpha}\right] \quad \forall\tau$$

$$\frac{d\mathcal{L}}{dk_{\tau+1}} \quad : \quad E_t\left[\lambda_{\tau+1}.\left(\left(\iota_{\tau+1} - J(\iota_{\tau+1})\right).(1-\alpha)\,a_{\tau+1}(n_{\tau+1})^{\alpha}.k_{\tau+1}^{-\alpha} + (1-\delta) + \frac{\varkappa}{k_{\tau+1}}\left(\frac{k_{\tau+2}}{k_{\tau+1}}\right)\left(\frac{k_{\tau+2}-(1-\delta)k_{\tau+1}}{k_{\tau+1}}\right)\right)\right]$$

$$+E_t\left[\lambda_{\tau+2}.(1-\iota_{\tau+1}).(1-\alpha)\,a_{\tau+1}(n_{\tau+1})^{\alpha}.k_{\tau+1}^{-\alpha}\right] = \mathbb{E}_t\left[\lambda_\tau\left(1+\frac{\varkappa}{k_\tau}\left(\frac{k_{\tau+1}-(1-\delta)k_\tau}{k_\tau}\right)\right)\right] \quad \forall\tau$$

$$\frac{d\mathcal{L}}{d\iota_\tau} \quad : \quad \mathbb{E}_t\left[\lambda_\tau\left(1-J'(\iota_\tau)\right)y_\tau\right] = \mathbb{E}_t\left[\lambda_{\tau+1}.y_\tau\right] - \mathbb{E}_t\left[\kappa_\tau\right] \quad \forall\tau$$

$$\frac{d\mathcal{L}}{ds_{\tau+1}} \quad : \quad \mathbb{E}_t\left[\lambda_\tau\right] - \mathbb{E}_t\left[\mu_\tau\right] = E_t\left[\lambda_{\tau+1}.(1-\upsilon)\right] \quad \forall\tau$$

$$\frac{d\mathcal{L}}{d\lambda_\tau} \quad : \quad \mathbb{E}_t\left[c_\tau + s_{\tau+1} + k_{\tau+1} - (1-\delta)k_\tau - \frac{\varkappa}{2}\left(\frac{k_{\tau+1}-(1-\delta)k_\tau}{k_\tau}\right)^2\right] = E_t\left[(\iota_\tau - J(\iota_\tau)).y_\tau + (1-\upsilon).s_\tau + f_\tau\right] \quad \forall\tau$$

$$\frac{d\mathcal{L}}{d\kappa_\tau} \quad : \quad \mathbb{E}_t\left[\kappa_\tau \iota_\tau\right] = 0 \quad \forall\tau$$

$$\frac{d\mathcal{L}}{d\mu_\tau} \quad : \quad \mathbb{E}_t\left[\mu_\tau s_{\tau+1}\right] = 0 \quad \forall\tau$$

Therefore the equations defining the equilibrium are (using $\tau = t$):

$$
\begin{aligned}
& U_c'(c_t)\left(1+\frac{\varkappa}{k_t}\left(\frac{k_{t+1}-(1-\delta)k_t}{k_t}\right)\right) - E_t\left[\beta^2.U_c'(c_{t+2}).(1-\iota_{t+1}).(1-\alpha)\,a_{t+1}(n_{t+1})^{\alpha}.k_{t+1}^{-\alpha}\right] \\
&= E_t\left[\beta U_c'(c_{t+1})\left(\left(\iota_{t+1}-J(\iota_{t+1})\right)(1-\alpha)\,a_{t+1}(n_{t+1})^{\alpha}.k_{t+1}^{-\alpha}+(1-\delta)+\frac{\varkappa}{k_{t+1}}\left(\frac{k_{t+2}}{k_{t+1}}\right)\left(\frac{k_{t+2}-(1-\delta)k_{t+1}}{k_{t+1}}\right)\right)\right] \\
N_n'(1-n_t) &= U_c'(c_t).(\iota_t - J(\iota_t))\alpha a_t (n_t)^{\alpha-1}.k_t^{1-\alpha} + \mathbb{E}_t\left[\beta.U_c'(c_{t+1}).(1-\iota_t)\alpha a_t (n_t)^{\alpha-1}.k_t^{1-\alpha}\right] \\
U_c'(c_t).(1-J'(\iota_t))\,y_t &= \mathbb{E}_t\left[\beta.U_c'(c_{t+1}).y_t\right] - \kappa_t \\
U_c'(c_t) - \mu_t &= E_t\left[\beta.U_c'(c_{t+1}).(1-v)\right] \\
c_t + s_{t+1} + k_{t+1} - (1-\delta)k_t &= (\iota_t - J(\iota_t)).y_t + (1-v).s_t + f_t - \frac{\varkappa}{2}\left(\frac{k_{t+1}-(1-\delta)k_t}{k_t}\right)^2 \\
\ln a_{t+1} &= \rho \ln a_t + \varepsilon_t \\
\kappa_t &\geq 0, \quad \iota_t \geq 0 \\
\mu_t &\geq 0, \quad s_{t+1} \geq 0
\end{aligned}
$$

Numerical Solution

In each period, the model can be solved using the approximations of the expectation terms (given by equations (1.33)-(1.34)) as follows:

1. Assume that the agent does not wish to store any goods but rather wishes to bring forward consumption; $s_{t+1} = 0, \mu_t > 0,\ \kappa_t = 0$, and $\iota_t \geq 0$:

   (a) The intratemporal Euler equation for labour allocation (equation (1.15)) uses 1 approximation and is given by:

   $$N_n'(1-n_t) = U_c'(c_t).(\iota_t - J(\iota_t))\alpha a_t (n_t)^{\alpha-1}.k_t^{1-\alpha} + (1-\iota_t)\alpha a_t (n_t)^{\alpha-1}.k_t^{1-\alpha}.\beta.\Psi(a_t, k_t, D_t; \psi)$$

   (b) The intertemporal Euler equation for investment (equation (1.14)) uses 2 approximations to yield:

   $$U_c'(c_t).\left(1 + \frac{\varkappa}{k_t}\left(\frac{k_{t+1} - (1-\delta)k_t}{k_t}\right)\right) = \beta.\Omega(a_t, k_t, D_t; \omega) + \beta^2.\Theta(a_t, k_t, D_t; \theta)$$

   (c) Using $\kappa_t = 0$, and (1.16), and the approximating function for expected marginal utility, we get the relevant Euler equation as

   $$U_c'(c_t).(1 - J'(\iota_t)) = \beta.\Psi(a_t, k_t, D_t; \psi)$$

   (d) In this case, the budget constraint (equation (1.18)) can be written as:

   $$c_t + k_{t+1} - (1-\delta)k_t + \frac{\varkappa}{2}\left(\frac{k_{t+1} - (1-\delta)k_t}{k_t}\right)^2 = (\iota_t - J(\iota_t)).y_t + D_t$$

(e) The 4 equations in (a)-(d) solve the 4 choice variables $(c_t, n_t, k_{t+1}, \iota_t)$ and:

$$\begin{aligned} y_t &= a_t (n_t)^{\alpha} .k_t^{1-\alpha} \\ D_{t+1} &= f_{t+1} = (1-\iota_t).y_t \end{aligned}$$

(f) Calculate κ_t from (1.16); if $\kappa_1 \leq 0$, skip to step 4; else, move to step 2.

2. If $\kappa_t \geq 0$ then set $\iota_t = 0$ ($\implies$ $f_{t+1} = y_t$); and check whether the agent wishes to store any extra goods:

   (a) The intratemporal Euler equation for labour allocation uses 1 approximation and is given by:

   $$N_n'(1-n_t) = \alpha a_t (n_t)^{\alpha-1} .k_t^{1-\alpha}.\beta.\Psi(a_t, k_t, D_t; \psi)$$

   (b) The intertemporal Euler equation for investment again uses 2 approximations to yield:

   $$U_c'(c_t).\left(1+\frac{\varkappa}{k_t}\left(\frac{k_{t+1}-(1-\delta)k_t}{k_t}\right)\right) = \beta.\Omega(a_t, k_t, D_t; \omega)+\beta^2.\Theta(a_t, k_t, D_t; \theta)$$

   (c) Using $\iota_t = 0, \mu_t = 0$ and (1.17), and the approximating function for expected marginal utility, we get the relevant Euler equation as

   $$U_c'(c_t) = \beta.(1-\upsilon)\Psi(a_t, k_t, D_t; \psi)$$

   (d) In this case, the budget constraint (equation (1.18)) can be written as:

   $$c_t + s_{t+1} + k_{t+1} - (1-\delta)k_t + \frac{\varkappa}{2}\left(\frac{k_{t+1}-(1-\delta)k_t}{k_t}\right)^2 = D_t$$

   (e) The 4 equations in (a)-(d) solve the 4 choice variables $(c_t, n_t, k_{t+1}, s_{t+1})$ and:

   $$\begin{aligned} y_t &= a_t (n_t)^{\alpha} .k_t^{1-\alpha} \\ D_{t+1} &= y_t + s_{t+1} \end{aligned}$$

   (f) Calculate μ_t from (1.17); if $\mu_t \leq 0$, skip to step 4; else, move to step 3.

3. Set $\iota_t = s_{t+1} = 0$;

(a) The intratemporal Euler equation for labour allocation uses 1 approximation and is given by:

$$N_n'(1-n_t) = \alpha a_t (n_t)^{\alpha-1} .k_t^{1-\alpha}.\beta.\Psi(a_t, k_t, D_t; \psi)$$

(b) The intertemporal Euler equation for investment again uses 2 approximations to yield:

$$U_c'(c_t).\left(1+\frac{\varkappa}{k_t}\left(\frac{k_{t+1}-(1-\delta)k_t}{k_t}\right)\right) = \beta.\Omega(a_t, k_t, D_t; \omega)+\beta^2.\Theta(a_t, k_t, D_t; \theta)$$

(c) In this case, the budget constraint (equation (1.18)) can be written as:

$$c_t + k_{t+1} - (1-\delta)k_t + \frac{\varkappa}{2}\left(\frac{k_{t+1}-(1-\delta)k_t}{k_t}\right)^2 = D_t$$

(d) The 3 equations in (a)-(c) solve the 3 choice variables (c_t, n_t, k_{t+1}) and:

$$\begin{aligned} y_t &= a_t (n_t)^{\alpha} .k_t^{1-\alpha} \\ D_{t+1} &= y_t \end{aligned}$$

4. The model is solved for period t; repeat for process for next period.

Chapter 2

The Great Moderation and Inventories

2.1 Introduction

The Great Moderation (or Great Stability as it is called in the UK) is the term used to describe the decline in the volatility of business cycles that has occurred since at least the 1980s (see for example, McConnell and Perez-Quiros (2000), Stock and Watson (2002), and Blanchard and Simon (2001)). Benati (2004) documents a similar decline in macroeconomic volatility in the UK. Figure 2.1 displays quarterly real GDP growth for the US since 1960; the decline in volatility can be seen clearly. Nonetheless, Figure 2.2 plots the 10-year rolling variance of GDP growth in the US between 1960 and 2007.

While there is generally agreement that there has been a substantial decline in the standard deviation of output growth, there is some disagreement about whether this change took the form of a trend decline or a step change. Both McConnell and Perez-Quiros (2000) and Stock and Watson (2002) argue that there was a structural break in the variance of the GDP growth series which occurred in the early 1980s (around 1983). Blanchard and Simon (2001) on the other hand suggest that rather than just being a phenomenon since the 1980s, this decline in volatility is a steady one since the 1950s, but was interrupted in the 1970s and early 1980s.

There are many competing explanations for what caused this increased stability. The main three are "good policy", "good luck", and better inventory management[1]. The "good policy" argument emphasises the role of either less volatile fiscal policy (Blanchard

[1] Others, not discussed here, include the idea that it is driven by a shift from highly-volatile production to less-volatile service sectors. However, many papers, including McConnell and Perez-Quiros (2000) and Stock and Watson (2002), have examined this and found no evidence that compositional shifts play an important role. Also, Acemoglu, Johnson, Robinson, and Thaicharoen (2003) argue that reduced macroeconomic volatility is driven by improvements in the institutional framework.

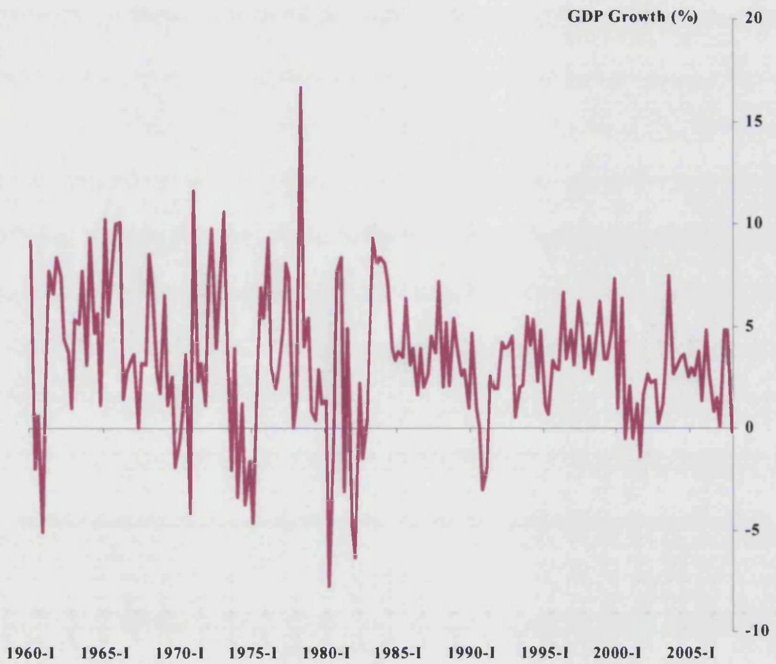


Figure 2.1: US Quarterly Real GDP Growth, 1960-2007

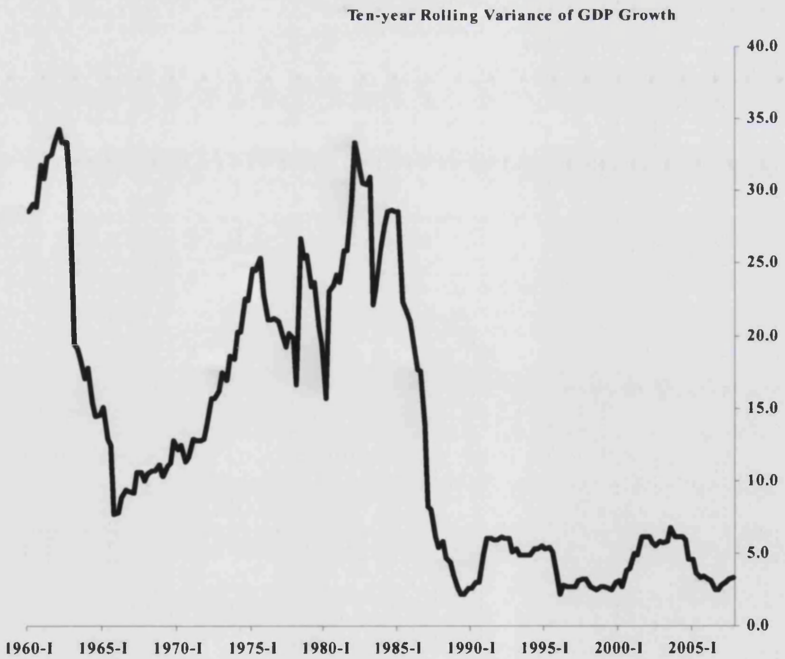


Figure 2.2: 10-year Rolling Variance of Quarterly US Real GDP Growth, 1960-2007

and Simon 2001), or more, often more activist monetary policy. The attractiveness of the monetary policy argument as an explanation for the Great Moderation in the US is the relatively close timing between the identified break in the volatility (around 1983), and the change in monetary policy in the US associated with the end of the Volcker disinflation (Taylor 2000). However, the timing does not work so well for other countries where the timing of the reduced volatility is similar, and this explanation is not consistent with the idea of a trend decline. In terms of fiscal policy, fiscal deficits have gone through a number of growing and shrinking phases since 1980, and the evidence suggests that automatic stabilisers have, if anything, weakened (Taylor 2000).

The "good luck" hypothesis argues that the greater stability is due simply to the absence of large shocks (such as the 1970s oil shocks) in the period since 1983. Justiniano and Primiceri (2006) and Stock and Watson (2002) tend to favour the "good luck" hypothesis; Stock and Watson attribute 20%- 30% of the volatility decline to improved monetary policy, and the rest to good luck.

Improved inventory management is the main explanation put forward by McConnell and Perez-Quiros (2000) and Kahn et al (2002). Their argument is that, with better inventory management, there is lower volatility of production for a given level of volatility of sales. Nonetheless, in the last 10 years, there has been an increase in research on the macroeconomic impact of inventories, partly to try to explain the Great Moderation. In particular, McConnell and Perez-Quiros (2000), argue that improvements in inventory management techniques, made possible by advances in information and communications technology, are the source of this lower volatility.

There is evidence, which I discuss in Section 2.2 of this paper, that supports the view that improved inventory management has played a role in the decline in the volatility of GDP, and the idea that improved inventory management has contributed to lower GDP volatility is pertinent amongst policy-makers[2]. However, in order to explore the implications of inventory management techniques on macroeconomic volatility, we need a model of the inventory behaviour that captures those motives for inventories that we believe have changed.

My contribution in this paper is to examine the role played by improved inventory management in explaining the Great Moderation using the model developed in Chapter

[2]For example, Charles Bean of the Bank of England said in a 2003 speech: "There are at least three possible explanations for this greater stability...Second, structural changes in the economy, possibly associated with the IT revolution and the advent of just-in-time production processes that have attenuated the amplification and propagation induced by the inventory cycle." While Bernanke (2004) reflects the Fed research on the topic, saying "Some economists have argued, for example, that improved management of business inventories, made possible by advances in computation and communication, has reduced the amplitude of fluctuations in inventory stocks, which in earlier decades played an important role in cyclical fluctuations."

1. There are many IT developments and management techniques which are likely to have led to improved inventory management; I examine them in Section 2.3. I then map the most salient features of these inventory management improvements into the baseline inventory model developed in Chapter 1. The aim of this experiment is to determine what variations in delivery and storage costs are required to capture the magnitude of the decline in output volatility in the United States since the mid-1980s. As the behaviour of inventories within my model is endogenously related to the volatility of shocks, I then perform a second exercise; I reduce the volatility of the supply shocks and see whether lower shock volatility (the "good luck" hypothesis) generates model predictions that fit the actual changes that have occurred in the last 23 years[3]

My main finding is that although there is little evidence to support the idea that inventory management techniques were a driving force in reducing aggregate volatility, these improvements appear to have played an important role in matching other changes in the aggregate data, such as a lower level and reduced procyclicality of the inventory-sales ratio. These other changes are not generated by the "good luck" explanation. I therefore conclude that the recent macroeconomic data are best explained by a combination of "good luck", which contributes to the lower volatility of GDP growth, and inventory management techniques, which help to match the behaviour of the inventory-sales ratio.

2.2 The Great Moderation

As mentioned above, the paper by McConnell and Perez-Quiros (2000) was one of the earliest papers to identify the Great Moderation.[4] They argued that the cause of the lower volatility was improved inventory management techniques. They identified the change as a step change occurring in the early 1980's (1983), and they traced this decline to a fall in the volatility of goods output which was driven by the reduced use of inventories in that sector. Thus, they conclude that it is changes in the use of goods inventories that has driven the lower volatility[5]. In this section I review some of the "smoking-gun" evidence that led them to conclude that the main explanation for the Great Moderation is inventory management techniques.

[3]Without any role for monetary policy in the model used in this paper, there is no scope to use it to explore the "good policy" hypothesis.

[4]Of course, there were much earlier analyses of the changing behaviour of GDP growth, such as DeLong and Summers (1986), but these did not identify the marked change in volatility around the early 1980s (the Great Moderation).

[5]Their argument that goods sales are unaffected is contested by Ahmed, Levin, and Wilson (2004) who find it was a decline in both sales and production volatility. Moreover, their analysis concludes that the main component of the goods inventories decline is durable goods. On the other hand, my analysis using the BEA's contributions data points to a clear role for non-durable goods inventories in explaining the decline of the variance of GDP growth.

Figure 2.3 shows the 10-year rolling variance of GDP growth in the US between 1960 and 2007, as well as the contributions to the variance from the goods output (further split into sales and inventories), services output ($y_t^{services}$), and structures output ($y_t^{structures}$). This graph uses the decomposition:

$$GDP_t = sales_t^{gds} + \Delta inventories_t^{gds} + y_t^{services} + y_t^{structures}$$

This graph supports the conclusions of McConnell and Perez-Quiros as the largest contributor to the appears to be goods inventories.

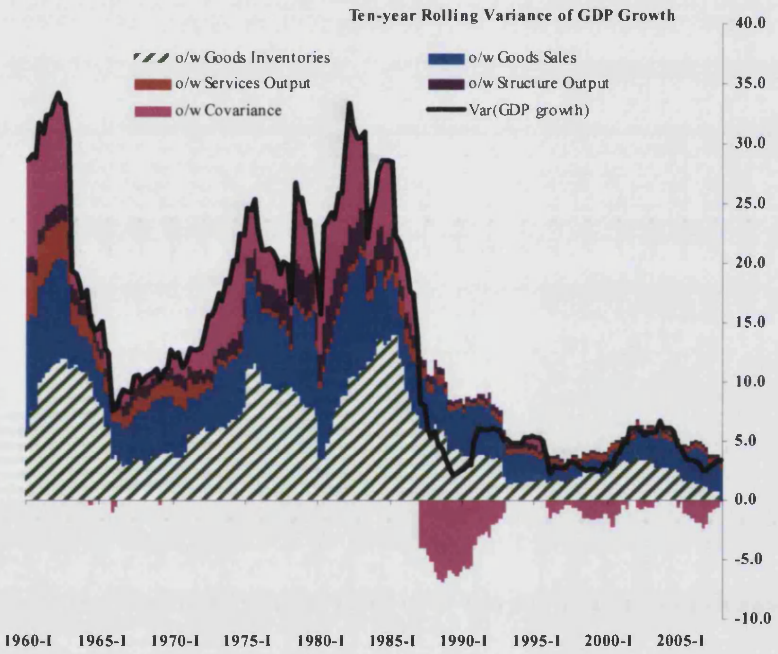


Figure 2.3: Ten-year rolling-variance of quarterly U.S. GDP growth and the contributions by types of product.

Figure 2.4 shows a similar disaggregation but now adds together all non-goods components together in order to focus on the goods sector, with goods output split further into the contribution from durable goods (D_goods) and non-durable goods (ND_goods). The decomposition used is:

$$GDP_t = sales_t^{D\text{-}goods} + \Delta inv_t^{D\text{-}goods} + sales_t^{ND\_goods} + \Delta inv_t^{ND\_goods} + others_t$$

Again this graph shows that there have been declines in both durable, and particularly, in non-durable goods inventories. However, the other main contributors to the decline are the lower covariance between durable and non-durable sectors, and the lower

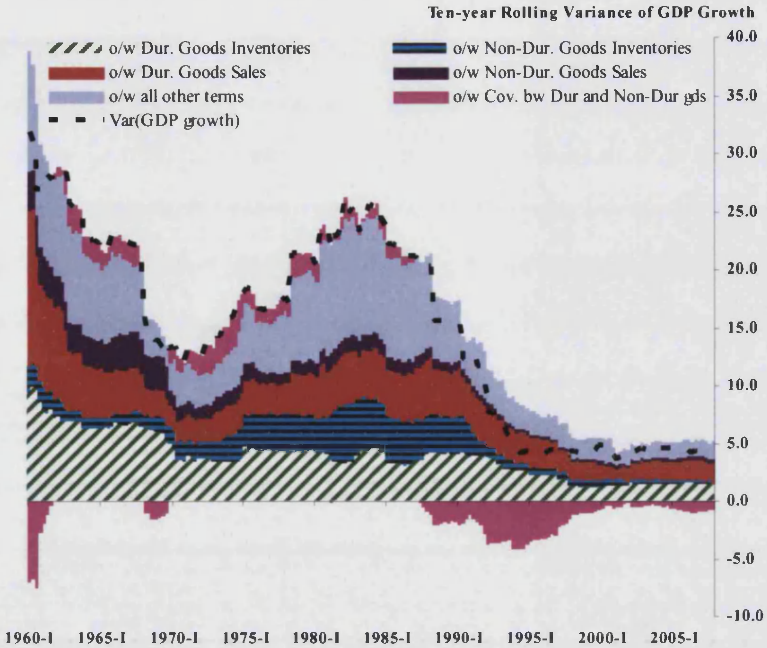


Figure 2.4: Ten-year rolling-variance of quarterly U.S. GDP growth and the contributions by types of product.

covariance between goods sectors and other sectors (which is a part of the "all other items" contribution).

Table 2.1 repeats the analysis of Table 1.1 but splits the 48 years between 1960 and 2007 into the two periods identified by McConnell and Perez-Quiros; a more volatile period from 1960-1983 and the Great Moderation era from 1984-2007. The variance of GDP growth during the Great Moderation is almost one-fifth of the variance from the earlier period (last column of the table showing the relative variance between periods). Moreover, there have been large declines in the main components of GDP between the two periods, albeit the declines are not as large as those in GDP volatility. This table also captures a key role for a decline in the covariance of the components of GDP which has swung from amplifying fluctuations in the components of GDP, to reducing them. Table 2.2 shows that a similar conclusion is reached if we disaggregate GDP according to the definition used in Figures 2.3 and 2.4.

The procyclicality of the inventory-sales ratio has changed as well in the post-1983 period. The correlation between the HP-filtered log I-S ratio and HP-filtered log GDP is -0.46 in the period including the 1970s, and increases to -0.15 in the period of the Great Moderation. There is, over the period of greater stability, also a coincident decline in both GDP volatility and the inventory-sales ratio. Figure 2.5 displays the real and nominal ratio of non-farm inventories to sales of goods and structures. Since the early

1980s, the ratio has declined by about 10% (from 2.53 in 1983 to 2.27 in 2007). However, if we look at the entirety of both periods, there is no change in the average I-S ratio between 1960 and 1983 when compared to the Great Moderation period. This a first indication that declining stock-sales ratios have not necessarily been a key element of the Great Moderation. The capital-output ratio, which is not shown in the figures, has, on average, not changed between the two periods.

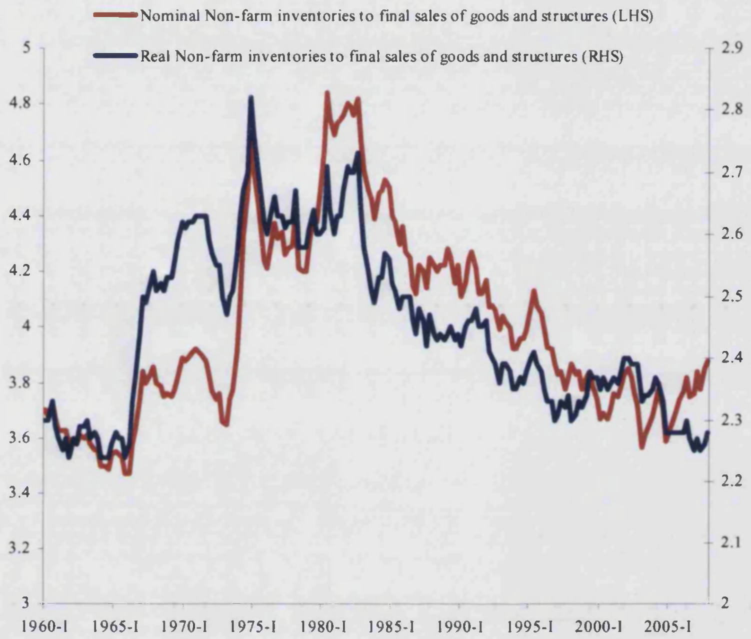


Figure 2.5: US Inventory-Sales Ratios: Real and Nominal.

2.3 Inventory Management

I now explore, using my model, the possibility that improvements in inventory management may have driven the decline in volatility of GDP. According to an industry website (www.inventorymanagement.com), inventory management refers to "the active control program which allows the management of sales, purchases and payments." The management of inventory encapsulates not only the monitoring and control of existing inventories but includes controlling their optimal level through the ordering of new stock at optimal times and the analysis of sales data as well. It is considered an important area in which companies can generate significant cost savings.

In recent years, particularly since the mid-1980s, inventory management has under-

Table 2.1: Contributions, by expenditure components, to changes in the volatility of US GDP growth, 1960-2007, S.A.A.R.

	1960-1983			1984-2007			Relative Variance
	Nominal GDP	Variance of	%	Nominal GDP	Variance of	%	$\frac{Var(1984+)}{Var(1960-1983)}$
	Share (%)	GDP growth	*of total*	Share (%)	GDP growth	*of total*	
GDP growth	100	19.9	*100%*	100	4.5	*100%*	0.22
of which							
Consumption	62	4.4	*22%*	67	1.6	*36%*	0.36
Investment	16	3.1	*15%*	16	1.1	*25%*	0.36
Δ Inventories	1	7.9	*40%*	0	2.6	*58%*	0.33
Government	21	1.8	*9%*	19	0.9	*20%*	0.49
Δ Net Trade	0	1.1	*6%*	-3	0.4	*10%*	0.40
Covariance		1.6	*8%*		-2.1	*-48%*	-1.31

Table 2.2: Contributions, by type of product, to changes in the volatility of US GDP growth, 1960-2007, S.A.A.R.

	1960-1983			1984-2007			Relative Variance
	Nominal GDP Share (%)	Variance of GDP growth	% *of total*	Nominal GDP Share (%)	Variance of GDP growth	% *of total*	$\frac{Var(1984+)}{Var(1960-1983)}$
GDP growth	100	19.9	*100%*	100	4.5	*100%*	0.22
of which							
Goods Sales	43	5.3	*27%*	35	2.4	*53%*	0.45
Δ Inventories	1	7.9	*40%*	0	2.6	*58%*	0.33
Services	45	1.1	*5%*	55	0.5	*11%*	0.46
Structures	11	1.8	*9%*	10	0.4	*9%*	0.22
Covariance		3.9	*20%*		-1.3	*-30%*	-0.34

gone major changes due primarily to the technological improvements[6]. The development of better IT (both hardware and software) have made it easier for firms to improve the management of demand and inventory (McCarthy and Zakrajsek (2007)). Such technologies include:

- Barcoding and scanners.
- Radio Frequency Identification Tags (RFID).
- Electronic Data Interchange (EDI) and Collaborative Planning, Forecasting and Replenishment (CPFR).

Barcodes and scanners, as well as Radio Frequency Identification Tags (RFID) have resulted in the improved the storage and control of inventories within and between warehouses. These inventions facilitate control and monitoring of inventory flows into and out of warehouses, without the need to investigate the contents of each box separately. With RFID tags it is possible to simply move past a shipment for a hand-held device to receive important information regarding the shipment (and to pass this information into a central database). These innovations reduce the marginal cost of storing and holding inventories both through time spent stock-keeping as well as reducing the loss through theft and obsolescence.

CPFR systems that have developed as a result of greater EDI technologies, provide a comprehensive system for the real-time analysis of sales and production data. This allows firms to distribute their goods more quickly and accurately to the outlets which require them, and it enables the firms to respond to changes in demand without the need to use inventories as a buffer. Overall, the combined effect of these improved technologies is that inventory managers have developed flexible distribution systems which actively manage inventories while still in the distribution chain.

These developments have led to three main changes in inventories; firstly, better analysis of sales data makes demand easier to monitor and therefore to forecast; secondly, the better control and monitoring of inventories; and finally, the active management of inventories in transit has reduced the overall costs of immediate delivery of produce to the final consumer. In the absence of demand shocks, I am unable to examine the implications of the first development. However, the latter two can be mapped into my framework as a reduction in costs of immediate delivery (w).

[6]Another problem with the improved inventory management story is that it would most likely have taken place gradually, rather than as a jump change in 1983 as McConnell and Perez-Quiros (2000) argue (Taylor 2000).

2.4 The Experiments

In order to explore how well the improved inventory management and "good luck" hypotheses perform as two possible explanations, I carry out a simulation analysis using the model of inventories that I developed in Chapter 1. I carry out three experiments. The calibration of the experiments is described in some greater detail below, but the basic idea of the experiments is:

1. Experiment 1 - "Improved Inventory Management"

   I model better inventory management techniques as lower costs of distribution, and then examine whether the model generates lower macroeconomic volatility that is comparable to the decline experienced during the "Great Moderation".

2. Experiment 2 - "Good Luck"

   I calibrate the decline in macroeconomic volatility using the changes in US TFP. While it is more directly going to generate lower volatility of GDP, the interesting test of this experiment is whether the inventory series change in accordance with the observed data is the result of "good luck".

3. Experiment 3 - "Both together"

   I run a combined experiment using the calibrations of both Experiment 1 and Experiment 2.

2.4.1 Details of the Calibration

As I use the Baseline Inventories model developed in Chapter 1, unless otherwise stated, all the calibration parameters come from Table 1.4. The alternative parameter values that are used in each experiment are displayed, at their monthly rate, in Table 2.4.

The first simulation, Experiment 1, maps the salient features of improved inventory management techniques into the models parameters as discussed above. Particularly, I reduce the cost of delivery such that the change in the steady-state inventory to sales ratio matches the actual decline from 1983 to 2007 (10%). To achieve this, the cost parameter associated with actively managing inventories (w) falls from 0.1 in the baseline model, to 0.0019 in Experiment 1.

The second simulation, Experiment 2, explores the "good luck" hypothesis and is designed to match the decline in volatility. In the Baseline model, I choose the AR(1) parameters to match the quarterly estimates of the following ARMA(1,1) equation:

$$\ln a^Q_{\tau+1} = \rho_z \ln a^Q_\tau + \varepsilon_t + \kappa \varepsilon_{t-1}$$

where the dependent variable, $\ln a^{Q}_{\tau+1}$, is the logged quarterly estimate of US TFP between 1961Q1 and 2006Q4. The data are detrended using a Hodrick-Prescott filter with the smoothing parameter set to 1600. These data are presented in Figure 2.6.

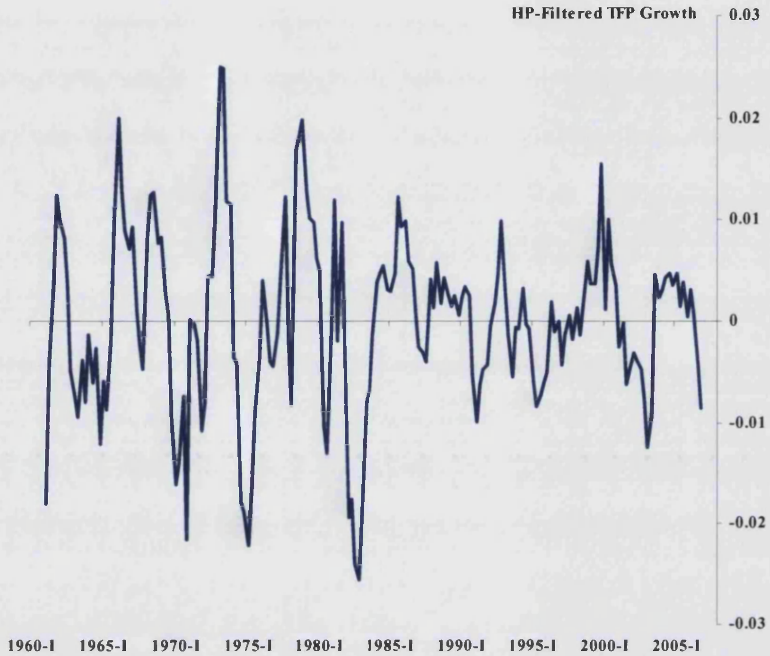


Figure 2.6: HP-filter Detrended US TFP.

The estimates from these equations are presented in Table 2.3. The first column corresponds to the estimates for the whole sample and corresponds to the values used in Chapter 1. Column 2 presents the estimates for the early period, while Column 3 presents the estimates for the Great Moderation period. The Pre-Moderation period had the same AR(1) coefficient as the overall sample, but higher volatility of the shocks, while the Great Moderation is characterised by lower volatility and higher persistence. As I need to calibrate a monthly estimate for the TFP process, I use the Monte Carlo approach discussed in Section 1.6 (Chapter 1) to derive the parameters for the Pre-Moderation Model and for Experiment 2. The values are presented in Table 2.4. As this will, by design, match the decline in aggregate volatility well, the test for Experiment 2 is whether it can match other features of the data that we associate with the Great Moderation such as the changing inventory-sales ratios and the reduced procyclicality of this ratio.

Experiment 3 combines the two explanations and explores the outcomes if both the "good luck" and better inventory management techniques play a role.

Table 2.3: Estimates of TFP process (ARMA(1,1)) Across Different Samples

	Full Sample	Pre-Moderation	Great Moderation
	1960 – 2006	1960 – 2006	1960 – 2006
ρ_z	0.69***	0.69***	0.76***
	(0.068)	(0.087)	(0.160)
κ	0.097	0.127	-0.038
	(0.078)	(0.098)	(0.110)
Constant	-0.000	-0.001	-0.001
	(0.002)	(0.003)	(0.002)
σ_z	0.006***	0.008***	0.004***
	(0.000)	(0.001)	(0.000)
Observations	184	88	96

Table 2.4: Parameters That Differ Across the Experiments

	Cost terms	AR(1) process	
Parameter	w	ρ_z	σ_z
Pre-Moderation Model	0.1	0.83	0.0069
Experiment 1 - Inventory improvement	**0.019**	0.83	0.0069
Experiment 2 - "Good Luck"	0.1	**0.87**	**0.0034**
Experiment 3 - Both together	**0.019**	**0.87**	**0.0034**

2.5 Results

The results in column 2 of Table 2.5 indicate that it is unlikely that declining costs of active inventory control could have generated the Great Moderation within my model. Lower costs of distribution actually increase the volatility of GDP growth. As was argued in Chapter 1, this is driven by the behaviour of labour hours; labour input is more volatile as the representative agent is more willing to take advantage of high (low) productivity by working hard (less) and using inventories to smooth consumption. Moreover, this adjustment comes at the cost of increasing the covariance between the main elements of GDP - when consumption and investment are falling, we run down inventories to smooth the negative growth period.

On the other hand, the "good luck" experiment matches the relative decline in GDP variance. This is unsurprising given that it was calibrated to achieve this result. But it cannot match other changes in the data. While the cheaper distribution experiment successfully lowers the inventory-sales ratio and reduces the counter-cyclicality of this ratio (slightly), neither of these are possible when we examine the "good luck" story alone. In fact, the reduced volatility of shocks makes the inventory-sales ratio more countercyclical.

Thus, it is not surprising that my final experiment, a combination of the two, is more successful at matching most of the relevant data. I would, therefore, conclude that the both stories are required to explain the recent behaviour of inventories and GDP volatility, although the "good luck" hypothesis contributes to the reduced variance of GDP growth.

2.6 Demand shocks

My results so far only allow for productivity shocks as a source of business cycle variation; Gali (1999), however, argues that demand shocks are a more likely source of business cycle variation. The main challenge posed by trying to take account of additional shocks is that adding another state variable increases the computational burden of the model considerably. Nonetheless, I make a small beginning here by examining a version of the model from Chapter 1 in which there are only taste shocks. I do this as it will give me an idea of whether the predictions of the analysis will be different under taste or preference shocks.

The model is solved using the PEA algorithm adapted for taste shocks. The main problem with the model using taste shocks is that it does not generate much volatility in terms of GDP. Using the same AR(1) parameters from the TFP process, but on an AR(1) for the taste variable ($\ln g_{\tau+1} = \rho \ln g_{\tau} + \epsilon_t$), yields volatility of HP-filtered GDP that is 12 times lower for the taste model compared with the TFP model.

However, the taste model does generate a large, negative covariance between components of GDP. The analysis has, therefore, convinced me that the observed falling covariance may be consistent with the a shift from supply to demand shocks after the end of the 1970s. This is suggested by Barnichon (2007). Therefore, in a model which includes both types of shock, the interaction of inventories, GDP and improved inventory management techniques may be greater. Developing this model further, therefore, is a priority area for research.

2.7 Conclusions

In this paper, I examine the impact on business cycle volatility of changes in the technology used to manage distribution inventories. In particular, I explore whether, according to my model, these technology changes can explain the decline in macroeconomic volatility in the last 30 years. Mapping the salient features of the improvements in inventory management into the parameters of my model, I find that although the inventory management changes are useful to match aspects of the changes in inventory behaviour over

Table 2.5: Great Moderation Experiments: Key ratios, Shares of GDP, and Contributions to the Variance of GDP Growth

	Pre-Moderation Model		Experiment 1		Experiment 2		Experiment 3	
	Level	*Rel. to Pre-Mod*	Level	*Rel. to Pre-Mod*	Level	*Rel. to Pre-Mod*	Level	*Rel. to Pre-Mod*
Var(GDP growth)	2.54	*1*	2.60	*1.02*	0.62	*0.24*	0.64	*0.25*
Capital-GDP ratio	2.7	*1*	2.7	*1*	2.7	*1*	2.7	*1*
Inventory-sales ratio	0.3238	*1*	0.29	*0.9*	0.32	*1*	0.29	*0.9*
$Corr\left(\frac{D}{S}, GDP\right)$	-0.25	*1*	-0.23	0.92	-0.59	2.4	-0.55	2.2

Table 2.6: Great Moderation Experiments: Key ratios, Shares of GDP, and Contributions to the Variance of GDP Growth

	Pre-Moderation Model	Experiment 1	Experiment 2	Experiment 3
	% of Var of GDP growth	*% of Var of GDP growth*	*% of Var of GDP growth*	*% of Var of GDP growth*
Consumption	1	1	1	1
Investment	61	49	60	50
Δ Inventory	28	15	26	13
Covariance	9	35	13	36

the period, they play no role in the reduction of the variance of GDP growth. In my model, the "good luck" hypothesis is a more likely explanation for the Great Moderation decline in volatility of GDP growth. However, the "good luck" hypothesis alone fails to match other developments in the aggregate data. These other developments are more closely matched by the inventory-management explanation. I therefore conclude that the two explanations have played a role in the behaviour of GDP since the mid-1980s.

My result is similar to the result in Khan and Thomas (2007b), and also in McCarthy and Zakrajsek (2007). In Kahn and Thomas' (s, S) model, to the extent that inventory improvements lowered the fixed costs of making an order, there would be little impact of such technology on macroeconomic volatility as sales become more volatile as inventory use is reduced. McCarthy and Zakrajsek (2007) conclude that inventory management has played only a reinforcing role in the Great Moderation.

However, even allowing for both improved inventory management techniques and "good luck", we miss a large part of the Great Moderation story. The combined experiment cannot match the decline in the covariance between components of demand, sectors of the economy, or types of product in the economy.

Nonetheless, the contribution of this paper remains. It has shown that the improved management of inventories has had, at best, a secondary role in the period of the Great Moderation. Instead, I conclude that the "good luck" hypothesis is a more likely explanation for the Great Moderation, though it is not the sole explanation.

Chapter 3

Assessing the Effectiveness of Mixed Committees: Evidence from the Bank of England MPC

3.1 Introduction

A dramatic change has occurred in how central banks around the globe determine monetary policy: responsibility for setting interest rates has shifted from individuals to committees. In fact, Pollard (2004) reports that ninety percent of eighty-eight surveyed central banks use committees to decide interest rates, underscoring their growing ubiquity. Although the trend is heavily in favour of collective decision making, some fundamental issues regarding the optimal structure of committees remain unclear. One of these is whether committee members should come from heterogeneous or homogeneous backgrounds. Some central banks, like the European Central Bank and US Federal Reserve, have committees composed solely of internal members (experts employed within the bank). Others, like the Bank of England and Reserve Bank of Australia, have committees that consist of internal as well as external members (experts who are not part of central bank staff).

The goal of this paper is two-fold. The first is to provide theoretical arguments in favour of mixed committees and the second is to examine whether the voting record of the Bank of England's Monetary Policy Committee (MPC) is consistent with these arguments. We build a model that allows a committee designer to select different kinds of experts to decide monetary policy. The model identifies two primary tasks for committee members. First, they communicate private information about economic shocks to each other prior to voting. We assume that members' private information is verifiable, which allows us to apply an unraveling argument to show that communication fully aggregates information. If different members have different dimensions of expertise, then mixing them together can lead to higher utility for the designer if members are sufficiently specialized.

The second task for members is to use the collective information set to select an appropriate interest rate. We allow members to differ in their beliefs about the correct interest rate given a history of economic shocks, and for the committee designer to consider all beliefs equally likely to be correct. Thus, when two experts disagree, the designer assigns the probability one-half that each member is correct. Nevertheless, if members' beliefs are public information, then the designer's preferred committee structure takes the form of an advisory board: all members provide information to the member with the most moderate belief. Hence, with publicly observed beliefs, there is no justification for giving members with different beliefs a vote on the committee.

If the designer cannot observe beliefs, then drawing members from two different distributions can improve the designer's utility if the means of each distribution lie at opposite extremes. In this case, mixing types from the two distributions can lead to a more moderate median voter than if the designer drew from just one distribution. Therefore, the justification for giving external members a voting role in addition to an advisory role must arise through their moderating influence on internal members.

We next turn to examining the voting record of the MPC. We begin by establishing cross-sectional differences between external and internal members, namely, that externals are: (1) more likely to deviate from the committee decision and from internal members; (2) vote for, on average, lower interest rates; and (3) have higher within-group voting dispersion. In themselves, these results are not surprising, and in fact have been documented by other authors as we discuss below.

The clearest prediction of our model concerns how voting behaviour changes over time. We obtain more original and interesting results when we examine voting dynamics. We find that the probability that external and internal members vote for different rates increases with time, and that the entire difference in voting behaviour between external and internal members arises from members who have been on the committee longer than twelve months. It is only at this point that external members begin voting for systematically lower rates. These results are important because they are inconsistent with the rationale for giving both externals and internals voting rights since they fail to moderate each other's views initially.

We then delve deeper into the sources of external behaviour and find an intriguing result: the entire drop in externals' voting levels arises from academics. We argue that this provides evidence of career concerns which influence the voting behaviour of non-academics as they face more future career uncertainty than academics, all of whom joined the MPC from tenured positions. To push the results further, we examine how externals' voting behavior changed in response to an exogenous change in the probability of reappointment. External members who served during periods in which reappointment was unlikely all began voting for lower rates after twelve months. This evidence is consistent with a story in which external members with career concerns mimic internal members through their tenure on the committee in order to increase their chances of reappointment.

Another possible cause of the voting differences, and one that is often discussed in the monetary literature, is that external members may have asymmetric preferences over inflation and output. In particular, external members may be more recession-averse meaning that they cut rates by more than internal members during downturns. We examine the evidence for this and find that although tests in isolation appear to provide evidence in favour of such preferences, we conclude that it is more likely that career concerns are the driving force.

We next set out a brief description of previous research on MPC voting behaviour before we explore our model more fully in Section 3.4. We then turn our attention to the data and the empirical analysis in the remaining sections. We conclude that the inclusion of external, together with internal, members on the MPC would create an unambiguous welfare gain if each group has specialized knowledge that it shares with the other, and that allowing external members to vote can also improve welfare under certain conditions. However, the evidence suggests that career concerns and the resulting failure of external members to moderate opinion, mean that these gains may be limited, or even negative. Our paper, therefore, highlights the need for a more complete model of reputation, taking account of its effect on the optimal design of mixed committees.

3.2 Previous Research on MPC Voting

There has been a great deal of research interest in committee behaviour. Blinder (2007) provides an excellent coverage of the issues relating to monetary policy committees. In the analysis below, we take for granted that there is transparency of voting behaviour of MPC members and that MPC meeting minutes are published; without such a design structure, the nature of our empirical work would be impossible. As a result our paper is not contributing to general discussion of whether having a committee influences monetary policy outcomes (interested readers are pointed toward Sibert (2006), Sibert (2003) and the references therein), or on the debate about optimal degree of transparency (see, for example, Geraats (2006) and Sibert (2002)).

Using an experimental set-up, Blinder and Morgan (2005) and Lombardelli, Proudman, and Talbot (2005) both conclude that committee decision making improves on the behaviour of individuals; although neither paper explicitly examines the behaviour of external members. Gerlach-Kristen (2006) constructs a model of monetary policy committee voting to formalize the idea that groups can outperform individuals, but does not explore strategic voting or communication. Li, Rosen, and Suen (2001) have studied the two-person committee voting problem in which members can report their non-verifiable private information strategically. They show that when members disagree about the correct decision, there is less than full reporting of private information. In this paper, committees fully aggregate information due to the verifiability of private information, which allows us to apply unraveling results (Grossman 1981, Milgrom 1981).

Numerous recent papers examine empirical differences in voting behaviour among MPC members. Gerlach-Kristen (2003), Spencer (2006), Harris and Spencer (2008), and Gerlach-Kristen (2009) all document the tendency of external members to dissent more often and to favour lower interest rates than internal members. Bhattacharjee and Holly (2005) and Besley, Meads, and Surico (2008) consider member heterogeneity more broadly, and find that there are systematic voting differences across members. None of these papers uncovers the growth of conflict on the MPC,[1] nor do they explore the normative implications of including internal and external members on the same committee. By and large, these papers assume member preferences derive from a weighted sum of inflation and output, with different members having different weights. However, such preferences alone are unable to explain our empirical results.

Unlike Spencer (2006) and Harris and Spencer (2008), we do find evidence of career concerns on the MPC. Our paper is also complementary to Meade and Stasavage (2008), who have found evidence of career concerns on the Federal Open Market Committee in the US.

3.3 MPC Background

Until 1997 the Chancellor of the Exchequer (the government official in charge of the Treasury) had sole responsibility for setting interest rates in the UK. One of Gordon Brown's first actions on becoming Chancellor in the government of Tony Blair was to set up an independent committee for setting interest rates in order to make monetary policy less arbitrary and susceptible to election cycles. The MPC first convened on 6 June 1997, and has met every month since. Majority vote determines the rate of interest. Its remit, as defined in the Bank of England Act (1998) (`http://www.bankofengland.co.uk/about/legislation/1998act.pdf`) is to "maintain price stability, and subject to that, to sup-

[1]However, Gerlach-Kristen (2003) does mention a delay in a member's first dissent: on average, it occurs after nine months.

port the economic policy of Her Majesty's government, including its objectives for growth and employment." In practice, the committee seeks to achieve a target inflation rate of 2%[2], based on the Consumer Price Index. If inflation is greater than 3% or less than 1%, the Governor of the Bank of England must write an open letter to the Chancellor explaining why. The inflation target is symmetric; missing the target in either direction is treated with equal concern.

The MPC has nine members; five of these come from within the Bank of England: the Governor, two Deputy Governors, the Chief Economist, and the Executive Director for Market Operations. The Chancellor also appoints four members (subject to approval from the Treasury Select Committee) from outside the Bank. There are no restrictions on who can serve as an external member. According to the Bank of England (`http://www.bankofengland.co.uk/monetarypolicy/overview.htm`), the purpose of external appointments is to "ensure that the MPC benefits from thinking and expertise in addition to that gained inside the Bank of England." Bar the governors, all members serve three year terms; the governors serve five year terms. When members' terms end, they can either be replaced or re-appointed. Through June 2008, 25 different members have served on the MPC – 11 internal members and 14 external members. Each member is independent in the sense that they do not represent any interest group or faction. The Bank encourages members to simply determine the rate of interest that they feel is most likely to achieve the inflation target.[3]

The MPC meets on the first Wednesday and Thursday of each month. In the month between meetings, members receive numerous briefings from Bank staff and regular updates of economic indicators. On the Friday before MPC meetings, members gather for a half-day meeting in which they are given the latest analysis of economic and business trends. On the Wednesday of the meeting, members discuss their views on several issues. The discussion continues on Thursday morning; each member is given some time to summarize his or her views to the rest of the MPC, and suggest what vote they favour (although they can, if they wish, wait to hear the others views before committing to a vote (Lambert 2006)). This process begins with the Deputy Governor for monetary

[2]This target changed from the RPIX to the CPI measure of inflation in January 2004, with a reduction in the inflation target from 2.5% to 2%.

[3]According to the Bank of England website (`http://www.bankofengland.co.uk/monetarypolicy/overview.htm`)

> Each member of the MPC has expertise in the field of economics and monetary policy. Members do not represent individual groups or areas. They are independent. Each member of the Committee has a vote to set interest rates at the level they believe is consistent with meeting the inflation target. The MPC's decision is made on the basis of one-person, one vote. It is not based on a consensus of opinion. It reflects the votes of each individual member of the Committee.

policy, concludes with the Governor, and other members are selected in random order in between. To formally conclude the meeting, the Governor suggests an interest rate that he believes will command a majority. Each member then chooses whether to agree with the Governor's decision, or dissent and state an alternative interest rate. The MPC decision is announced at 12 noon. Two weeks after each meeting, members' votes are published, along with minutes of the meeting with full, but unattributed comments.

We now set out a model that captures the essential institutional details of the MPC.

3.4 Committee Voting Model

3.4.1 Assumptions and set-up

The model has an infinite number of periods $t \in \{1, 2, ...\}$. The period t forecast for inflation at the horizon[4] is given by $\pi_t \sim N(\alpha_t + \theta - \beta r_t, \sigma^2)$ where α_t is a period t state variable that captures the history of shocks to hit the economy, $\theta \sim N(\overline{\theta}, \sigma_\theta^2)$ is a parameter related to the non-inflationary level of output and independent of α_t (for example, θ could capture the effect of long-run supply),[5] and β is a simplified monetary policy transmission mechanism.

We assume that α_t is persistent and is subject to two independent shocks, $s_t \sim N(0, \sigma_s^2)$ and $d_t \sim N(0, \sigma_d^2)$; in particular, $\alpha_t = \rho\alpha_{t-1} + s_t + d_t$ where ρ is the AR(1) persistence coefficient. The key issue is that economic conditions are not unidimensional, however, for the sake of the discussion, we shall refer to d and s as temporary demand and supply shocks.[6] This means we can write economic conditions as

$$\sum_{\tau=1}^{t} \rho^{t-\tau} (s_\tau + d_\tau).$$

There is a group of experts, each with period t preferences given by

$$-E\left[(\pi_t - \pi^*)^2\right], \tag{3.1}$$

[4]To reduce notation, we define this period t forecast inflation of inflation as π_t rather than $\pi t + h$. We shall also refer to this forecast as "current inflation".

[5]In the absence of transitory shocks, and assuming a constant interest rate $\overline{r}$, inflation will equal $\theta - \beta\overline{r}$. Thus, to meet their target, the central bank must ensure $E[\theta] - \beta\overline{r} = \pi^*$ holds. This equation defines the equilibrium real interest rate.

[6]Given our specification of how shocks impact expected future inflation, a positive supply shock would result in a negative s_t, while a positive demand shock would result in a positive d_t. Moreover, as the MPC members are only concerned with those shocks to which monetary policy reacts, we can think of s_t as the second round effects of supply shocks. Therefore, a positive s_t is the second round inflationary impact of the a negative supply shock (such as an oil price spike). An alternative could be to consider s_t as consumption (saving) shocks and d_t as investment (depreciation) shocks which both affect the level of demand and inflation.

where π^* is an exogenous inflation target. Thus, experts share the same preferences. However, they disagree in the sense that each believes that $\theta \sim N\left(\overline{\theta}_i, \sigma_\theta^2\right)$. Thus, experts do not necessarily agree on the distribution of inflation conditional on an interest rate. We assume that the prior beliefs on θ are common knowledge. In contrast, we assume that experts know g up to a constant, which can be absorbed into uncertainty about θ. While this assumption may seem strong, insider accounts from the MPC suggest that most disagreements are about economic conditions rather than the transmission mechanism.[7]

In every period, each expert receives verifiable private signals about the current shocks equal to $\widehat{s}_{it} = s_t + \varepsilon_i^s$ and $\widehat{d}_{it} = d_t + \varepsilon_i^d$, where $\varepsilon_i^s \sim N(0, \sigma_{is}^2)$ and $\varepsilon_i^d \sim N(0, \sigma_{id}^2)$. The paper will refer to the ratios $\gamma_i^s = 1/\sigma_{is}^2 \in (0, \infty)$ and $\gamma_i^d = 1/\sigma_{id}^2 \in (0, \infty)$ as the skill of member i in identifying s and d shocks, respectively. For example, as $\gamma_i^s \to 0$, member i has no useful private information about the supply shocks, and as $\gamma_i^s \to \infty$ he has near perfect knowledge of them.

The verifiability assumption on the private signals is key in the model. The motivation is that monetary policy experts arrive at their private views about the latest economic shocks through analyzing and interpreting economic data, reports and forecasts. This in turn means that when communicating their views to others, they can produce hard information to back it up. Thus, verifiability is a natural assumption given the model's application.

A committee designer (who one can think of as the government) with preferences

$$-\sum_{t=1}^{\infty} \delta^t E\left[(\pi_t - \pi^*)^2\right] \tag{3.2}$$

can appoint two experts to a committee that decides interest rates in a manner specified below. The designer receives no private information about the shocks. It also has higher-order uncertainty about the distribution of θ: it believes $\theta \sim N\left(\overline{\theta}, \sigma_\theta^2\right)$ and that $\overline{\theta} \sim U\left[-a, a\right]$. So, whereas the experts have a clear prior belief about θ, the designer does not. For consistency, we assume that for all members, $-a \leq \overline{\theta}_i \leq a$, so that the committee designer believes each member's view is correct with equal probability. The designer's incentives to appoint experts depend on what they can do once they join the committee, so to complete the model we describe this.

Once on the committee, and after receiving their private signals, experts (whom we call members hereafter) have the opportunity to communicate with each other prior to voting. For both $\widehat{d}_{it}$ and $\widehat{s}_{it}$, members simultaneously choose whether to disclose their

[7]For example, see Barker (2007). In addition, Bhattacharjee and Holly (2005) find heterogeneity in estimated individual policy reaction functions for MPC members, and argue that differences in the way individual members assimilate information supplied to them generate such differences.

Table 3.1: Distribution of Unique Votes Across Meetings

Unique Votes	Frequency	Percentage
1	47	35.3
2	81	60.9
3	5	3.8
Total	133	100

private information or not. One can characterize member i's strategy space with two sets Θ_{it}^d and Θ_{it}^s, with the interpretation that member i withholds his period t signals whenever $\widehat{d}_{it} \in \Theta_{it}^d$ and $\widehat{s}_{it} \in \Theta_{it}^s$. These sets are choice variables for each player i in each period t, and we solve below for their equilibrium structure. Because private information is verifiable, credible communication is not an issue.[8] Allowing communication is important in light of the extensive discussions that MPC members have with each other in the days leading up to the final vote. We assume that the committee designer does not observe what members communicate to each other, only the final decision that they take.

After sharing information with each other, the members simultaneously select an interest rate $r_{it} \in \{\underline{r}_t, \overline{r}_t\}$, where without loss of generality $\underline{r}_t < \overline{r}_t$. Table 3.1 provides a motivation for this assumption. In 96.2 per cent of meetings, members all vote for one or two interest rates, even though there are no restrictions (legal or otherwise) in place that prevent them from selecting other rates. We assume that if $r_{1t} = r_{2t} = \underline{r}_t$, then $r_t = \underline{r}_t$; that if $r_{1t} = r_{2t} = \overline{r}_t$, then $r_t = \overline{r}_t$; and that if $r_{1t} = \underline{r}_t$ and $r_{2t} = \overline{r}_t$, or $r_{1t} = \overline{r}_t$ and $r_{2t} = \underline{r}_t$, then member 1's preferred rate is chosen with probability p. This assumption simply says that the committee has a way of breaking ties, and that there is some non-zero probability that the tie could go either way. This is similar to the fact that the Governor of the Bank of England is charged with breaking any ties that remain after all other members have cast their votes.

After setting the interest rate r_t, all members observe the random variable $\widehat{\pi}_t = \pi_t + u_t$ where $u_t \sim N(0, \sigma_u^2)$ is again a white noise term. In other words, members receive information about the success they had in period t in achieving the inflation target before they vote in period $t+1$. This information could, for example, come from national accounts and other data releases, as well as Inflation Report projection updates which are regularly done within quarters to help interpret new data.

To summarize, the timing of the game is the following:

1. Members receive signals $\widehat{d}_{it}$ and $\widehat{s}_{it}$

2. Members simultaneously choose whether or not to disclose their signals to each

[8]One could allow members to send arbitrary messages to each other in the case where they do not provide verifiable information without altering the intuitions that underpin the solution of the model.

other

3. Members simultaneously vote for $\underline{r}_t$ or $\overline{r}_t$

4. r_t is implemented

5. Members observe π_t

3.4.2 Member Behaviour

This section solves the committee voting model laid out in the previous section by backward induction. It begins by deriving the Bayesian Nash Equilibrium of the voting stage given an arbitrary outcome of the communication stage, and then solves for the Bayesian Nash Equilibrium of the communication stage given equilibrium behavior in the voting stage.

Voting

There are two relevant parameters that a member needs to consider when selecting his vote in period t. The first is his estimate of current economic conditions α_t. We denote this estimate as $\widehat{\alpha}_{it} = E[\alpha \mid I_{it}]$, where I_{it} the information set of member i at time t. The second is his current belief about θ. We denote this by $\widehat{\theta}_{it} = E[\theta \mid I_{it}]$.

With strategic voting, agents have to take into account not only their private estimates of payoff-relevant parameters when selecting an optimal action, but also the strategies of the other players. A strategic effect potentially arises because when agents condition on their vote being pivotal, they might obtain information about other agents' private information. In this model, a strategic effect does not arise because each agent can independently influence the interest rate. For example, if member 1 votes for $\overline{r}_t$, then by also voting for $\overline{r}_t$, member 2 guarantees that $\overline{r}_t$ is the outcome. On the other hand, if member 2 instead votes for $\underline{r}_t$, then $\underline{r}_t$ is the outcome with probability p. Therefore, it is a dominant strategy for each member to maximize (3.1) conditional on his private information only.

Proposition 3.1 *Member i votes for $\overline{r}_t$ if and only if $\widehat{\alpha}_{it} \geq \alpha^*_{it}\left(\widehat{\theta}_{it}\right)$, where $\alpha^*_{it}\left(\widehat{\theta}_{it}\right)$ is strictly decreasing.*

To understand this result, it is first important to examine what interest rate member i would choose if he were not constrained to choose between $\underline{r}_t$ and $\overline{r}_t$. The proof of proposition 3.1 shows that the ideal interest rate r^*_{it} satisfies

$$\beta r^*_{it} + \widehat{\alpha}_{it} + \widehat{\theta}_{it} = \pi^*. \tag{3.3}$$

That is, if he could choose any interest rate, member i would choose the one that set the expected mean of the inflation distribution equal to the inflation target π^*. Moreover, one can easily show that preferences are single peaked in the sense that (3.1) is strictly declining as r_t moves away from r_{it}^*. To see the implications for voting behaviour, one can examine Figure 3.1, which plots out expected utility for member i given $\widehat{\alpha}_{it}$ and $\widehat{\theta}_{it}$, as well as examples of $\underline{r}_t$ and $\overline{r}_t$. Member i will choose the interest rate that maximizes his expected utility. In terms of the figure, this entails choosing $\underline{r}_t$ over $\overline{r}_t$.

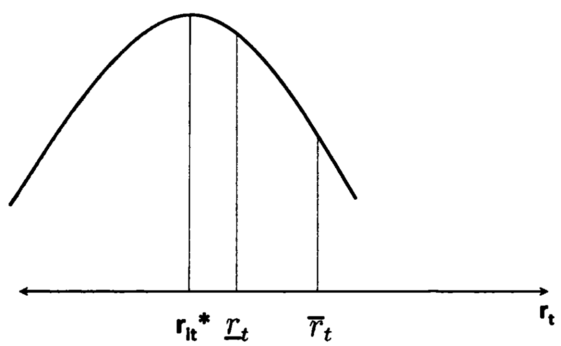


Figure 3.1: Member Preferences

We now turn to analyzing how voting depends on $\widehat{\alpha}_{it}$ and $\widehat{\theta}_{it}$. The top half of Figure 3.2 depicts the same preferences as in Figure 3.1, when the ideal interest rate for member i is r_{it}^*. We first consider what happens when $\widehat{\alpha}_{it}$ increases. In this case, member i believes more inflationary pressures have accumulated in the economy in period t, and his ideal interest rate increases. When $\widehat{\alpha}_{it}$ increases by enough, member i votes for $\overline{r}_t$ over $\underline{r}_t$, as demonstrated in the bottom half of the figure. One can therefore characterize member i's voting rule with a single parameter α_{it}^*: whenever $\widehat{\alpha}_{it} < \alpha_{it}^*$, he votes for $\underline{r}_t$, and whenever $\widehat{\alpha}_{it} \geq \alpha_{it}^*$, he votes for $\overline{r}_t$.[9]

We next consider what happens when $\widehat{\theta}_{it}$ increases. Now, for fixed beliefs about the temporary shocks, the ideal rate increases since member i believes long-term inflationary pressures are higher. The effect on preferences is the same as when $\widehat{\alpha}_{it}$ increases: the ideal rate increases. So, the preferences in the top half of Figure 3.2 shift to the right. This in turn decreases α_{it}^* since member i needs less evidence of temporary inflationary shocks to prefer the higher rate.

[9]Here, we have resolved indifference in favour of $\overline{r}_t$, an unessential assumption.

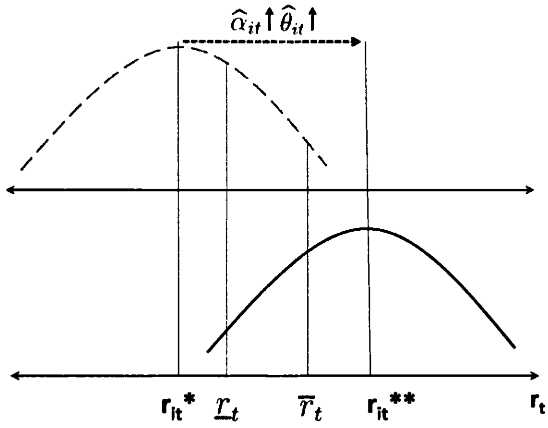


Figure 3.2: Member Preferences

Communication

Before discussing the equilibrium of the communication game, it is important to first discuss exactly how each member uses information in his decision-making. To begin, we focus on just the first period, and suppose that member 1 has a lower prior belief on θ than member 2 ($\overline{\theta}_1 < \overline{\theta}_2$). This means that member 1 requires evidence of higher temporary shocks to vote for the higher interest compared to member 2. Furthermore, instead of each member's signals being private information, we suppose that they are public information. By Proposition 3.1, member i votes for $\overline{r}_1$ if and only if $\widehat{\alpha}_{i1} \geq \alpha_{i1}^{*}$, where $\alpha_{11}^{*} > \alpha_{21}^{*}$.

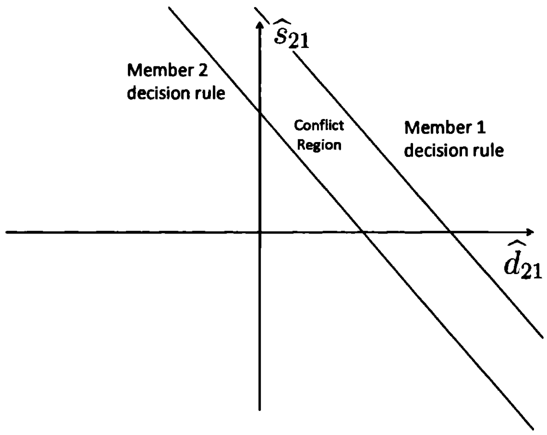


Figure 3.3: Decision Rules for Members 1 and 2 Given $\widehat{d}_{11}$ and $\widehat{s}_{11}$

Figure 3.3 graphically illustrates the decision rules of each member for fixed values of $\widehat{d}_{11}$ and $\widehat{s}_{11}$. Since both members' signals are mixtures of normal random variables, $\widehat{\alpha}_{i1}$ is linearly increasing in each signal. This means that we can represent member 1's decision rule (for a fixed $\widehat{d}_{11}$ and $\widehat{s}_{11}$) as a negatively sloped line in $\left(\widehat{d}_{21}, \widehat{s}_{21}\right)$ space that represent the combinations of member 2's signals at which $\widehat{\alpha}_{11} = \alpha^*_{11}$. All combinations of $\widehat{d}_{21}$ and $\widehat{s}_{21}$ that lie on or above this line lead member 1 to accept $\overline{r}_1$, and all combinations that fall below lead him to accept $\underline{r}_1$. Member 2's decision rule is simply member 1's shifted down by $\overline{\theta}_2 - \overline{\theta}_1$, the amount by which their beliefs on expected inflation for any realization of the signals differs.

There are three distinct regions that emerge from Figure 3.3. The first is realizations of $\left(\widehat{d}_{21}, \widehat{s}_{21}\right)$ that lie below the line $\widehat{\alpha}_{21} = \alpha^*_{21}$. In this region, both members agree that $\underline{r}_1$ is the correct interest rate. The second lies above the line $\widehat{\alpha}_{11} = \alpha^*_{11}$. Here, both members agree that $\overline{r}_1$ is the correct rate. The third region lies between $\widehat{\alpha}_{21} = \alpha^*_{21}$ and $\widehat{\alpha}_{11} = \alpha^*_{11}$. In this area, there is disagreement between the members: person 1 believes $\underline{r}_1$ is the correct rate, and person 2 believes that $\overline{r}_1$ is. This is the "conflict region" in which disagreement between the members arises. Its size is key to understanding the equilibrium.

One can now turn to analyzing the effects of communication when members privately observe their signals. For expositional purposes, we consider an equilibrium in which member 1 withholds some realizations of his demand shock, and always discloses his signal on the supply shock. When member 1 observes some $\widehat{d}_{11} \in \Theta^d_{11}$, he anticipates that person 2 will vote for $\overline{r}_1$ whenever

$$\widehat{\alpha}_{21} = E\left[\alpha_1 \mid \widehat{d}_{11} \in \Theta^d_{11}, \widehat{s}_{11}, \widehat{d}_{21}, \widehat{s}_{21}\right] \geq \alpha^*_{21}.$$

Figure 3.4 plots the line $\widehat{\alpha}_{21} = \alpha^*_{21}$ above which member 2 votes for $\overline{r}_1$. This line is the one furthest to the southwest. On the other hand, member 1 believes that the correct decision rule is to vote $\overline{r}_1$ whenever $\left(\widehat{d}_{21}, \widehat{s}_{21}\right)$ lies above $\widehat{\alpha}_{11} = \alpha^*_{11}$.

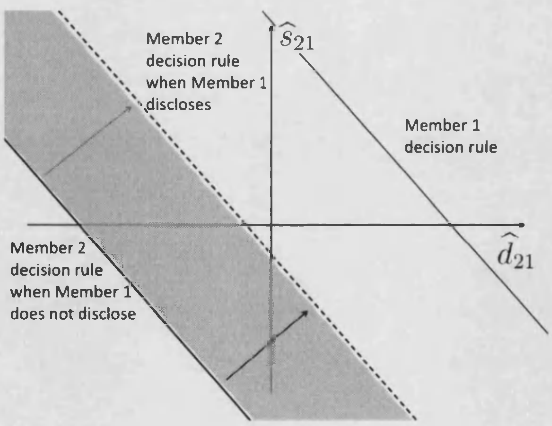


Figure 3.4: The Effect of Member 1 Disclosure on Member 2 Decision Rule

For an equilibrium to exist, it must be the case that member 1 actually wishes to withhold information whenever $\widehat{d}_{11} \in \Theta^d_1$. The inherent conflict between the two committee members is over the threshold at which the higher interest rate becomes appropriate. Member 1 would like to convince member 2 that the shocks are as small as possible in order to get him to vote for the high interest rate less often. Consider the incentives of member 1 when he observes some $\widehat{d}_{11} - \inf \Theta_1^d > \varepsilon$ for ε near 0. If member 1 shares this information with member 2 then

$$\begin{aligned} \widehat{\alpha}_{21} &= E\left[\alpha_1 \mid \widehat{d}_{11} \in \Theta_1^d, \widehat{s}_{11} \in \Theta_1^s, \widehat{d}_{21}, \widehat{s}_{21}\right] \\ &\geq E\left[\alpha_1 \mid \widehat{d}_{11}, \widehat{s}_{11} \in \Theta_1^s, \widehat{d}_{21}, \widehat{s}_{21}\right] \\ &= \widehat{\alpha}_{21}'. \end{aligned}$$

In other words, when member 1 discloses some $\widehat{d}_{11}$ that is one of the smallest elements in Θ_1^d, member 2 forms a lower belief on α than when member 2 withholds such a $\widehat{d}_{11}$. This happens because without disclosure, member 2 forms his belief on α_1 knowing only that $\widehat{d}_{11} \in \Theta_1^d$, so he takes the average over this set. With disclosure, member 2 infers d_1 to be lower, and so also adjusts his belief on α down. This in turn shifts member 2's decision rule to the northeast, as illustrated in Figure 3.4. For all $\left(\widehat{d}_{21}, \widehat{s}_{21}\right)$ in the shaded region, member 2 now votes for $\underline{r}_1$ instead of $\overline{r}_1$. Thus, from member 1's perspective, information disclosure reduces the probability that member 2 will take the wrong action, and strictly improves expected utility. In this way, any equilibrium without full information disclosure "unravels" since there is always some type that strictly prefers disclosing to withholding.

Proposition 3.2 *In the unique equilibrium of the communication game,* $\Theta_{it}^d = \emptyset$ *and* $\Theta_{it}^s = \emptyset\ \forall i, t$.

This result that communication on committees can indeed lead information aggregation, even when members have conflicting ideas about how to interpret each others' information.[10] It also echoes results in Grossman (1981) and Milgrom (1981), who demonstrate similar results in exchange economies with adverse selection.

Learning

We have concluded that behaviour consists of full sharing of private information followed by all members' voting for their preferred interest rate in every period. One might then wonder what a dynamic structure adds to the model. The answer lies in the release of the inflation signal $\widehat{\pi}_t$. While members enter the committee with heterogeneous priors on θ, they are able to adjust their views when they obtain information on how the interest

[10]The verifiability of private information is crucial for establishing this result. Okuno-Fujiwara, Postlewaite, and Suzumura (1990) show that full information revelation need not occur if even some private information is not verifiable.

rate chosen by the committee maps into actual inflation. Since the demand and supply shocks are not correlated with θ, the communication of private signals does not allow for learning.

3.4.3 Mixed committees and welfare

So far, we have discussed two dimensions of member behavior: communication and voting. We now show how each dimension provides a margin on which mixed committees can affect welfare.

Information aggregation and welfare

The first result of our model formalizes the idea that mixed committees can add value to society due their ability to draw on members' diverse expertise.

Proposition 3.3 *For small enough a, there exist numbers $0 < \underline{d} < \overline{d}$ and $0 < \underline{s} < \overline{s}$ such that a committee composed of solely of members with $\gamma_i^d < \underline{d}$ and $\gamma_i^s > \overline{s}$ or solely of members with $\gamma_i^d > \overline{d}$ and $\gamma_i^s < \underline{s}$ will yield the committee designer a lower expected utility than a committee composed of a mixture of these types.*

To understand the intuition of this result, suppose there are only two types of experts, both of whom agree with the committee designer that $\theta \sim N(0, \sigma_\theta^2)$:[11] d-types perceive d perfectly ($\gamma_i^d \to \infty$) but have no private information about s ($\gamma_i^s = 0$); s-types perceive s perfectly ($\gamma_i^s \to \infty$) but have no private information about d ($\gamma_i^d = 0$). Once on the committee, either type will share his information with the other. When they make interest rate decisions, a committee with just d-types will therefore know d but know nothing about s, and a committee with just s-types will know s but know nothing about d. On the other hand, a mixed committee will know both d and s. Since both types agree with the committee designer about the appropriate interest rate, a mixed committee yields the designer strictly higher utility, since it has more information on which to base its decision.

This result is important because it shows that a committee composed of members with different kinds of policy-making expertise can produce a better outcome for society, even if the members do not agree perfectly about the right course of action. The key to the argument is information aggregation, since members have access to each other's expertise when they vote.

[11]The relationship between member information and designer utility is not clear when there is the possibility for members to be very far from the correct belief about θ.

Belief diversity and welfare

We have said nothing so far about voting per se. The previous result shows that information aggregation can lead to better outcomes for some level of belief diversity, but now we ask another question: whether there is a value to having a diversity of beliefs among committee members for its own sake. To isolate this issue, we assume for the moment that members' identities do not affect the amount of information to which committee members have access.

Proposition 3.4 *Suppose that members observe public information about the d and s shocks prior to voting, and have no private information. Furthermore, suppose that* $\overline{\theta}_1 = \overline{\theta}_2 = \overline{\theta}'$. *The committee designer's welfare is strictly decreasing in* $\left|\overline{\theta}'\right|$.

While the committee designer believes that all prior beliefs about θ between $-a$ and a are equally likely, the designer is not indifferent among members with these different beliefs. The more moderate the beliefs of the committee members—in the sense of distance from 0—the better off the designer is. To see the intuition for the result, an example is helpful. Suppose that $a = 1$ and the designer can appoint members for whom $\overline{\theta}_i = 0.5$ or for whom $\overline{\theta}_i = 0.75$. Then, whenever $\overline{\theta} < 0.5$, the former types take the correct decision more often. But, since $\overline{\theta} < 0.5$ is more likely than not given the distributional assumption on $\overline{\theta}$, the expected utility from the more moderate belief is higher. This has an immediate and important implication for committee design.

Corollary 3.1 *Suppose member beliefs are public information and* $\overline{\theta}_1 \neq \overline{\theta}_2$. *Then the committee designer's welfare is highest either as* $p \to 0$ *or* $p \to 1$.

p is the parameter that measures the probability that member 1's preferred rate is chosen when he conflicts with member 2. Moreover, its value does not affect the communication behavior of any member because as long as there is some probability of everyone's vote mattering, each member would like to influence the other through information disclosure. The designer can thus choose p without altering the amount of information that each member has when selecting rates. Therefore, if the designer can observe member's prior beliefs about θ, it should give full decision authority to the member with the more moderate belief. In other words, it can appoint members as advisors to the decision maker, without giving them any responsibility for decision making.

Corollary 3.1 has the important implication that a committee with heterogeneous beliefs can only benefit the designer if it does not observe members' priors. If this is the case, appointing members with different (expected) beliefs can moderate the outcome.

In order to see this, one must move beyond a two-person committee and consider the possibility of larger groups. Suppose that the designer can draw members from one of two groups. The first group has members with beliefs distributed $U\left[-a, \frac{a}{2}\right]$ and the second has members with beliefs distributed $U\left[-\frac{a}{2}, a\right]$. By appointing half the members from the first group and half the members from the second, the designer ensures moderation for a large enough committee size, since the median voter's belief converges to $\overline{\theta}_i = 0$ as the committee size becomes large. If it only appointed members from one of the two groups, the median voter's belief converges to $\left|\overline{\theta}_i\right| = \frac{a}{4}$, resulting in a utility loss relative to the mixed committee.

In terms of our application to the MPC, there would be a justification for including externals as *voting* (as opposed to advisory) members if the UK government felt that they balanced the views of internal members to yield a more moderate outcome. One might suspect that when we look at the data we will find differences in voting behavior between members—and indeed we do. The question is whether the differences we observe are consistent with moderation. Our final theoretical result provides a useful test.

Proposition 3.5 $\Pr\left[r_{1t} \neq r_{2t}\right] \xrightarrow{p} 0.$

Different beliefs about θ lead to a positive probability of members' selecting different interest rates; however, after each period, members have the opportunity to adjust their beliefs, and results from statistical theory (Blackwell and Dubins 1962, Savage 1972) show that members' beliefs about θ converge when they are exposed to a sufficient amount of information about the relationship between interest rates and inflation. Therefore, the probability of members' voting for different interest rates becomes negligible after they have sat for long enough together on the committee. In an N-person committee, one can simply apply this result to each pair of members to generate the same result.

3.5 Data

In order to test Proposition 3.5 we use the MPC voting records between July 1997 and June 2008 (data available from `http://www.bankofengland.co.uk/monetarypolicy/decisions.htm`). The data contain a record of every decision ($decision_t$) taken by the MPC, as well as each member's vote in each meeting ($vote_{it} = \Delta r_{it}$).[12] Before June 1998 there is information about whether members preferred higher or lower interest rates compared with the decision, but not about their actual preferred rate. In these cases, we treat a member's vote as either 25 basis points higher or lower than the decision, in the

[12] We express members' votes in terms of their preferred change in interest rates rather than their preferred level. This makes no difference to the results.

direction of disagreement. The Bank website also provides information on which members were external appointments and which were internal. For every member we gathered biographical information, including previous occupation, educational background, and age from press releases associated with their appointment and from information provided to the Treasury Select Committee ahead of their confirmation.

We drop the emergency meeting held after September 11th 2001 from our dataset for the programming convenience of having only one meeting per month. This does not affect our results: in the meeting after 9/11, voting was unanimously in favour of lowering interest rates, so it would not be used for econometric identification given our use of time fixed effects. Howard Davies served on the MPC for the first two meetings and is the only member who voted exclusively on unanimous committees and thus his inclusion/exclusion is unimportant for econometric identification; although we include him in our baseline regressions. Lord George, the Governor for most of our sample, always voted with the majority regardless of his starting position; as a result we think that these voting records do not represent his own views in all cases. Even under the governorship of Mervyn King, the Governor has only deviated twice since taking office in July 2003. Nonetheless, we include the observations for the Governor in the regression results presented below, though all of the results stand if we exclude the data on the Governor at each meeting.

In Table 3.2 we provide summary statistics of the individual members on the MPC. Of the 25 MPC members that we consider in our sample, 14 are external and 11 are internal as indicated by the variable[13]

$$INT_i = \begin{cases} 0 \text{ if member i is an external member} \\ 1 \text{ if member i is an internal member} \end{cases}$$

The average vote shows the mean of all votes cast by the member during their time on the MPC within our sample; this is driven largely by when a member served on the committee. The variance column reports the analogous second-moment for the voting data. Table 3.2 also shows that the educational background of both groups is heterogenous and that both groups contain members who worked as academics prior to their appointment ($acad_i = 1$).

In our model, the committee has two members each of whom can choose two interest rates, so the probability of their not agreeing on the correct rate is the only natural measure of disagreement. On the actual MPC there is not just one internal member and one external member, but many of each. Therefore, determining the correct measure of disagreement is not as straightforward. We therefore explore several possibilities for

[13]No member has so far served as both an external member and an internal member, though there is nothing that prohibits this from happening in the future

Table 3.2: Sample Statistics by Member

Member	INT_i	Average Vote	Variance of Vote	Education	$Acad_i$	Meetings
A. Sentance	0	0.07	0.026	Prof/PhD	0	21
C. Goodhart	0	0.01	0.050	Prof/PhD	1	36
C. Allsopp	0	-0.13	0.020	Masters/Accountancy	1	36
D. Blanchflower	0	-0.11	0.032	Prof/PhD	1	25
D. Walton	0	0.00	0.023	Masters/Accountancy	0	12
D. Julius	0	-0.12	0.036	Prof/PhD	0	45
K. Barker	0	-0.01	0.020	Undergraduate	0	85
M. Bell	0	-0.01	0.018	Masters/Accountancy	0	36
R. Lambert	0	0.02	0.013	Undergraduate	0	34
A. Budd	0	-0.06	0.070	Prof/PhD	0	18
S. Nickell	0	-0.05	0.028	Prof/PhD	1	72
S.Wadhwani	0	-0.11	0.041	Prof/PhD	0	36
T. Besley	0	0.07	0.025	Prof/PhD	1	22
W. Buiter	0	0.00	0.105	Prof/PhD	1	36
C. Bean	1	-0.02	0.017	Prof/PhD	1	93
D. Clementi	1	-0.04	0.034	Masters/Accountancy	0	60
I. Plenderleith	1	-0.03	0.034	Masters/Accountancy	0	60
J. Vickers	1	0.00	0.060	Prof/PhD	1	28
M. King	1	0.02	0.027	Prof/PhD	0	133
P. Tucker	1	0.03	0.014	Undergraduate	0	73
R. Lomax	1	0.02	0.010	Masters/Accountancy	0	60
A. Large	1	0.07	0.016	Masters/Accountancy	0	40
E. George	1	-0.03	0.029	Undergraduate	0	73
J. Gieve	1	0.01	0.024	Undergraduate	0	29
H.Davies	1	0.25	0.000	Masters/Accountancy	0	2

measuring conflict.

The first measure (and the one most common in the literature) is whether a member deviates from the majority of members on the committee. We therefore define the variable

$$D\left(Dev\_MPC\right)_{it} = \begin{cases} 0 \text{ if } \Delta r_{it} = decision_t \\ 1 \text{ if } \Delta r_{it} \neq decision_t \end{cases}$$

However, a measure of disagreement that is closer in spirit to our model would explicitly measure conflict between externals and internals, not compare each member against the majority. We therefore construct a second dummy variable that measures when internal (external) members deviate from the modal vote of the external (internal) group. This variable more closely captures disagreements between internals and externals on the committee. Defining the modal vote of the subset of internal (external) members in period t as $decision_t^{INT=1}$ ($decision_t^{INT=0}$), we can define:

$$D\left(Dev\_group\right)_{it} = \begin{cases} 0 \text{ if } \Delta r_{it} = decision_t^{INT=1} \& INT_i = 0 \\ 0 \text{ if } \Delta r_{it} = decision_t^{INT=0} \& INT_i = 1 \\ 1 \text{ if } \Delta r_{it} \neq decision_t^{INT=1} \& INT_i = 0 \\ 1 \text{ if } \Delta r_{it} \neq decision_t^{INT=0} \& INT_i = 1 \end{cases}$$

One issue that arises with this approach is that the modal vote among externals is not always uniquely defined; in 20 of the 133 meetings in our sample the external vote distribution is bimodal. Therefore, we need to decide between these two modes. One of the two external modes always corresponds to the mode of the internal members (which is always unique). In the construction of $D\left(Dev\_group\right)_{it}$ we set $decision_t^{INT=0} = decision_t^{INT=1}$ whenever $decision_t^{INT=0}$ is multi-valued. This reduces the number of group deviations in the sample and so may bias us toward finding support for our model. However, we also define an alternative dummy variable called $D(Dev\_group\_alt)_{it}$, which is defined similarly to $D\left(Dev\_group\right)_{it}$, except with $decision_t^{INT=0} \neq decision_t^{INT=1}$ whenever $decision_t^{INT=0}$ is multivalued.

Table 3.3 compares how frequently members deviate according to each of our measures. While the internal and external groups each contain members who deviate more and less often in all three senses, the tendency is clearly for external members to deviate from the committee decision more often than internal members. Indeed, differences along these lines have already been pointed out by Gerlach-Kristen (2003). The table also highlights that, according to the $D(Devgroup)\_it$ measure, externals deviate more frequently with internals than vice versa. This is perhaps unsurprising given the greater within-group dispersion among externals combined with the fact that $D(Devgroup)\_it$ equates the modal votes of internals and externals when the external votes is bimodal. Once we use the alternative group mode for external members, internal and external members have much more similar patterns of deviation from the other group.

Disagreement is in general quite common. For instance, in 14% of the observations of $D\left(Dev\_MPC\right)_{it} = 1$. While this number might seem quite low, we find that 65% of the 133 meetings in our sample have at least one deviation from the committee majority. Figure 3.5 shows the level of interest rate chosen by the MPC, where the markers indicate the votes of individual members; deviations from the majority are those that are off the MPC decision line. These deviations occur regularly and not just around turning points in the interest rate cycle (marked with shading on the figure).

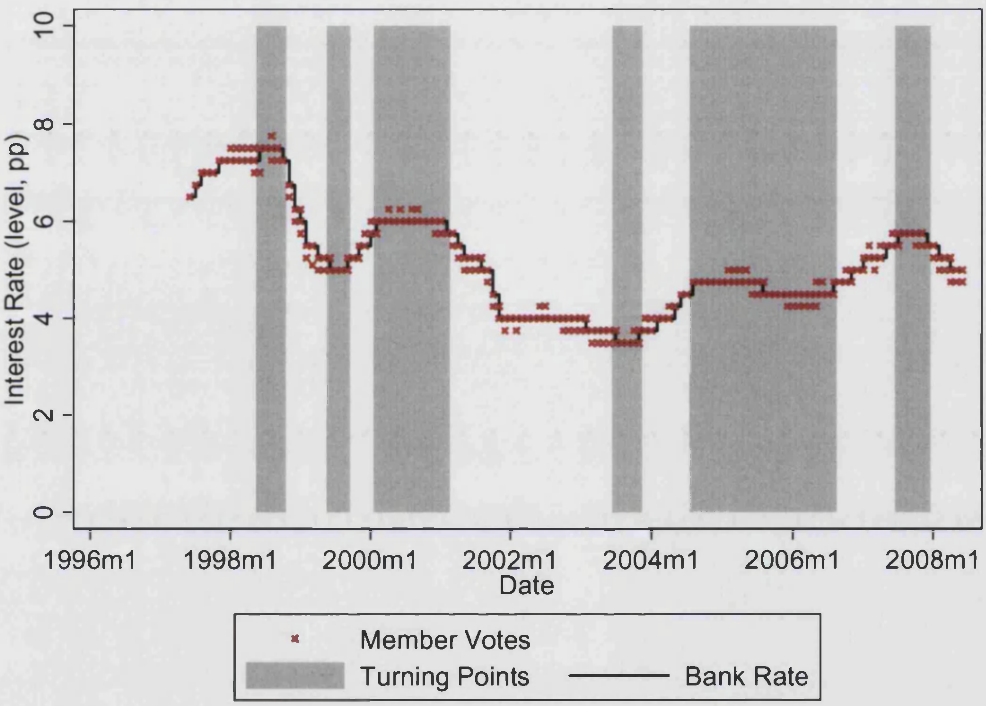


Figure 3.5: Votes and Decisions of the Monetary Policy Committee

The fact that there are numerous disagreements within the MPC is not surprising. What is unclear is what generates these differences. This paper argues that there are two likely candidates. The first is divergent beliefs. Even though members share the same access to data as each other, and communicate their views extensively with each other, they can still have fundamentally different beliefs about the inflationary pressures facing the economy. The second is preferences. Members can have fundamental differences in what they hope to achieve when selecting interest rates. As our model shows, these two stories are empirically distinguishable. If members differ because of beliefs, then

Table 3.3: Total and Percentage Deviations using 3 Different Approaches, by Member

Member			$D(Dev\_MPC)_{it}$		$D(Dev\_group)_{it}$		$D(Dev\_group\_alt)_{it}$	
	INT_i	Meetings	Total	% Deviations	Total	% Deviations	Total	% Deviations
A. Sentance	0	21	5	23.8	6	28.6	6	28.6
C. Goodhart	0	36	3	8.3	3	8.3	3	8.3
C. Allsopp	0	36	10	27.8	13	36.1	13	36.1
D. Blanchflower	0	25	13	52.0	12	48.0	12	48.0
D. Walton	0	12	3	25.0	4	33.3	4	33.3
D. Julius	0	45	13	28.9	15	33.3	15	33.3
K. Barker	0	85	5	5.9	8	9.4	8	9.4
M. Bell	0	36	5	13.9	5	13.9	5	13.9
R. Lambert	0	34	0	0.0	1	2.9	1	2.9
A. Budd	0	18	4	22.2	4	22.2	4	22.2
S. Nickell	0	72	17	23.6	17	23.6	17	23.6
S.Wadhwani	0	36	12	33.3	15	41.7	15	41.7
T. Besley	0	22	5	22.7	6	27.3	6	27.3
W. Buiter	0	36	16	44.4	16	44.4	16	44.4
C. Bean	1	93	5	5.4	7	7.5	23	24.7
D. Clementi	1	60	4	6.7	8	13.3	15	25.0
I. Plenderleith	1	60	5	8.3	9	15.0	14	23.3
J. Vickers	1	28	5	17.9	5	17.9	8	28.6
M. King	1	133	14	10.5	19	14.3	35	26.3
P. Tucker	1	73	7	9.6	12	16.4	21	28.8
R. Lomax	1	60	5	8.3	7	11.7	14	23.3
A. Large	1	40	9	22.5	13	32.5	16	40.0
E. George	1	73	0	0.0	7	9.6	20	27.4
J. Gieve	1	29	3	10.3	4	13.8	8	27.6
H.Davies	1	2	0	0	0	0	0	0

differences between members should become less pronounced.

3.6 Econometric Modelling and Results

The primary goal of this section is to examine the time path of individual voting behaviour on the MPC in order to shed light on the source of conflict within the MPC. It first analyzes how the probability of deviating evolves, and then turns to looking at the actual votes that members cast. The main result is that on a variety of measures, conflict *increases* with time, leading us to conclude that members are likely to have differences arising from their preferences; we will explore the main two potential preference differences.

3.6.1 Probability of Deviating

The measures of deviation we introduced in the previous section are all dummy variables, so ordinary least squares (OLS) will produce inconsistent estimates. Instead, we adopt the regression model:

$$\begin{aligned} \text{logit}\left(D\_dev_{it}\right) &= \alpha + \lambda \cdot z_i + \psi_1 \cdot INT_i + \psi_2 \cdot exp_{it} + \psi_3 \cdot (INT_i exp_{it}) \\ &\quad + \sum_t \tau_t \cdot Time_t + \sum_T \delta_T \cdot Q_T + \sum_j \kappa_j \cdot COM_j + \varepsilon_{it} \end{aligned} \tag{3.4}$$

where:

- D_dev_{it} is the deviation outcome variable of interest;
- INT_i is the internal dummy variable defined earlier;
- exp_{it} is a dummy variable indicating that a member has experience on the committee (defined below in more detail);
- z_i are time-invariant individual characteristics;
- $Time_t$ are monthly dummy variables (month fixed effects);
- Q_T are quarterly dummies (quarter fixed effects);
- COM_j is a committee fixed effect

The two sets of time fixed effects control for the variation in voting behaviour that is common to each period of time, such as variations in the business cycle. We include, in addition to month fixed effects, quarter fixed effects to capture the fact that some key information is quarter specific (national accounts data, as well as the Bank's own forecast). An alternative was to include data on inflation and GDP, as well as the information that comes from Bank of England quarterly forecast meetings as controls; this approach does not alter the conclusions of our work.

As a further control, we also include committee fixed effects. In the regressions we run, there is a separate dummy variable for each unique combination of committee members in our sample. This is potentially important if a member's vote (and the extent to which it conflicts with other members') is affected by the identity of the other committee members. These committee fixed effects require inclusion of a separate dummy variable for *every* different committee composition that has met. Therefore, if a member leaves the committee and is replaced by a new member, this represents a new committee composition and so a new dummy variable. Also, if a member is absent and so only 8 members meet in a particular month, then this committee composition is also different and so controlled for separately.

In order to ensure that INT_i is not capturing the effects of other variables that are correlated with being an internal member, we include a set of controls for individual characteristics. The regressions control for age as well as dummy variables for whether a member worked in the private sector immediately before joining the committee, whether a member was an academic immediately before joining the committee, and whether a member holds a Master's or PhD degree.[14]

We allow the errors to be clustered by MPC member since it is unlikely that members' errors are independent across time periods, especially if there is some systemic heterogeneity in member voting. Clustering corrects the standard errors of the estimates for this correlation, making it less likely that we wrongly fail to reject a null hypothesis of coefficient significance. However, our results are unchanged without clustering the errors by member.

The key variable of interest in our regressions is exp_{it}, the variable that distinguishes new MPC members from those with experience. This variable is:

$$exp_{it} = \begin{cases} 0 \text{ if member } i \text{ in time } t \text{ has been on the committee 12 months or less} \\ 1 \text{ if member } i \text{ in time } t \text{ has been on the committee more than 12 months} \end{cases}$$

The 12 month cutoff represents one-third of the term for non-Governor MPC members, and half the average number of meetings attended by an external member in our sample. Since this threshold may seem arbitrary, we shall carry out robustness tests to ensure

[14]The effect of the two kinds of degrees was similar in the regressions, so we combine them. Also, most of the professors in our sample without a PhD hold a Master's degree.

that results are qualitatively unchanged if we consider alternative cutoff values to define experience. In particular, we consider 9-month and 18-month cutoffs.

The regression output in the tables below reports the estimated odds-ratios associated with each variable. Interpreting the output therefore requires some care. If we define the odds of deviating as

$$odds(deviate) = \frac{\Pr(deviate)}{\Pr(not\ deviate)}$$

then the odds-ratio for the INT_i variable is given by:

$$\begin{aligned} odds - ratio(internals) &= \frac{(\,odds\,(deviate) \mid INT_i = 1\,)}{(\,odds\,(deviate) \mid INT_i = 0\,)} \\ &= \frac{\left(\frac{\Pr(deviate)|INT_i=1}{\Pr(not\ deviate)|INT_i=1}\right)}{\left(\frac{\Pr(deviate)|INT_i=0}{\Pr(not\ deviate)|INT_i=0}\right)}. \end{aligned}$$

Therefore the odds-ratio, as reported in the tables below, will always be greater than zero. If it is greater (less) than 1, this means that, holding all other variables constant, the odds of deviating for internals is higher (lower) than for external members. Finally, the interpretation of the coefficient ψ_3 — the coefficient on the interaction term $INT_i \cdot exp_{it}$ — is that of the ratio of the odds-ratios. It will tell us if the odds-ratio for experience is different between internals and externals.

Table 3.4 reports the results from estimating equation (3.4) without the exp_{it} variables. The results confirm what was expected from the earlier examination of Table 3.3. Namely, for the first two measures of deviation ($D(Dev\_MPC)_{it}$ and $D(Dev\_group)_{it}$), internals are less likely to deviate than externals. For the third approach to measuring deviations ($D(Dev\_group\_alt)_{it}$), there is no statistically significant difference between internals and externals. These results are robust to the inclusion of the other covariates, and all regressions include the month, quarter and committee fixed effects discussed above.

Table 3.5 introduces the exp_{it} variables; for each deviation variable, we estimate (3.4) both excluding and including the interaction term. These regression results provide a clear test of our model. If conflict on the committee arises because people have different beliefs about the correct monetary policy, then over time there should be fewer deviations since members' beliefs should converge after observing enough data. In fact, the opposite is true. In all cases, the exp_{it} odds-ratio is larger than 1 and statistically significant at the 5% level. This means that, holding all other variables constant, the likelihood of deviating *increases* when an MPC member has been on the committee for more than 12 months. In terms of magnitude, 12 months on the committee makes a member over twice as likely to deviate in nearly all cases. In columns (2) and (4), the interaction term

Table 3.4: Logit Model - Basic Regression Results

	(1)	(2)	(3)	(4)	(5)	(6)
	$D(Dev\_MPC)_{it}$		$D(Dev\_group)_{it}$		$D(Dev\_group\_alt)_{it}$	
INT_i	0.287***	0.193***	0.340***	0.271***	1.338	1.150
	(0.103)	(0.078)	(0.137)	(0.114)	(0.587)	(0.499)
D(high education)		5.089***		3.987***		2.845**
		(2.323)		(2.046)		(1.211)
D(private sector)		0.396**		0.536		0.532
		(0.164)		(0.249)		(0.245)
Age when start		0.9359**		0.9511		0.9637
		(0.0301)		(0.0340)		(0.0249)
Month FE?	Yes	Yes	Yes	Yes	Yes	Yes
Quarter FE?	Yes	Yes	Yes	Yes	Yes	Yes
Committee FE?	Yes	Yes	Yes	Yes	Yes	Yes
Clustered Residuals?	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.215	3.046	16.216*	6.731	6.861	434.538***
	(0.231)	(6.111)	(26.416)	(14.950)	(9.966)	(939.464)
Observations	763	763	754	754	754	754

Odds-ratios reported rather than coefficient estimates

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

is insignificantly different from 1, indicating that there is no difference in the odds-ratio for experienced internals and experienced externals. In column (6), where we use the alternative measure, internals that become experienced have a smaller increase in their probability of deviating than externals who become experienced.

The results in Table 3.6 replicate the results in columns (2), (4), and (6) in Table 3.5 using the alternative cut-off values for experience discussed above. The variable exp_{it}^{9} measures experience as beginning after 9 months on the MPC, while the exp_{it}^{18} uses a value of 18 months. The results are qualitatively unchanged, and in fact the estimated magnitudes on the experience variable are almost always higher. Thus, there is robust evidence that members do not vote more in line with each other as they gain experience.

3.6.2 Voting Levels and Dispersion

So far, we have looked at members' deviation probabilities in order to stay true to our model. We now turn to members' actual votes. There are several reasons for doing so. First, the change in the average vote level between internals and externals provides another test of convergence. Second, the voting data allows us to examine the direction of conflict, not merely its existence. Third, we can use voting data to construct measures of within-group voting dispersion for internals and externals to see how it behaves through time.

There are three possible measures for voting dispersion:

1. the squared deviation from the average vote in each time period $\left(\Delta r_{i,t} - \overline{\Delta r_t}\right)^2$;
2. the squared deviation from the committee's decision $\left(\Delta r_{i,t} - \Delta r_t^{dec}\right)^2$;
3. the squared deviation from the average external or internal vote $\left(\Delta r_{i,t} - \overline{\Delta r_t}^{grp}\right)^2$.

Each of these variables measures the dispersion of member i from the group, thereby capturing the underlying variance of their voting behaviour. In practice, these three measures are highly correlated (with correlation coefficients above 0.9), so we shall report only a selection of the regressions focusing on the first measure.

Following equation (3.4), we now estimate the following regression model using ordinary least squares:[15]

$$\begin{aligned} y_{it} &= \alpha + \lambda.z_i + \psi_1.INT_i + \psi_2.exp_{it} + \beta_1.\left(INT_i.exp_{it}\right) \\ &\quad \sum_t \tau_t.Time_t + \sum_T \delta_T.Q_T + \sum_j \kappa_j.COM_j + \varepsilon_{it} \end{aligned} \tag{3.5}$$

[15]Although our data is categorical (in 25bp devisions) we proceed using OLS. Use of multinomial logit estimation is not feasible with seven distinct groupings in our sample (and theoretically more groupings).

Table 3.5: Logit Model - Experience Regression Results

	(1)	(2)	(3)	(4)	(5)	(6)
	$D(Dev\_MPC)_{it}$		$D(Dev\_group)_{it}$		$D(Dev\_group\_alt)_{it}$	
INT_i	0.171***	0.126***	0.230***	0.309	1.009	2.476
	(0.073)	(0.076)	(0.108)	(0.236)	(0.475)	(1.587)
D(high education)	5.606***	5.460***	4.413***	4.512***	3.048**	3.318***
	(2.907)	(2.798)	(2.504)	(2.583)	(1.355)	(1.535)
D(private sector)	0.405**	0.405**	0.541	0.540	0.509	0.500
	(0.163)	(0.164)	(0.246)	(0.246)	(0.235)	(0.232)
Age when start	0.9324**	0.9323*	0.9469	0.9471	0.9598	0.9607
	(0.0329)	(0.0334)	(0.0370)	(0.0367)	(0.0273)	(0.0271)
exp_{it}	2.141**	1.927*	2.574**	2.889**	2.410**	4.122**
	(0.673)	(0.677)	(1.102)	(1.451)	(1.003)	(2.346)
$INT_i{}^*exp_{it}$		1.460		0.690		0.301*
		(1.072)		(0.491)		(0.189)
Month FE?	Yes	Yes	Yes	Yes	Yes	Yes
Quarter FE?	Yes	Yes	Yes	Yes	Yes	Yes
Committee FE?	Yes	Yes	Yes	Yes	Yes	Yes
Clustered Residuals?	Yes	Yes	Yes	Yes	Yes	Yes
Constant	1.807	2.024	0.702	0.616	0.247	0.141
	(5.837)	(6.501)	(2.334)	(2.037)	(0.681)	(0.385)
Observations	763	763	754	754	754	754

Odds-ratios reported rather than coefficient estimates

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 3.6: Logit Model - Robustness to Different Experience Variables

	(1)	(2)	(3)	(4)	(5)	(6)
	$D(Dev\_MPC)_{it}$		$D(Dev\_group)_{it}$			$D(Dev\_group\_alt)_{it}$
INT_i	0.179***	0.219**	0.641	0.402	5.402***	1.824
	(0.101)	(0.145)	(0.507)	(0.289)	(3.489)	(1.082)
D(high education)	5.455***	6.197***	4.512***	4.920***	3.199**	3.278**
	(2.661)	(3.372)	(2.484)	(2.971)	(1.463)	(1.566)
D(private sector)	0.418**	0.397**	0.563	0.529	0.538	0.492
	(0.169)	(0.162)	(0.254)	(0.245)	(0.246)	(0.227)
Age when start	0.9349**	0.9318*	0.9486	0.9482	0.9629	0.9616
	(0.0320)	(0.0339)	(0.0352)	(0.0368)	(0.0258)	(0.0271)
exp^9_{it}	2.134*		3.396**		4.147**	
	(0.873)		(2.092)		(2.515)	
$INT_i*exp^9_{it}$	0.998		0.324		0.144***	
	(0.716)		(0.260)		(0.103)	
exp^{18}_{it}		3.173**		3.509**		3.696**
		(1.458)		(1.721)		(1.907)
$INT_i*exp^{18}_{it}$		0.581		0.395		0.354*
		(0.371)		(0.231)		(0.197)
All regressions contain the usual month, quarter and committee FE, and residuals are clustered by member.						
Constant	1.807	2.024	0.702	0.616	0.247	0.141
	(5.837)	(6.501)	(2.334)	(2.037)	(0.681)	(0.385)
Observations	763	763	754	754	754	754

Odds-ratios reported rather than coefficient estimates
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

where y_{it} is the outcome variable of interest, and the other variables are as in (3.4). Here, the interpretation of the coefficients is more straightforward. The three coefficients of interest are ψ_1, the marginal effect of being an internal member; ψ_2, the marginal effect of having at least one year of MPC experience; and β_1, the marginal effect of being an experienced, internal member. Another advantage of the OLS model is that estimation with member fixed effects (i.e., modelling the error terms as $\varepsilon_{it} = \nu_i + \eta_{it}$, where ν_i is a member-specific intercept that captures any unobserved heterogeneity at the member level) becomes computationally feasible. We will estimate (3.5) both with and without member fixed effects, since their inclusion forces us to drop all time-invariant individual characteristics.

The results of estimating (3.5) are reported in Table 3.7. Columns (1) - (3) report the coefficient estimates when $y_{it} = \Delta r_{i,t}$. In Column (1), only time and committee fixed effects, the usual covariates, and the INT_i variable are included. It is clear that internal members vote, on average, for higher interest rates. The three basis point difference between internals and externals is economically significant. Consider the conterfactual switching an external member to an internal member. Since members conventionally vote in 25 basis point increments, this would mean that such a member would vote for higher interest rates in 12% more meetings ($\frac{3}{25} \approx 0.12$). What is rather suprising is that this effect arises even while controlling for individual characteristics. Internals and externals appear to vote for different interest rates not because of different educational or occupational backgrounds, but simply because one group has managerial responsibilities within the Bank and the other does not.

In Column (2) we include the exp_{it} variable as well as the interaction term. This essentially allows us to use a differences-in-differences approach for estimating convergence of opinions. The results are striking. The effect of being an internal is no longer significant, but the effect of being experienced is highly significant and large in magnitude (-5.3 bps lower on average). Moreover, the coefficient on the interaction term is also highly significant and large (+5.5 bps higher on average). Thus, the effect of experience is different for internals and externals. Experience by itself leads people to vote for lower rates, but this is driven entirely by the external members; it is not possible to reject the hypothesis that internal members do not change their vote once they become experienced. Therefore, neither inexperienced nor experienced internals vote for different rates on average. This implies that although inexperienced externals do not behave any differently from inexperienced internals, experienced externals vote for systematically lower interest rates on average. This finding is qualitatively robust to the inclusion of member fixed effects (Column (3)). These regressions provide yet more evidence of growing disagreement between externals and internals on the MPC.

Table 3.7: Level and Vote Variablilty Regression Results

	(1) $vote_{it}$	(2) $vote_{it}$	(3) $vote_{it}$	(4) $(\Delta r_{i,t} - \overline{\Delta r_t})^2$	(5) $(\Delta r_{i,t} - \overline{\Delta r_t})^2$	(6) $(\Delta r_{i,t} - \overline{\Delta r_t}^{grp})^2$
INT_i	0.030**	-0.007	-	-0.006**	-	-0.006**
	(0.014)	(0.019)		(0.002)		(0.002)
D(high education)	-0.010	-0.013	-	0.004**	-	0.002***
	(0.013)	(0.013)		(0.002)		(0.001)
D(private sector)	-0.010	-0.010	-	-0.002	-	-0.002
	(0.016)	(0.015)		(0.002)		(0.002)
Age when start	0.000	0.000	-	-0.000	-	-0.000
	(0.001)	(0.001)		(0.000)		(0.000)
exp_{it}		-0.053***	-0.034***	0.002	0.002	-0.001
		(0.016)	(0.009)	(0.002)	(0.002)	(0.002)
INT_i*exp_{it}		0.0547***	0.0454***	-0.0006	0.0004	0.0012
		(0.0158)	(0.0117)	(0.0025)	(0.0020)	(0.0030)
Month FE?	Yes	Yes	Yes	Yes	Yes	Yes
Quarter FE?	Yes	Yes	Yes	Yes	Yes	Yes
Committee FE?	Yes	Yes	Yes	Yes	Yes	Yes
Clustered Residuals?	Yes	Yes		Yes		Yes
Member FE?			Yes		Yes	
Constant	0.235***	0.257***	0.247***	0.007	-0.000	0.006*
	(0.042)	(0.042)	(0.035)	(0.005)	(0.006)	(0.003)
Observations	1163	1163	1163	1163	1163	1163
R^2	0.79	0.80	0.82	0.22	0.20	0.24

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Columns (4) and (5) repeat the regressions in columns (2) and (3) using $y_{it} = \left(\Delta r_{i,t} - \overline{\Delta r_t}\right)^2$. The main finding is that externals as a group display more volatility in their voting behaviour, and that volatility does not decline with time for either internals or externals. Thus, not only do internals and externals not reach consensus with each other through time, but they also do not seem to reach a consensus with each other. Moreover, the greater volatility of external members clearly reduces the expected utility of a committee designer with preferences given by (3.2), so the only rationale for including them at all must come from some other margin. Column (6) shows the robustness of the findings to an alternative definition of group dispersion $\left(\left(\Delta r_{i,t} - \overline{\Delta r_t}^{grp}\right)^2\right)$.

To summarize, the main empirical findings are that:

- There are systematic differences in the voting behaviour of internals and externals;
- On numerous measures, internal and externals members display increasing conflict through time;
- Through their greater volatility, external members reduce the welfare of a committee designer with a quadratic loss function.

Our second finding is the most important. We believe that it rules out a model in which all members share the same preferences over interest rates. We have shown that such a model generates declining disagreement, but in fact the opposite is true in the data. Therefore, the source of conflict between members must arise for reasons other than conflicting beliefs, and the most likely candidate is conflicting preferences. However, if internals and externals have different preferences, then at least one group maximizes an objective function other than the committee designer's. Thus, we also believe that we have identified an agency problem on the MPC. In other words, the MPC appears to not work as effectively as its designers might have hoped. In the next section, we explore what preferences underlie internals' and externals' behaviour.

3.7 Alternative Models

Exposure to increasing amounts of information should not drive Bayesian agents apart, and yet our econometric results show that this is the case on the MPC. The data also show that external members separate from internal members and vote for systematically lower interest rates. Therefore, although our regressions offer no support for the model of ideal mixed-committee voting presented above, we are not given an insight into why the model fails.

We believe that any reasonable model with Bayesian learning and ideal behaviour assumptions could not explain the patterns in the data. This finding is important because it indicates the presence of an agency problem resulting from the presence of internal and external members on the MPC. If we are going to reject the model of ideal voting behaviour, however, a natural question to ask is what model we need to use in its place. Also, the policy and committee design implications depend on the underlying reasons for the failure of our ideal behaviour model.

To begin with, we shall take as given the initial period of agreement and examine what causes the votes to change, and in particular why the votes of externals appear to become systematically lower. In this section we explore a number of the leading candidate explanations; we examine the presence of career concerns, and the possibility of asymmetric preferences.

3.7.1 Career Concerns

One possibility is that members not only want to maximize equation (3.1), but also want to signal their competence or preferences through their voting record. In other words, committee members may have career concerns. There are many reasonable career concern stories. For example, internals may want to signal to the government and to the central banking community that they are tough inflation fighters. Externals, who face more uncertainty about their future prospects after their terms end, may want to signal that they are competent economists. These concerns may lead MPC members to vote for interest rates that differ from those predicted by our ideal voting model.

We shall examine a particular form of career concern that is consistent with the idea that MPC members reputation shall be assessed, largely, by the central banking community and by the government. Gordon Brown was not only the Chancellor who set-up the MPC structure, but he was the key person in approving the members who got appointed to the MPC over the majority of our sample. In setting up the MPC with a narrowly-defined inflation target, he made clear his belief that the correct focus of monetary policy is fighting inflation. He was clearly aware that attempts to try to exploit short-run output gains from monetary policy would quickly lead to inflation. While it is often assumed that internal members would worry about their inflation-fighting credibility, it also seems clear that in order to either build a reputation, or in terms of getting reappointed, external members would need to be considered inflation-averse.

Our experience effect may, therefore, already be capturing a career concern; upon joining, new members may wish to build a reputation for fighting inflation and so start by voting with the other members. Our results are consistent with this being the case particularly in the first year, and applying, on average, to both internal and external members.

However, after the initial reputation building period, career concerns may play a differential role with different members. If career concerns explain the behaviour of MPC members after one year, then we would expect to see the change in behaviour only for those groups for whom career concerns do not play a major role. To test this hypothesis, we divide internals and externals into groups for which reputational considerations should play varying roles and examine whether these different groups display the same divergence as they gain experience[16]. If they do, then signalling is not a convincing factor in explaining our experience results, while if they don't, it cannot be ruled out.

We split the members according to whether, or not, they are an academic when they join the committee. There are substantial numbers of academics and non-academics in both the internal and external group. Because of the tenure system, one could argue that academics should have less of a need to signal since they have a stronger outside option should they fail to build a good reputation. In order to test whether non-academics and academics differ in voting behaviour, we run the following regression with member fixed effects[17]:

$$\begin{aligned} y_{it} &= \alpha + \lambda.z_i + \psi_1.INT_i + \psi_2.exp_{it} + \psi_3.Acad_i \\ &+\beta_1.\left(INT_i.exp_{it}\right) + \beta_2.\left(INT_i.Acad_i\right) + \beta_3.\left(exp_{it}.Acad_i\right) \\ &+\mu_1.\left(INT_i.exp_{it}.Acad_i\right) \\ &+\sum_t \tau_t.Time_t + \sum_T \delta_T.Q_T + \sum_j \kappa_j.COM_j + \nu_i + \eta_{it} \end{aligned} \tag{3.6}$$

where $Acad_i$ is the dummy variable indicating that a member is an academic, and all other variables are as defined above.

With two different distinguishing dummy variables ($Acad_i$ and INT_i), there are four different "types" of MPC member. For each type, the last dummy variable (exp_{it}) allows us to calculate the effect of experience on each group. Rather than discuss the values of the coefficients themselves, it is easier to discuss the sums of coefficients that represent this experience effect for each particular set of characteristics. For example, the experience effect of being an internal, non-academic is $\psi_2 + \beta_1$[18] and the experience effect of being an external academic is $\psi_2 + \beta_3$. The results are listed in Table 3.8; the experience effect is listed along with the P-value associated with the null hypothesis that

[16] We have also carried out the same analysis for the variance of voting behaviour; these results are not included as the variance results are less puzzling than the level results, but are available on request.

[17] Estimating without member-fixed effects leads to qualitatively unchanged results.

[18] The effect of being an experienced, internal, non-academic is $\psi_1 + \psi_2 + \beta_1$ while the effect of being a new, internal, non-academic is ψ_1. The experience effect for this group is the difference of these two.

Table 3.8: Estimates of "Experience-Effect" by Member Type: Career Concerns

	Members		Experience Effect	P-Value	95% Confidence Interval	
(1)	External	Non-academic	-0.01	0.57	-0.03	0.02
(2)	External	Academic	-0.07	0.00	-0.10	-0.05
(3)	Internal	Non-academic	0.01	0.57	-0.02	0.03
(4)	Internal	Academic	0.01	0.50	-0.03	0.05

the effect is zero, and the 95% confidence intervals.

The results clearly lend support to the career concerns hypothesis. Controlling for whether members are academic or not can seemingly explain the entire experience result. Experience drives the voting of academic externals down by 7bps. Hypothesis tests confirm that the experience effect for academic externals is different from zero, and from the experience effect of other types of member (all of whom have no experience effect). This is surprising as the regression controls for not only the time and committee fixed effects, but also for member fixed effects.

Thus, our results seem consistent with the idea that career concerns, the building of an anti-inflation reputation, remain important for some external members beyond the initial period on the committee.

3.7.2 Asymmetric Preferences

Although the UK Treasury officially sets the inflation target and instructs MPC members that the target is symmetric, it may be that individual members, consciously or subconsciously, view phases of the business/inflation cycle differently. We have assumed symmetric preferences in our model of voting behaviour, but the results in Table 3.8 may be consistent with asymmetric preferences; this is our second potential explanation.

The idea of asymmetric preferences is not new in monetary economics (see Surico (2007)). Gerlach-Kristen (2009) simulates an asymmetric preferences voting model and concludes that it would lead to similar patterns of voting to that of the MPC. External members, in her model, are assumed to be recession-averse in that they dislike negative output gaps more than positive output gaps. To be consistent with our findings, this hypothesis states that, after initially behaving as the government expected them to, some members reveal themselves to be less willing to fight inflation at the expense of a recession.

We split the interest rate cycle into a tightening phase (when interest rates are, or have been most recently, increasing) and a loosening phase (when interest rates have most recently been declining) so that we can examine the evidence for recession aversion. We use the variable $Loosen_i$ - a dummy variable indicating that period t is in a loosening phase - to distinguish the two phases. These are displayed in Figure 3.6; grey shading denotes the tightening cycle, and other periods are therefore considered the loosening cycle.

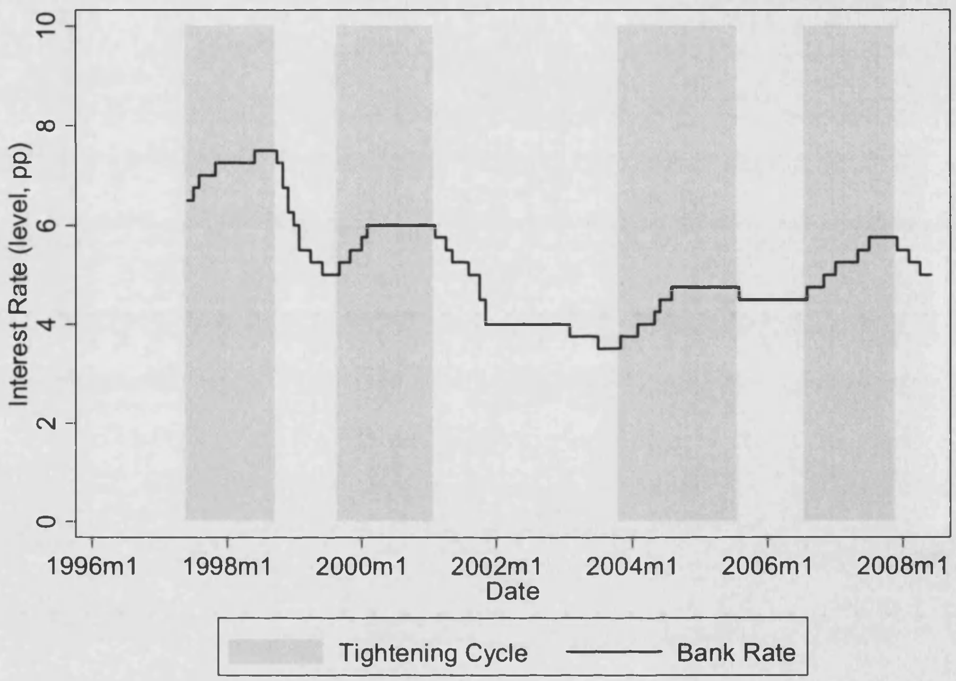


Figure 3.6: Interest Rate Cycles in the UK

In order to test whether the behaviour of MPC members differs over the phases of the interest rate cycle, we run a regression similar to equation (3.6) but instead of distinguishing between academics and non-academics, we use the variable $loosen_t$ to distinguish between the phases of the interest rate cycle. Thus, we estimate:

$$
\begin{aligned}
y_{it} &= \alpha + \lambda.z_i + \psi_1.INT_i + \psi_2.exp_{it} + \psi_4.loosen_t \\
&\quad + \beta_1.(INT_i.exp_{it}) + \beta_4.(INT_i.loosen_t) + \beta_5.(exp_{it}.loosen_t) \\
&\quad + \mu_2.(INT_i.exp_{it}.loosen_t) \\
&\quad + \sum_t \tau_t.Time_t + \sum_T \delta_T.Q_T + \sum_j \kappa_j.COM_j + \nu_i + \eta_{it} \qquad (3.7)
\end{aligned}
$$

Table 3.9: Estimates of "Experience-Effect" by Member Type:

	Members		Experience Effect	P-Value	95% Confidence Interval	
(1)	External	Tighten	-0.02	0.20	-0.04	0.01
(2)	External	Loosen	-0.04	0.01	-0.07	-0.01
(3)	Internal	Tighten	0.02	0.18	-0.01	0.05
(4)	Internal	Loosen	0.01	0.44	-0.02	0.04

The results for the estimated experience effect, analogous to the results in Table 3.8, are displayed in Table 3.9. The evidence is not conclusively for or against the asymmetric preferences story. While the experience effect is only significantly different from zero for external MPC members in a loosening phase, we cannot reject the null hypothesis that the experience effect is the same in tightening and loosening cycles for externals. Therefore, while it is likely that the effect is larger in the loosening cycle, and we cannot reject the null hypothesis that there is a different experience effect for internals and externals, the fact that there is an experience effect in tightening cycles, weakens the evidence for recession-aversion as driving our experience result.

3.7.3 Testing both together

One concern may be that the two explanatory variables may not be orthogonal. The results for the cycle could be driven by the academics; most inexperienced academics in our sample (who would be building a reputation under our story), cast their votes in tightening cycles.

Also, it is not clear that career concerns would be symmetric over the cycle. A member who is trying to build a reputation for being tough on inflation in order to get reappointed may require more evidence of falling inflationary pressures to cut rates, than an optimally-behaving member would require to increase rates.

Therefore, as we could not conclusively eliminate one story, we test for both the stories together in a combined regression given by equation (3.9), where the variables are as defined before. If we find that the importance of either the academics, or the loosening cycle, disappears, then it may be the smoking-gun that we are looking for in determining which of our stories is most likely to explain the behaviour.

Table 3.10: Estimates of "Experience-Effect" by Member Type: Combined Career Concerns and Asymmetric Preferences Regression

	Members			Experience Effect	P-Value	95% Confidence Interval	
(1)	External	Tighten	Non-academic	-0.01	0.67	-0.03	0.02
(2)	External	Tighten	Academic	-0.02	0.27	-0.05	0.01
(3)	External	Loosen	Non-academic	0.00	0.88	-0.02	0.03
(4)	External	Loosen	Academic	-0.12	0.00	-0.17	-0.08
(1)	Internal	Tighten	Non-academic	0.02	0.30	-0.01	0.04
(2)	Internal	Tighten	Academic	0.03	0.37	-0.02	0.08
(3)	Internal	Loosen	Non-academic	0.01	0.62	-0.02	0.04
(4)	Internal	Loosen	Academic	0.01	0.58	-0.03	0.05

$$\begin{aligned}
y_{it} = {} & \alpha + \lambda.z_i + \psi_1.INT_i + \psi_2.exp_{it} + \psi_3.Acad_i + \psi_4.loosen_t \\
& +\beta_1.(INT_i.exp_{it}) + \beta_2.(INT_i.Acad_i) + \beta_3.(exp_{it}.Acad_i) \\
& +\beta_4.(INT_i.loosen_t) + \beta_5.(exp_{it}.loosen_t) + \beta_6.(Acad_i.loosen_t) \\
& +\mu_1.(INT_i.exp_{it}.Acad_i) + \mu_2.(INT_i.exp_{it}.loosen_t) + \mu_3.(INT_i.Acad_i.loosen_t) \\
& +\mu_4.(exp_{it}.Acad_i.loosen_t) \\
& +\phi_1.(INT_i.exp_{it}.Acad_i.loosen_t) \\
& +\sum_t \tau_t.Time_t + \sum_T \delta_T.Q_T + \sum_j \kappa_j.COM_j + \nu_i + \eta_{it} \qquad (3.8)
\end{aligned}$$

The results in Table 3.10 for the estimated experience effect, are reported as before. It is now the case that the experience effect can be attributed solely to external, academic members during the loosening phase of the business cycle. Thus, we are no closer to eliminating either explanation as both are consistent with this result; either the academics have recession averse preferences, or the other members are affected by a career concern that keeps them voting for higher interest rates.

3.8 A Natural Experiment

Ideally we would have an exogenous variation in the extent of career concerns which would help us to disentangle these two effects and determine which is driving the behaviour. Fortunately, we have one such natural experiment. The Act that created the MPC allows for the reappointment of all members, internal and external. When the first group of externals and internals served on the MPC, they thus operated under the assumption that reappointment to the committee was possible, although uncertainty still existed about how the reappointment system would function. Then, on 18 January 2000, Willem Buiter wrote an open letter to then Chancellor Gordon Brown that laid down forceful arguments for not reappointing external members (Buiter 2000). To quote from this letter:

> With the end of my term approaching, I have given considerable thought to whether I should be a candidate for re-appointment. I have come to the conclusion that both the appearance and the substance of independence of the external members of the MPC are best served by restricting their membership to a single term - three years as envisaged in the Bank of England Act 1998.

It seems that this letter swayed Brown's decision; he did not reappoint a single external member from the original group, even though some were still among the most prominent monetary policy experts in the UK. A clear precedent was set: external members would find reappointment difficult, most likely extremely so. All external members served for only one term until February 2003 (almost 6 years since the first MPC meeting), when Brown unexpectedly reappointed Stephen Nickell to the MPC (HM Treasury 2003). Since then, Kate Barker has also been reappointed twice.

If career concerns play a role, one would expect different voting patterns between external members serving from February 2000 to February 2003 and those serving at other times, since the rewards to reputation presumably changed when reappointment was and was not possible. There are 322 votes cast during this period in which reappointment of external members was not possible. Of course, there is no reason to expect that this lack of reappointment opportunities for external member to affect internal member voting; during this period many external members were reappointed to the committee. To this end, we define a dummy variable $reappoint_{it}$ which equals 1 before February 2000 and after February 2003. We then estimate the following career concerns regression:

Table 3.11: Estimates of "Experience-Effect" by External Type: Career Concerns Regression from Natural Experiment

	Members			Experience Effect	P-Value	95% Confidence Interval	
(1)	External	$reappoint_{it} = 0$	Non-academic	-0.05	0.04	-0.09	0.00
(2)	External	$reappoint_{it} = 0$	Academic	-0.06	0.01	-0.11	-0.02
(3)	External	$reappoint_{it} = 1$	Non-academic	0.01	0.55	-0.02	0.04
(4)	External	$reappoint_{it} = 1$	Academic	-0.07	0.00	-0.10	-0.03
(5)	Internal	$reappoint_{it} = 0$	Non-academic	-0.01	0.69	-0.06	0.04
(6)	Internal	$reappoint_{it} = 0$	Academic	0.03	0.31	-0.03	0.09
(7)	Internal	$reappoint_{it} = 1$	Non-academic	0.01	0.36	-0.01	0.04
(8)	Internal	$reappoint_{it} = 1$	Academic	0.00	0.98	-0.06	0.06

$$\begin{aligned}
y_{it} &= \alpha + \lambda.z_i + \psi_1.INT_i + \psi_2.exp_{it} + \psi_3.Acad_i + \psi_5.reappoint_t \\
&\quad +\beta_1.(INT_i.exp_{it}) + \beta_2.(INT_i.Acad_i) + \beta_3.(exp_{it}.Acad_i) \\
&\quad +\beta_7.(INT_i.reappoint_t) + \beta_8.(exp_{it}.reappoint_t) + \beta_9.(Acad_i.reappoint_t) \\
&\quad +\mu_1.(INT_i.exp_{it}.Acad_i) + \mu_5.(INT_i.exp_{it}.reappoint_t) + \mu_6.(INT_i.Acad_i.reappoint_t) \\
&\quad +\mu_8.(exp_{it}.Acad_i.reappoint_t) \\
&\quad +\phi_2.(INT_i.exp_{it}.Acad_i.reappoint_t) \\
&\quad +\sum_t \tau_t.Time_t + \sum_T \delta_T.Q_T + \sum_j \kappa_j.COM_j + \nu_i + \eta_{it} \qquad (3.9)
\end{aligned}$$

The results in Table 3.11 lend support to the idea that this exogenous variation has led external members to behave differently, while internal members have been unaffected. Rows (1) and (2) shows that, when reappointment was not possible, the experience effect was the same across types of external member; there is no longer a differential effect between external academics and non-academics. The effect uncovered earlier in Table 3.8 is driven by the differential behaviour when reappointment was possible.

We now attempt to distinguish between the preferences and career concerns story using our natural experiment and the combined effects equation given by (3.9). However, we now augment this equation with differential effects for when reappointment was possible; the resulting (large) equation is:

$$
\begin{aligned}
y_{it} = \; & \alpha + \lambda.z_i + \psi_1.INT_i + \psi_2.exp_{it} + \psi_3.Acad_i + \psi_4.loosen_t + \psi_5.reappoint_t \\
& + \beta_1.\,(INT_i.exp_{it}) + \beta_2.\,(INT_i.Acad_i) + \beta_3.\,(exp_{it}.Acad_i) \\
& + \beta_4.\,(INT_i.loosen_t) + \beta_5.\,(exp_{it}.loosen_t) + \beta_6.\,(Acad_i.loosen_t) \\
& + \beta_7.\,(INT_i.reappoint_t) + \beta_8.\,(exp_{it}.reappoint_t) + \beta_9.\,(Acad_i.reappoint_t) \\
& + \beta_{10}.\,(loosen_t.reappoint_t) \\
& + \mu_1.\,(INT_i.exp_{it}.Acad_i) + \mu_2.\,(INT_i.exp_{it}.loosen_t) + \mu_3.\,(INT_i.Acad_i.loosen_t) \\
& + \mu_4.\,(exp_{it}.Acad_i.loosen_t) + \mu_5.\,(INT_i.exp_{it}.reappoint_t) + \mu_6.\,(INT_i.Acad_i.reappoint_t) \\
& + \mu_7.\,(INT_i.loosen_t.reappoint_t) + \mu_8.\,(exp_{it}.Acad_i.reappoint_t) \\
& + \mu_9.\,(exp_{it}.loosen_t.reappoint_t) + \mu_{10}.\,(Acad_i.loosen_t.reappoint_t) \\
& + \phi_1.\,(INT_i.exp_{it}.Acad_i.loosen_t) + \phi_2.\,(INT_i.exp_{it}.Acad_i.reappoint_t) \\
& + \phi_3.\,(INT_i.exp_{it}.loosen_t.reappoint_t) + \phi_4.\,(INT_i.Acad_i.loosen_t.reappoint_t) \\
& + \phi_5.\,(exp_{it}.Acad_i.loosen_t.reappoint_t) \\
& + \iota_1.\,(INT_i.exp_{it}.Acad_i.loosen_t.reappoint_t) \\
& + \sum_t \tau_t.Time_t + \sum_T \delta_T.Q_T + \sum_j \kappa_j.COM_j + \nu_i + \eta_{it} \qquad (3.10)
\end{aligned}
$$

When we estimate the effect, two of the interaction terms are automatically dropped because of dependency among the independent variables; the dropped variables are fully explained by other variables in the regression. Given the number of interaction terms, this is perhaps not surprising. The variables dropped by Stata (the econometrics package we use) are $(INT_i.exp_{it}.Acad_i.reappoint_t)$ and $(INT_i.Acad_i)$ meaning that β_2 and ϕ_2 will not be separately identified. This means that we are unable to accurately identify the separate effects of experience on different types of internal members. However, as we would expect from our natural experiment, and as suggested by the results in Table 3.11 above, the reappointment period only affects external member behaviour. We, therefore, use the estimates of this equation to examine their behaviour only and present the "experience effect" results in Table 3.12.

The results when reappointment is possible mirror those of the estimations reported in Table 3.10 and Table 3.11 above. We reject the hypothesis that the experience effect is the same across different types of external members when reappointment is possible ($F(3, 983) = 0.38, Prob > F = 0.7638$). However, the results change markedly when we look at the behaviour when reappointment was not possible (Columns (3) and (4)). In particular, the behaviour of all externals is much more similar; we cannot reject the null hypothesis that all external types experience the same experience effect ($F(3, 983) =$

Table 3.12: Estimates of "Experience-Effect" by External Type: Combined Career Concerns and Asymmetric Preferences Regression from Natural Experiment

	Members		$reappoint_{it}$= 1		$reappoint_{it}$= 0	
			Coefficient	P-Value	Coefficient	P-Value
			(1)	(2)	(3)	(4)
External	Tighten	Non-academic	0.00	0.84	-0.05	0.29
External	Tighten	Academic	-0.02	0.41	-0.03	0.47
External	Loosen	Non-academic	0.03	0.27	-0.04	0.10
External	Loosen	Academic	-0.18	0.00	-0.08	0.01

$3.58, Prob > F = 0.0136$).

These results suggest that it is only in the presence of career concerns that the interest rate cycle plays a role. In terms of distinguishing between the two potential explanations, it seems that career concerns play a larger role. In fact, it may be that the extent of career concerns is influenced by the cycle; it is easier to appear anti-inflation by keeping interest rates higher in a downturn. However, to examine the reasons for such interactions we would need to develop a model that explicitly considers career concerns and the economic cycle.

3.9 Conclusion

MPC members communicate their views (signals) about the state of the world, and they also have different views about the economic structure. Our model provides two justifications for appointing different types of committee members. First, if different members have different dimensions of expertise, then mixing them together can improve the outcome for the committee designer. Second, where the designer cannot observe member beliefs about the economic structure, drawing members from two distributions which are likely to lie at extremes of the distribution of possible views of the economy is more likely to generate a moderate median voter. The first benefit can be attained through a simple advisory role, whereas the second relies on external members having a vote.

We find that internals and externals only vote for different interest rates after a period of time on the committee. This is an important finding; if members are failing to moderate each other's views initially, then it fails to justify appointing externals in a voting capacity. We explore what might drive this behaviour; we find evidence of career concerns as some external members vote differently in an attempt to be reappointed. Career concerns not only reduce the benefits of appointing members with different views about the economic structure, but, if there is less learning about the economic shocks, then the information sharing may be impeded also.

The systematic difference between internals and externals should be particularly surprising given the fact that internals are often appointed from very similar backgrounds to externals and, therefore, the two groups differ only in the sense that the internals are appointed to the staff of the Bank of England, taking on management roles in the day-to-day running of the Bank.

Our results suggest that career concerns may play a role in MPC voting (though they obviously cannot prove the existence of career concerns). This finding is of independent interest because papers such as Levy (2007) and Sibert (2003) have stressed the theoretical consequences of career concerns in committee voting, and Meade and Stasavage (2008) have uncovered patterns in the voting record of the FOMC that they interpret as identifying career concerns. These papers largely focus on voting differences when deliberation and voting is either transparent or secretive. These dimensions do not vary with regard to the MPC and yet we find evidence supporting career concerns.

Our results on the effect of experience are important in the wider literature. We show that herding does not arise in this environment. Scharfstein and Stein (1990), Banerjee (1992), and Ottaviani and Sorenson (2000) have shown that when experts have private signals about the state of the world and take decisions one after the other, then in equilibrium experts can "herd", or ignore their private information and follow those that voted before them, either because of reputational or optimal decision making preferences. If anything, our results show the opposite. MPC members begin with no disagreement whatsoever, and then after several rounds of voting begin to disagree.

As our model shows, the voting behaviour of the Bank of England's MPC indicates that the gains to a mixed committee may be reduced or even made negative. The finding is particularly striking as the MPC is, otherwise, close to our ideal committee in terms of set-up; if optimal behaviour fails on this committee, it is more likely to fail on other committees where differences in preferences are more acceptable. Exploring the benefits of a mixed committee in the context of career concerns is required in order to better understand the decision to appoint external experts to a committee. Nonetheless, the conclusion of this paper is that mixed committees are not a panacea to ensuring optimal monetary policy decisions.

3.A Proofs

3.A.1 Proof of Proposition 3.1

Proof. The optimal strategy for each member i is to maximize (3.1) conditional on I_{it}, the information set of member i at time t. In the proof, we suppress I_{it} for notational simplicity; the expectations should be understood to be taken with respect to I_{it}. We decompose (3.1) in the following manner:

$$\begin{aligned} E\left[(\pi_t-\pi^*)^2\right] &= E\left[\pi_t^2\right]-2\pi^*E\left[\pi_t\right]+(\pi^*)^2 \\ &= V\left[\pi_t\right]+E\left[\pi_t\right]^2-2\pi^*E\left[\pi_t\right]+(\pi^*)^2 \\ &= V\left[\pi_t\right]+\left(E\left[\pi_t\right]-\pi^*\right)^2, \end{aligned}$$

where

$$E\left[\pi_t\right]=g\left(r\right)+\widehat{\alpha}_{it}+\widehat{\theta}_{it}$$

and

$$V\left[\pi_t\right]=E\left[V\left[\pi_t \mid \alpha_t,\theta\right]\right]+V\left[E\left[\pi_t \mid \alpha_t,\theta\right]\right]=\sigma^2+V\left[\alpha_t+\theta\right].$$

The interest rate only affects $E\left[\pi_t\right]$, not $V\left[\pi_t\right]$. Clearly, utility is highest when $r_t=r_{it}^*$, where r_{it}^* satisfies

$$g\left(r_{it}^*\right)+\widehat{\alpha}_{it}+\widehat{\theta}_{it}=\pi^*.$$

Also, since g is strictly increasing, utility is strictly increasing when $r_t<r_{it}^*$ and strictly decreasing when $r_t>r_{it}^*$. So, expected utility is continuous and single peaked.

Member i is indifferent between a given $\underline{r}_t$ and $\overline{r}_t$ when $\widehat{\alpha}_{it}=\alpha_{it}^*$, where

$$\alpha_{it}^*+\widehat{\theta}_{it}-g\left(\underline{r}_t\right)=g\left(\overline{r}_t\right)-\alpha_{it}^*-\widehat{\theta}_{it},$$

which implies

$$\alpha_{it}^*=\frac{g\left(\overline{r}_t\right)-g\left(\underline{r}_t\right)}{2}-\widehat{\theta}_{it}. \tag{3.11}$$

Since preferences are single-peaked with the bliss point depending positively on $\widehat{\alpha}_{it}$, member i votes for $\underline{r}_t$ for all $\widehat{\alpha}_{it}<\alpha_{it}^*$ and for $\overline{r}_t$ for all $\widehat{\alpha}_{it}\geq\alpha_{it}^*$. From (3.11) one can see that α_{it}^* is decreasing in $\widehat{\theta}_{it}$. ■

3.A.2 Proof of Proposition 3.2

Proof. Suppose the game is in period 1, and that there is an equilibrium in which Θ_{i1}^d and Θ_{i1}^s are non-empty. Moreover, without loss of generality, suppose that $\overline{\theta}_1<\overline{\theta}_2$. For this equilibrium to exist, it must be that case that member 1's expected utility is higher from withholding than disclosing $\forall \widehat{d}_{11} \in \Theta^d_{11}, \widehat{s}_{11} \in \Theta^s_{11}$.

Using standard results in Bayesian decision theory (Greene 2003, p.871-2), one can construct two separate beliefs for member 2:

$$\begin{aligned}\widehat{\alpha}'_{21} &= E\left[\alpha_1 \mid \widehat{d}_{11}, \widehat{s}_{11}, \widehat{d}_{21}, \widehat{s}_{21}\right] \\ &= \lambda_1 \widehat{d}_{11} + \lambda_2 \widehat{s}_{11} + \lambda_3 \widehat{d}_{21} + \lambda_4 \widehat{s}_{21};\end{aligned}$$

and

$$\begin{aligned}\widehat{\alpha}''_{21} &= E\left[\alpha_1 \mid \widehat{d}_{11} \in \Theta^d_{11}, \widehat{s}_{11} \in \Theta^s_{11}, \widehat{d}_{21}, \widehat{s}_{21}\right] \\ &= \lambda_1 E\left[\widehat{d}_{11} \mid \widehat{d}_{11} \in \Theta^d_{11}, \widehat{d}_{21}\right] + \lambda_2 E\left[\widehat{s}_{11} \mid \widehat{s}_{11} \in \Theta^s_{11}, \widehat{s}_{21}\right] \\ &\quad + \lambda_3 \widehat{d}_{21} + \lambda_4 \widehat{s}_{21}.\end{aligned}$$

In these equations, the λ terms are linear weights that depend on the variance terms of the underlying signals. $\widehat{\alpha}'_{21}$ is member 2's belief on α when he observes member 1's signals, and $\widehat{\alpha}''_{21}$ is his belief when he does not, in which case he knows that they lie in the sets Θ^d_{11} and Θ^s_{11}.

Define $\Theta^{d\varepsilon}_{11} \equiv \left\{ \widehat{d}_{11} \mid \widehat{d}_{11} \in \Theta^d_{11}, \left(\widehat{d}_{11} - \inf \Theta^d_{11}\right) > \varepsilon \right\}$, and define $\Theta^{s\varepsilon}_{11}$ analogously. For the rest of the proof, we suppose that ε is small enough so that

$$\begin{aligned}E\left[\widehat{d}_{11} \mid \widehat{d}_{11} \in \Theta^d_{11}, \widehat{d}_{21}\right] &> \widehat{d}_{11} \ \forall \widehat{d}_{21}, \forall \widehat{d}_{11} \in \Theta^{d\varepsilon}_{11} \text{ , and} \\ E\left[\widehat{s}_{11} \mid \widehat{s}_{11} \in \Theta^s_{11}, \widehat{s}_{21}\right] &> \widehat{s}_{11} \ \forall \widehat{s}_{21}, \forall \widehat{s}_{11} \in \Theta^{s\varepsilon}_{11}.\end{aligned}$$

Now, fix some $\widehat{d}_{11} \in \Theta^{d\varepsilon}_{11}$ and $\widehat{s}_{11} \in \Theta^{s\varepsilon}_{11}$. One can define the following sets:

$$\begin{aligned}R_1 &= \left\{ \left(\widehat{d}_{21}, \widehat{s}_{21}\right) \mid \widehat{\alpha}''_{21} < \alpha^*_{21} \right\} \\ R_2 &= \left\{ \left(\widehat{d}_{21}, \widehat{s}_{21}\right) \mid \widehat{\alpha}''_{21} \geq \alpha^*_{21}, \widehat{\alpha}'_{21} < \alpha^*_{21} \right\} \\ R_3 &= \left\{ \left(\widehat{d}_{21}, \widehat{s}_{21}\right) \mid \widehat{\alpha}'_{21} \geq \alpha^*_{21}, \widehat{\alpha}'_{21} < \alpha^*_{11} \right\} \\ R_4 &= \left\{ \left(\widehat{d}_{21}, \widehat{s}_{21}\right) \mid \widehat{\alpha}'_{21} \geq \alpha^*_{11} \right\}\end{aligned}$$

These sets are all non-empty since $\widehat{\alpha}'_{21} < \widehat{\alpha}''_{21}$ whenever $\widehat{d}_{11} \in \Theta^{d\varepsilon}_{11}$ and $\widehat{s}_{11} \in \Theta^{s\varepsilon}_{11}$.

For some fixed $\widehat{d}_{11} \in \Theta^{d\varepsilon}_{11}$ and $\widehat{s}_{11} \in \Theta^{s\varepsilon}_{11}$, let

$$U^1\left[r_{11}\left(\widehat{d}_{21}, \widehat{s}_{21}\right), r_{21}\left(\widehat{d}_{21}, \widehat{s}_{21}\right)\right]$$

be the expected utility of member 1 when member 2 has drawn $\left(\widehat{d}_{21}, \widehat{s}_{21}\right)$, member 1 votes for r_{11}, and member 2 votes for r_{21}. The payoff for member 1 from withholding his information from member 2 in the proposed equilibrium is

$$E\left\{U^1\left[r_{11}\left(\widehat{d}_{21},\widehat{s}_{21}\right),\underline{r}_1\right] \mid \left(\widehat{d}_{21},\widehat{s}_{21}\right)\in R_1\right\}\Pr\left[\left(\widehat{d}_{21},\widehat{s}_{21}\right)\in R_1\right]$$
$$+\sum_{i=2}^{4}E\left\{U^1\left[r_{11}\left(\widehat{d}_{21},\widehat{s}_{21}\right),\overline{r}_1\right] \mid \left(\widehat{d}_{21},\widehat{s}_{21}\right)\in R_i\right\}\Pr\left[\left(\widehat{d}_{21},\widehat{s}_{21}\right)\in R_i\right],$$

while his payoff from disclosing information is

$$\sum_{i=1}^{2}E\left\{U^1\left[r_{11}\left(\widehat{d}_{21},\widehat{s}_{21}\right),\underline{r}_1\right] \mid \left(\widehat{d}_{21},\widehat{s}_{21}\right)\in R_i\right\}\Pr\left[\left(\widehat{d}_{21},\widehat{s}_{21}\right)\in R_i\right]$$
$$+\sum_{i=3}^{4}E\left\{U^1\left[r_{11}\left(\widehat{d}_{21},\widehat{s}_{21}\right),\overline{r}_1\right] \mid \left(\widehat{d}_{21},\widehat{s}_{21}\right)\in R_i\right\}\Pr\left[\left(\widehat{d}_{21},\widehat{s}_{21}\right)\in R_i\right],$$

which is strictly larger his payoff from withholding since

$$U^1\left[r_{11}\left(\widehat{d}_{21},\widehat{s}_{21}\right),\underline{r}_1\right] > U^1\left[r_{11}\left(\widehat{d}_{21},\widehat{s}_{21}\right),\overline{r}_1\right]$$

whenever $\left(\widehat{d}_{21},\widehat{s}_{21}\right)\in R_2$. Thus, there cannot exist an equilibrium in the first period in which member 1 withholds information. Similar arguments show that there also cannot exist an equilibrium in which member 2 withholds information in the first period. Thus, the equilibrium of the communication game in the first period features full disclosure.

Now consider the communication game in period 2. Since all information in period 1 continues to be public information, the game is isomorphic to the game in period 1. Therefore, the equilibrium of the period 2 communication game is also full disclosure. Repeating this argument ad infinitum gives the result. ■

3.A.3 Proof of Proposition 3.3

Proof. In the proof, all expectations taken at time t are understood to depend on $\{\widehat{\pi}_\tau\}_{\tau=1}^{t}$ as well as the variables explicitly noted. Suppose that $\overline{\theta}_i = \overline{\theta}_d$ for all possible appointees. Let

$$\underline{R}_t = \left\{ \{d_\tau, s_\tau\}_{\tau=1}^{t} \mid \begin{array}{l} E\left[(\pi_t-\pi^*)^2 \mid \{d_\tau,s_\tau\}_{\tau=1}^{t},\underline{r}_t\right] \geq \\ E\left[(\pi_t-\pi^*)^2 \mid \{d_\tau,s_\tau\}_{\tau=1}^{t},\overline{r}_t\right] \end{array} \right\}$$

and

$$\overline{R}_t = \left\{ \{d_\tau, s_\tau\}_{\tau=1}^{t} \mid \begin{array}{l} E\left[(\pi_t-\pi^*)^2 \mid \{d_\tau,s_\tau\}_{\tau=1}^{t},\overline{r}_t\right] > \\ E\left[(\pi_t-\pi^*)^2 \mid \{d_\tau,s_\tau\}_{\tau=1}^{t},\underline{r}_t\right] \end{array} \right\}.$$

Now, the expected utility of the committee designer at time t computed in the first period is equal to

$$
\begin{aligned}
&E\left[(\pi_t-\pi^*)^2\right] = \\
&\left\{\begin{array}{l}
E\left[(\pi_t-\pi^*)^2 \mid \{d_\tau, s_\tau\}_{\tau=1}^t \in \underline{R}_t, \underline{r}_t\right] \times \\
\Pr\left[r_t=\underline{r}_t \mid \{d_\tau, s_\tau\}_{\tau=1}^t \in \underline{R}_t\right] + \\
E\left[(\pi_t-\pi^*)^2 \mid \{d_\tau, s_\tau\}_{\tau=1}^t \in \underline{R}_t, \overline{r}_t\right] \times \\
\Pr\left[r_t=\overline{r}_t \mid \{d_\tau, s_\tau\}_{\tau=1}^t \in \underline{R}_t\right]
\end{array}\right\} \Pr\left[\{d_\tau, s_\tau\}_{\tau=1}^t \in \underline{R}_t\right] + \\
&\left\{\begin{array}{l}
E\left[(\pi_t-\pi^*)^2 \mid \{d_\tau, s_\tau\}_{\tau=1}^t \in \overline{R}_t, \underline{r}_t\right] \times \\
\Pr\left[r_t=\underline{r}_t \mid \{d_\tau, s_\tau\}_{\tau=1}^t \in \overline{R}_t\right] + \\
E\left[(\pi_t-\pi^*)^2 \mid \{d_\tau, s_\tau\}_{\tau=1}^t \in \overline{R}_t, \overline{r}_t\right] \times \\
\Pr\left[r_t=\overline{r}_t \mid \{d_\tau, s_\tau\}_{\tau=1}^t \in \overline{R}_t\right]
\end{array}\right\} \Pr\left[\{d_\tau, s_\tau\}_{\tau=1}^t \in \overline{R}_t\right]
\end{aligned}
$$

Expected utility reaches a maximum when there is at least one member for whom $\gamma_i^d \to \infty$ and one member for whom $\gamma_i^s \to \infty$ because in this case $\Pr\left[r_t = \overline{r}_t \mid \{d_\tau, s_\tau\}_{\tau=1}^t \in \underline{R}_t\right] \to 0$ and $\Pr\left[r_t = \underline{r}_t \mid \{d_\tau, s_\tau\}_{\tau=1}^t \in \overline{R}_t\right] \to 0$. This follows from the fact that members share their private information with each other prior to voting. The result follows from the continuity of $E\left[(\pi_t - \pi^*)^2\right]$ in $\overline{\theta}_i$, γ_i^d, and γ_i^s. ■

3.A.4 Proof of Proposition 3.5

Proof. Let $\widehat{\alpha}_t$ be the members' shared belief about α_t at time t. By (3.11)

$$\Pr\left[r_{1t} \neq r_{2t}\right] = \Pr\left[\frac{g(\overline{r}_t) - g(\underline{r}_t)}{2} < \widehat{\alpha}_t < \frac{g(\overline{r}_t) - g(\underline{r}_t)}{2} + \left|\widehat{\theta}_{1t} - \widehat{\theta}_{2t}\right|\right]$$

Since $\widehat{\alpha}_t$ has a continuous distribution for all t, a sufficient condition for the result to hold is $\left|\widehat{\theta}_{1t} - \widehat{\theta}_{2t}\right| \xrightarrow{p} 0$.

By standard results in Bayesian decision theory, the conditional distributions of $\theta \mid \{d_\tau, s_\tau, \widehat{\pi}_{\tau-1}\}_{\tau=1}^t$ for both members are normal with means $\widehat{\theta}_{1t}$ and $\widehat{\theta}_{2t}$. Let $\tilde{f}_t^1(\theta)$ and $\tilde{f}_t^2(\theta)$ be the associated probability density functions.

Now, since both members' prior distributions on θ assign positive probability to all subsets of $\mathbb{R}$, they are absolutely continuous with respect to each other; so, one can apply Proposition 1 in Kalai and Lehrer (1994), which implies

$$1 - \varepsilon \geq \frac{\tilde{f}_t^1}{\tilde{f}_t^2} \geq 1 + \varepsilon \tag{3.12}$$

for large enough t for all $\varepsilon > 0$. Since $\tilde{f}_t^i(\theta)$ are unimodal, (3.12) implies that $\left|\widehat{\theta}_{1t} - \widehat{\theta}_{2t}\right| < \delta$ for all $\delta > 0$ for large enough t. So, $\left|\widehat{\theta}_{1t} - \widehat{\theta}_{2t}\right| \xrightarrow{p} 0$, establishing the result. ■

Chapter 4

Policy Uncertainty and Precautionary Savings

4.1 Introduction

This paper uses German micro data and a quasi-natural experiment to provide new evidence on the empirical importance of precautionary savings, defined as "the additional saving that results from the knowledge that the future is uncertain" (Carroll and Kimball, 2007). The use of a quasi-natural experiment allows us to overcome the identification problem that often affects estimates of precautionary savings based on aggregate data. Micro data allow us to control for individual characteristics and thus for heterogeneity across individuals.

Our quasi-natural experiment draws on a sharp increase in the number of people who respond that they are "uncertain about the general economic situation" when asked a specific question in the German Gfk consumer survey which covers a sample of some 2,000 individuals. The increase in uncertainty - which occurs despite households expecting (on average) an improvement in the general economic situation and a fall in unemployment - was observed in the run-up to the general election held in September 1998. This election was one of the closest in postwar Germany (James, 2000) and ultimately marked the end of the Kohl era. We therefore view the increase in uncertainty as being driven by the election, its difficulty to call, and particularly the differential policies that might be pursued depending on the outcome.

We estimate the effect of the increase in uncertainty on household saving using a diff-in-diff estimator and household data from the German Socioeconomic Panel (GSOEP), an annual longitudinal study which now covers some 10,000 German households and provides information on numerous aspects of their life, including household composition, family biographies, employment, social security, earnings and health. Using data from repeated yearly surveys we build a panel which extends over a 6-year period (1995 to 2000) and contains 2,854 households yielding a total of about 17,000 observations. We use fixed effects to control for unobservable characteristics, such as differences across heads of households in their degree of risk aversion. We use civil servants as the control group in our diff-in-diff estimator because civil servants, with jobs for life and a separate (and protected) pension system, were unaffected by the two reasons that are the best candidates to explain the increase in uncertainty that we observe: concern about the effect of the election outcome on unemployment and on pension rules.

We find that household saving increases significantly following the increase in uncertainty about the future path of income: this suggests a significant precautionary saving motive. A household can increase its savings either by consuming less or by working more: departing from previous studies on precautionary saving we also analyze households' response in terms of their labour market choices, hours worked in the primary and (possibly) in secondary jobs by all working-age household members. We find evidence of a labour supply response by workers who can use the margin offered by part-time employment.

There is an existing literature that examines the effects of uncertainty on the economy. Bloom (2007, 2009) shows that uncertainty increases markedly in response to major economic and, most relevant for this paper, political shocks. His work shows that increased uncertainty reduces firm investment and hiring (2009), as well as R&D (2007). He does not consider the effect on households.

Gourinchas and Parker (2001) have investigated the role of precautionary saving using structural estimates of a dynamic stochastic model of households expenditure over the life cycle with uninsurable labour income uncertainty. They show that the precautionary saving motive is especially important at young ages while it becomes negligible for older households who, on average, hold large amounts of liquid wealth. Our data allow us to test whether the precautionary saving induced by the increase in uncertainty affects individuals differently depending on their age.

Fuchs-Schündeln (2008), examining the differential saving behaviour of East and West German households over the 1990s, finds that "the precautionary saving motive is essential" in order for her life-cycle model to be able to match this behaviour. Thus, there is already strong evidence that precautionary saving plays a role in German household behaviour.

Carroll and Kimball (2007) conclude their excellent survey of the empirical research on precautionary saving with these words: *"The qualitative and quantitative aspects of the theory of precautionary behavior are now well established. Less agreement exists about the strength of the precautionary saving motive. [...] Structural models that match broad* *features of consumption and saving behavior* [such as Gourinchas and Parker (2002), Cagetti (2003)] *tend to produce estimates of the degree of prudence that are less than those obtained from theoretical models in combination with risk aversion estimates from survey evidence. Direct estimates of precautionary wealth seem to be sensitive to the exact empirical procedures used, and are subject to problems of unobserved heterogeneity [...] A problem that plagues all these efforts is identifying exogenous variations in uncertainty across households."* Our experiment is immune from these problems.

We are not the first to follow this route: Lusardi (1998) splits households into groups distinguished by their self-assessed risk of job loss, and uses the groups with low or zero risk to estimate the importance of precautionary saving. Closer to our approach, Fuchs-Schündeln and Schündeln (2005), using data drawn from the same German survey, employ German civil servants as a control for group with low precautionary saving motives. Our paper differs from theirs in focus and timing; the focus of their paper is on the role of self-selection by risk-averse agents into safer careers which biases typical estimates of precautionary saving down, and they focus on the natural experiment of reunification as an exogenous shock to labour market risk for East Germans [1].

Our results are independent of the reasons why uncertainty jumped in the run-up to the 1998 election. It is nonetheless interesting to ask what could have produced such an increase in uncertainty. The 1998 election, which, as we mentioned, was one of the closest elections in postwar German history (even professional polling institutes failed to predict the swing in voting preference in the final election run, see James, 2000), was fought on two major themes beyond the obvious political themes of the personalities of the two candidates, Helmut Kohl and Gerhard Schröder, and the make-up of the government coalition after the election (Pulzer, 1999). The two themes were the high level of unemployment, particularly in the new Eastern Länder, and the incumbent government's "reform of the century", the 1997 pension reform which Schröder was pledging to revoke.[2] The possibility that Kohl's reform might be revoked was particularly prominent in the campaign because in order to justify the adoption of new pension rules Chancellor Kohl had explained to the German public that the existing system was unsustainable. The argument seemed convincing because under the existing rules by 2050 payroll contribution rates would need to reach 25%, from 18% in the mid-1990s (Borsh-Supan, 2003). The reform adopted by Kohl addressed these issues restricting the accrual of pension rights not based on contributions and gradually reducing the replacement rate from 70% to 67%. Over time the new law would have stabilized the payroll contribution rate at

[1] Also, as we discuss below, the papers use different measures of saving.

[2] This fact allows us, as we said, to use civil servants as the control group in our diff-in-diff estimator: German civil servants have lifetime jobs and Kohl's pension reform had left the generous pension entitlements of civil servants intact specifically excluding them from any change in pension rules.

around 21% (Schulze and Jochem, 2007). The possibility that Schröder might win the election and the pension system returned to an unsustainable path is thus a candidate explanation for the observed increase in uncertainty. Such an explanation appears consistent with the observation that while uncertainty about future economic conditions was increasing, German people were expecting (on average) an improvement in the general economic situation and a fall in unemployment.

Reform reversals, *i.e.* the adoption by one government of a new set of rules and their revocation by a subsequent government, are not infrequent. Underlying these experiences is often a 'war of attrition' among various groups in society, each trying to protect themselves and to shift the burden of the reform on someone else. Reforms of pay-as-you-go pension systems in countries where population growth is decelerating are a frequent example. There is rarely a disagreement on the fact that the rules will eventually have to be changed but, as one reform plan after the other is considered, decisions often keep being been postponed because political parties are unable to agree on how the burden should be shared between various groups in society and in particular between the young and the old [3]

Thus a political economy interpretation of our experiment is that such "wars of attrition" can have significant economic effects. People do not simply sit and wait. When a reform is motivated with the argument that the system in place is unsustainable, delays in adopting new rules, or the possibility that they might be revoked once adopted, do not simply perpetuate the status quo. They raise uncertainty and induce households to save more: consumption may fall and the economy might slow down for no other reason than the inability to agree on a reform.

Our results support the view that the revocation of Kohl's reform lowered private consumption contributing to the slowdown of the German economy at the start of this millennium. (The household saving rate, as a share of disposable income, increased in Germany precisely at the time of the debate surrounding pension reform: from below 10% of disposable income in the mid 1990's to 11% at the start of the millennium; something similar also happened in Japan). We find that German PAYG workers, the large majority in the population, saved more. For instance, a household that previously was holding savings constant at 9.8% of disposable income (the average saving rate in our balanced sample in 1998) would, *ceteris paribus*, have a saving rate of about 15.8% by the year 2000. Households whose pension status was affected by the Kohl reform and by its subsequent revocation also worked more, exploiting the margin provided by

[3]Boeri, Borsch-Supan and Tabellini (2001), using survey data, analyze the opinions of European citizens regarding pension reform trying to understand why a political consensus is so difficult to achieve. They find that conflicts of interests over welfare reform are generally aligned along three main dimensions: age, income, and the insider/outsider status in the labour market.

part-time employment. For instance, a head of household working only part-time, who previously worked 10 hours per week (the 10th percentile of part-time hours per week in our balanced sample in 1998), would increase her hours to around 19 hours per week (up to the 25th percentile).

4.2 The Quasi-Natural Experiment

In order to measure time-varying consumer uncertainty, we use the Gfk consumer survey which is the German component of the European Commission Consumer Survey. Conducted monthly, the survey asks about 2,000 German households to answer a number of both backward-looking and forward-looking questions; we focus on the forward looking component. The respondents choose from a menu of multiple choice answers for each question. The answers are all qualitative, and accord to a five-option ordinal scale: "+ +" (most positive answer), "+" (positive answer), "=" (neutral answer), "-" (negative answer), and "- -" (most negative answer); "Don't know" is an alternative answer. Using the responses to individual questions over the period 1994 - 2002, we calculate a measure of the mean answer (to measure the average response)[4], and also examine the "Don't know" answers separately as a measure of uncertainty.

Here, we focus on two specific questions taken from this survey. Figure 4.1 provides the mean and uncertainty measure to the question "How do you expect the general economic situation in this country to develop over the next 12 months?". Despite the improved outlook on average (top panel), there is a marked increase in uncertainty in the months that lead up to the September 1998 election (bottom panel), and this uncertainty seems to only fall back gradually over the following 3 years. Figure 4.2 shows that answers to the question "How do you expect the number of people unemployed in this country to change over the next 12 months?" follow a similar pattern; although unemployment is expected to decline (consistent with falling unemployment over the period), uncertainty increases around the election[5].

4.2.1 Timing

To study how households' saving and labour supply decisions respond to this increase in uncertainty we need to define both the period when uncertainty jumped, and, in order to employ the diff-in-diff approach, a treatment and a control group. We do this by

[4]We use the following mapping from qualitative answers in order to derive a quantitative measure of the average response: "++"= 2, "+"= 1 "="= 0, "−"= −1, "−−"= −2. Hence, a higher mean indicates a more positive response.

[5]The figure shows that a similar increase in uncertainty occurred earlier in the 1990s, but this increase was associated with a deteriorating labour market.

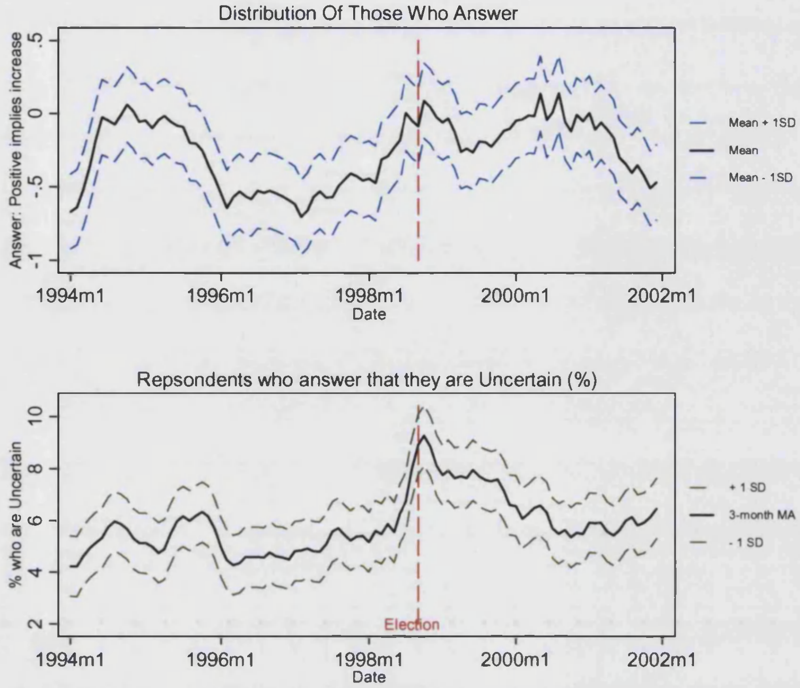


Figure 4.1: Gfk Consumer Survey: Expectations about the economics situation over the next 12 months.

defining an uncertainty dummy which corresponds to the period of increased uncertainty indicated in Figure 4.1. Thus, we define:

$$uncertainty_t = \begin{cases} 1 & \text{between August 1998 and December 1999} \\ 0 & \text{otherwise} \end{cases}$$

Although the election, which took place in September 1998, is the focal point of the uncertainty (the figures indicate that it is where the uncertainty peaks), we do not define the increase in uncertainty as occurring only then. Instead we allow for some anticipation of the close election. As shown in Figure 4.1 and 4.2, uncertainty begins to increase in the months leading up to the election; we use August 1998 as the start date of the uncertainty period. The end date, December 1999 is selected to coincide with the month in which general economic uncertainty first returns to the level in June 1998. In the econometric analysis below, we perform robustness tests allowing for less anticipation (a later start date for the uncertainty) and a slower return to the lower uncertainty state (a later end date).

Since we observe the month in which the interview is conducted, we can precisely identify those who answered in the uncertainty period. For instance, during the course

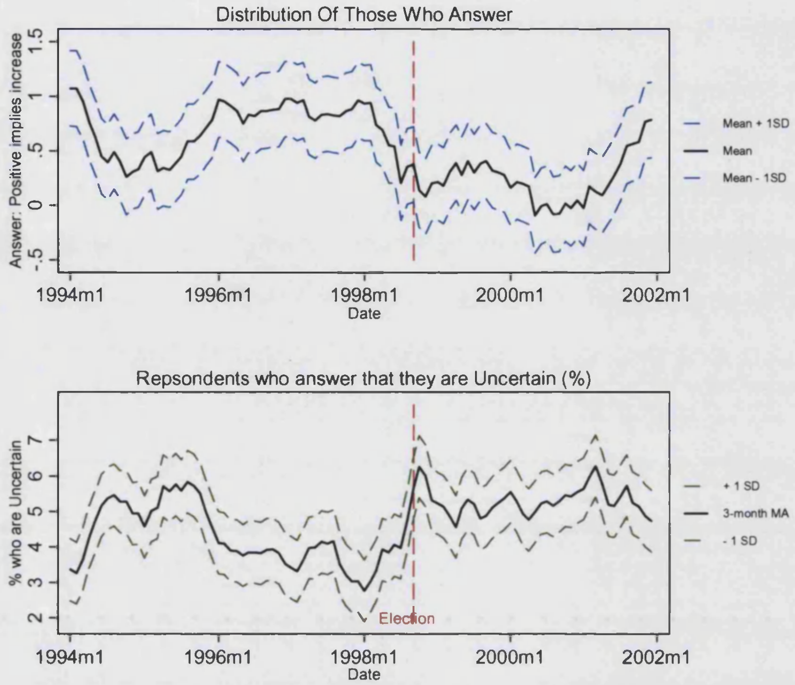


Figure 4.2: Gfk Consumer Survey: Expectations about unemployment over the next 12 months.

of 1998, we know which households were interviewed before July, and those which were interviewed after this date. Our sample includes the years from 1995 (three years before the election) to 2000 (2 years after the election) inclusive.

4.2.2 Treatment and Control Group

We identify the effect on household saving of the increase in uncertainty using a diff-in-diff estimator. The "treated group" includes those households who are likely to have been affected by the increase in uncertainty. Our "control group" consists of households whose head is a civil servant.

As discussed above, there were two main concerns in the run-up to the 1998 election that are the best candidates to explain the increase in uncertainty: concern about unemployment and concern about possible changes in the pension system. Unemployment had been a major economic issue in Germany since reunification. Figure 4.3 shows that in the run up to the 1998 election unemployment was falling. Nonetheless, there were concerns that unemployment was still persistently high in the New Länder. Moreover, following the end of government subsidies to construction, unemployment in this particular sector was rising. Policies affecting unemployment were, therefore, a major issue of the election.

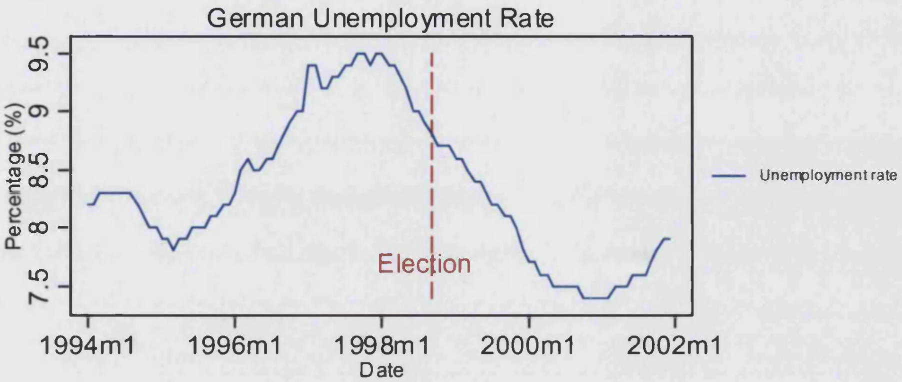


Figure 4.3: German Unemployment Rate

The other big election issue was pensions. Since the early 1990's Germany had gone through a long debate that increased the public's awareness about the unsustainability of the existing pay-as-you-go (PAYG) pension system. In August 1997 Chancellor Kohl announced a major reform explaining that the existing rules were no longer sustainable: the reform was adopted in December 1997 and was due to come into effect in 1999 (*des Rentenreformgesetzes* 1999, December 16, 1997). The main provision of the new law was the indexation of pension benefits to future gains in life-expectancy: over time this provision would have reduced the replacement rate from 70% to 67%. During the 1998 election campaign Gerhard Schröder made the revocation of this law one of his main campaign promises: when he won, one of the first decisions of the new Chancellor was to revoke Kohl's pension reform (*Rentenkorrekturgesetz*, November 20, 1998). Nothing happened on pension reform for almost three years, until the adoption (in 2001) of the Riester reform which, along with a gradual reduction of benefits, mostly encouraged enrolment in private pension plans. Though outside of our sample, the anticipation of this reform could have contributed to the decline in uncertainty that we observe in 2000.

The pension rights of civil servants had been insulated from the effect of the Kohl reform. This had happened through the adoption—at the end of January 1997 and thus before the Kohl reform—of a new set of rules for public sector employees. The main purpose of the new rules, (*Gesetz zur Reform des öffentlichen Dienstrechts*) which had come into force on July 1, 1997 was to create a more market-driven system for career civil servants, to introduce flexibility in work practices and performance-related pay, and to increase mobility across jobs. Among the many provisions of this law was a measure which marginally modified the rules of civil service pensions,[6] but de-facto safeguarded

[6]The reform involved civil servants contributing to the financing of their pensions through a fixed

the generosity of the system going forward, and more importantly insulated civil servants from the effects of reforms of the PAYG system that might be introduced in the future - and indeed the subsequent Kohl reform did not apply to civil servants.

With unemployment and pension reform being the most likely explanations for the observed increase in uncertainty, we are presented with a natural control/treatment distinction for our diff-in-diff estimator:

Civil Servants: Households headed by a civil servant constitute our "control" group. First, civil servants, with a job for life, face no labour income risk. Second, German civil service pensions are run separately from the PAYG system and, as we discussed, civil servants knew that their pensions rights would be insulated from the effects of the Kohl reform, whatever direction such reform might take.

Individuals who are not Civil Servants (Non-CS): The majority of the individuals in the GSOEP survey (about 64% in 1998) are members of the PAYG public pension system [7] and constitute our "treated group": people in this group face uncertainty with regard to both the future of their pension rights and unemployment.[8]

We thus define

$$treated_{i,t} = \begin{cases} 0 & \textit{if civil servant} \\ 1 & \textit{otherwise (non-CS)} \end{cases}$$

The diff-in-diff estimator that we shall use relies on the assumption that prior to the treatment, households in the treated and in the control group are indistinguishable, *i.e.*

reduction of 0.2% in the annual pay every year between 2001 and 2016.

[7]Membership in the PAYG pension system is mandatory for almost all German workers. To be eligible for a pension a worker's earnings must be above a certain threshold.

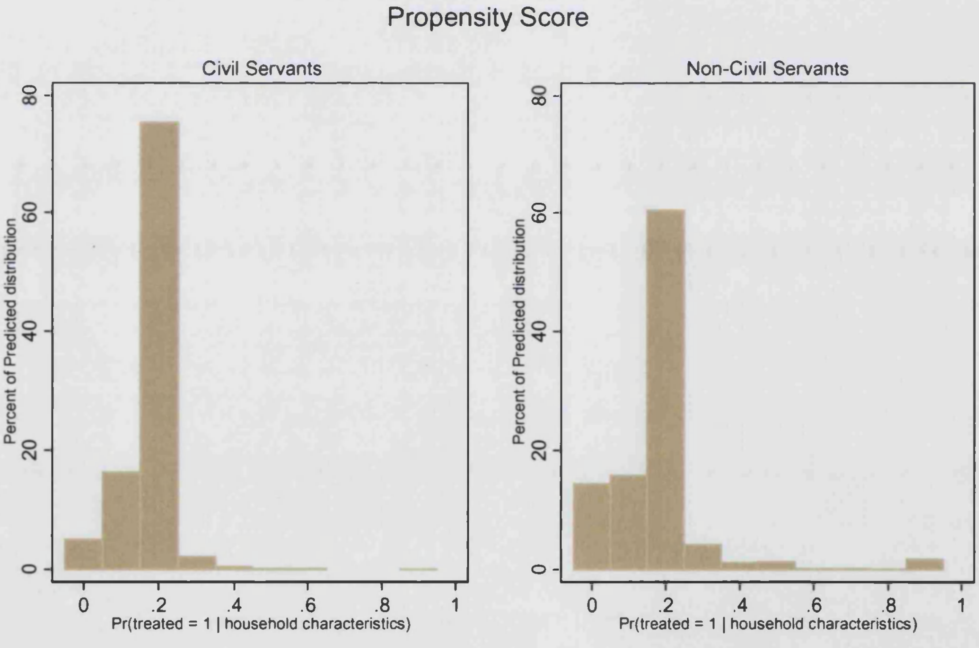
[8]We drop from our sample other groups which may or may not have been affected by the reform. Firstly foreign nationals, a group which is over-represented in the GSOEP survey, may have very different saving motives to German citizens. What is more, some may only be in Germany temporarily, or expect to leave Germany before retirement. If a person who has contributed to the public pension system leaves Germany before they can claim their pension, there are rules in place to treat their accrued pension wealth fairly. (These rules can be quite complicated and differ depending on where the person moves to. If they move to another EU country, then the years of pension contribution in Germany could count toward a public pension at home. If instead the person moves to outside the EU they can generally claim their contributions back. In either case, such a worker is likely to be less affected (if at all) by changes to the German public pension system.). As such, we eliminate all foreigners from our sample group.

Two other broad classifications of workers that we exclude are the self-employed and professionals. Self-employed workers can choose whether or not they wish to join the public pension system; this group will thus contain some members who are affected by the reform and others who are not. This group is also more difficult to link to the worries about unemployment. Professionals, such as lawyers, accountants, vets, doctors, etc., are required to join private pension plans and are thus unaffected by a reform of the public pension system. They are also less at risk (though not immune) from unemployment. In our analysis we exclude both groups.

Finally, we eliminate pensioners from the control and treatment groups. Most proposed reforms of the pension system protect the benefits of those already in retirement and pensioners are no longer part of the labour market. Pensioners should thus be unaffected by both types of uncertainty.

that the treatment is random. In other words, that households headed by a civil servant are similar to all other households except for the fact that they are headed by a civil servant. We have checked this assumption looking at "propensity scores". These are reported in Figure 4.4.

The horizontal axis in Figure 4.4 shows the estimated probability of being treated measured from a panel logit regression of "being treated"- that is being headed by a non-CS individual - on various controls including a household fixed effect. The vertical axis shows the percent of households in each group. We find controls and treated groups close to both extremes of the estimated probabilities of treatment. In the left panel, for instance, we find households headed by a civil servant that have a high probability of being treated, that is whose characteristics closely match those of the treated group, namely non-CS individuals. Symmetrically, the right panel of the figure shows that there are households headed by a non-CS individual who, considering their characteristics, might have been civil servants. This reassures us that the two groups are not too different from each other - that is that the assumption that the treatment is random, conditional on fixed effects, is not too extreme.

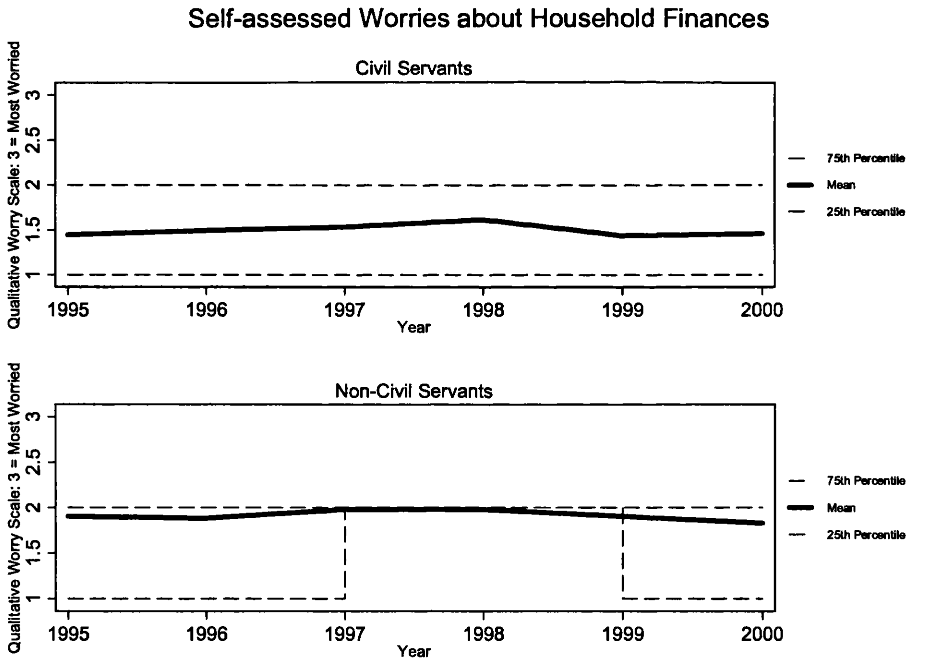


The horizontal axis shows the estimated probability of being treated measured from a panel logit regression of being treated - being affected by the uncertainty (a non-CS individual) - on various controls including a household fixed effect. The vertical axis shows the percent of households in each group.

Figure 4.4: Propensity Scores - Probability of Being Treated

Our diff-in-diff estimator also relies on there being some evidence that non-CS workers became more worried over the period 1998-2000, compared with civil servants. Unfortunately, we cannot decompose the responses used in Figures 4.1 and 4.2 into civil servants and others. Therefore, we instead use the answers to a GSOEP question which asks "Does your own financial situation worry you?". The mean, 25th percentile and 75th percentile of the distribution of answers in each year is shown in Figure 4.5. This figure shows that non-CS workers had an increase in worries (3 indicates the highest level of worry, 1 the least worry) around 1998 (the 25th percentile shifted up) that is unmatched by what happened to civil servants. Even though the question is not a perfect measure of the type of uncertainty depicted in the bottom panels of Figures 4.1 and 4.2, this is further comfort for us in the use of civil servants as the control group.

Figure 4.6, subject to the same caveats as the previous Figure, finds no major changes in the level of worries about job security. Notice that the absolute level of worry remains consistently lower, on average, for civil servants. Below, we shall make use of this self-assessed worry variable in order to control for time-varying individual concerns about job security, and how these might affect saving behaviour.



Baseline sample using GSOEP data: uses only households where the same respondent answers each year.

Figure 4.5: Worries about personal finances.

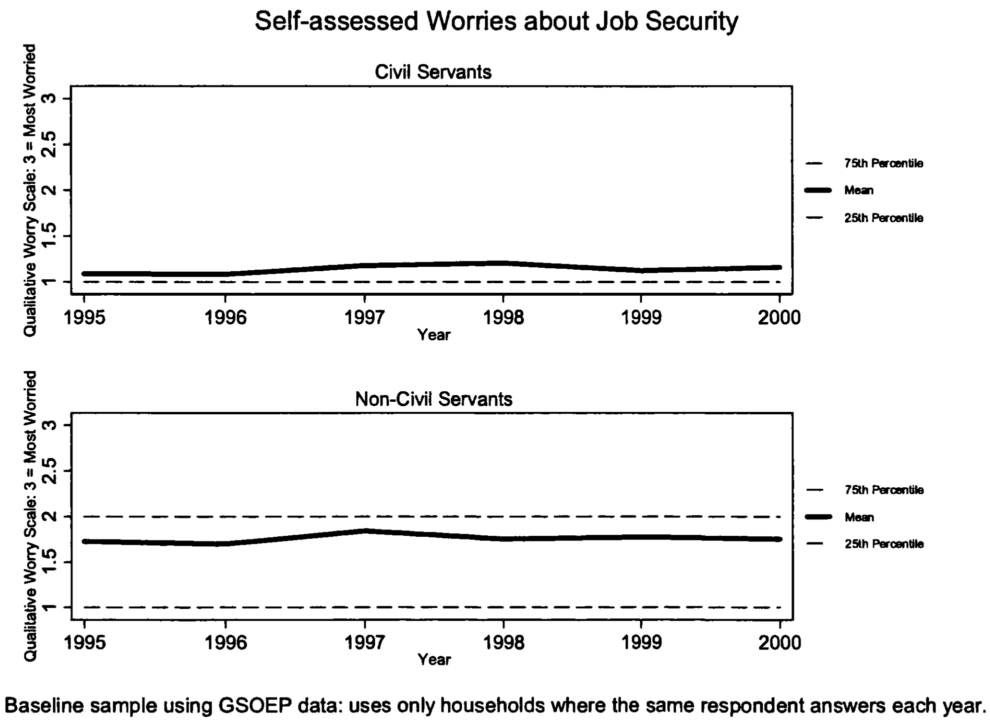


Figure 4.6: Worries about job security. We exclude the unemployment for whom the question does not apply.

4.3 Data

Our data are from the German Socioeconomic Panel (GSOEP). This survey, first conducted in 1984, is an annual longitudinal study which now covers some 10,000 German households providing information on numerous aspects of their life, including household composition, family biographies, employment, social security, earnings and health. The number of households surveyed rises over time since subsequent waves have increased the coverage of the sample, and attrition rates are low. Balanced samples over a sufficiently long number of years are relatively small: when we restrict our analysis to households who report their savings, the size of a balanced panel covering the 6-year period 1995-2000 contains 2,854 households yielding a total of about 17,000 observations.

Two main surveys are conducted each year. The first is an individual questionnaire in which *all adult household members* answer questions regarding their own situation. The second is a household questionnaire in which *the head of the household* is asked questions regarding the entire household. We combine the information from the two questionnaires.[9] From the first we obtain information about each member of the household: age,

[9]We also make use of the variables contained in the Cross-National Equivalent File (CNEF). These

education and employment status, which defines the future pension status, hours worked, etc. for each individual. From the second, we obtain information relating to the entire household: income, household taxes paid (including a separate measure of social security contributions), pension income received from both public and private sources, as well as demographic information such as marital status, number of children, area of residence, etc. The concept of saving we use thus refers to the entire household. The head of household is defined in the GSOEP as "the person who knows best about the general conditions under which the household acts". In most cases, this coincides with the main earner in the household although this not always the case. In order to establish the main public pension status of household, and whether or not it is affected by the reforms, we use the information on the main earner (in terms of gross income per annum) rather than on the GSOEP-defined head of the household; when we repeated our analysis using the GSOEP head of household data our results were qualitatively the same.

The GSOEP survey is generally conducted early in the year, although some respondents are interviewed as late as October and November. Using an "interview month" identifier, we can tell whether the interview happened during the period characterized by the increase in uncertainty.

We construct a balanced sample using six waves of the GSOEP survey: those from 1995 (three years before the election) to 2000 (the year before the Riester Law). Table 4.1 describes the characteristics of the 1,718 households included in the balanced panel (Table 4.1 considers their responses in 1998). The household proportions in terms of the key variables in the balanced sample are similar to those in the unbalanced data (not reported).

4.3.1 Household saving

The GSOEP survey asks about household savings posing the following question: *"Do you usually have an amount of money left over at the end of the month that you can save for larger purchases, emergency expenses or to acquire wealth?"* Households that answer "Yes" then provide the average amount of money left over in euro. The amount given as the answer to this question is our main household saving variable [10], which we then

data are also based on the GSOEP responses, but are constructed ex-post in order to provide variables that are comparable with the British Household Panel and Panel Study on Income and Dynamics (PSID) - see Burkhauser et al. (2001) for details. The variable we use to measure social security contributions comes from this dataset.

[10] Our measure of household saving differs from that used by Fuchs-Schündeln and Schündeln (2005) who use wealth levels as their dependent variable. To construct this variable these authors assume that each household receives an average return from the assets it holds. Such a definition however is subject

Table 4.1: Sample Size and Basic Household Characteristics: Balanced Sample

	Balanced Panel (1995-2000)		
	1998 data		
	Total	Civil Servants	Non-Civil Servants
Total who report income	1,924	167	1757
by household saving			
o/w positive saving	1,275	136	1139
o/w saving unreported	649	31	618
by labour force participation			
o/w full-time	1,655	161	1,494
o/w part-time	113	6	107
o/w unemployed	110	0	110
o/w out of the labour force	46	0	46

express as a percentage of household disposable income or, alternatively, of household consumption.

One problem with our survey data concerns those households who do not save (Households that answer "No"). The GSOEP survey reports saving only for those households that declare positive saving: if a household has zero or negative saving, the amount of saving is left unanswered or a zero is entered. Income is instead reported for all households. The number of households for which there is no information about saving is significant: for instance 619 out of 1,718 households in the balanced sample in 1998, or about 35% (see Table 4.1). Among the main earners of the household who do not report saving, 20% (in the balanced sample in 1998) are unemployed. The percentage of non-savers is reasonably constant along the age distribution. We treat those with non-reported savings as zero savers; in section 4.4 we discuss the truncation problem this choice might induce.[11].

A second problem with our definition of saving arises from the PAYG pension system.

to measurement error. The same stock of total assets will in general yield different returns depending on the particular asset composition: if this happened, households with identical stocks of assets would end up being attributed different stocks of wealth. The measure of saving reported in the GSOEP survey is immune from this problem since the question is directly about additions to the stock of wealth. Moreover, since our focus is on the reaction of household saving to a sudden increase in uncertainty; it is unlikely that household wealth (a stock) will immediately be affected by the sudden change in the saving rate (the flow). We therefore choose to examine the reported saving of households. In a more recent paper, Fuch-Schündeln (2008) measures flows into financial wealth using the same measure of saving as we do in this paper.uses the same measure of saving as we do to measure flows into financial wealth.

[11]In an appendix to Giavazzi and McMahon (2008), we follow Browning and Leth-Petersen (2003), amongst others, and impute saving rates for those for whom no saving is reported. The results are little changed when we use the sample which also includes estimated negative saving by households who do not report saving.

The answers to the question about saving miss two portions of actual household saving. First, social security contributions by workers and by firms [12], which are not reported as savings although they are a form of saving (which increases with income). Thus reported savings increase over a person's working life by less than "true"saving. Second, the pension payments an individual receives are misreported as income, rather than being considered negative savings. Thus reported savings remain positive even after retirement when actual savings are likely to be negative [13]. A similar problem arises for private pension plans. In the GSOEP survey, individual contributions to such plans are correctly reported as saving [14], but money withdrawn from a private plan is incorrectly reported as income. The bottom line is that the savings reported in the GSOEP answers represent a fraction of actual household saving.

This problem is discussed in Poterba (1994) and its implications are shown in Figure 4.7. Poterba shows that the age profile of the German saving rate (defined as the ratio of reported saving to disposable income in 1998) is at odds with the life cycle hypothesis: the difference is particularly sharp when compared with the US profile obtained from the PSID survey and reported in Poterba, 1994. Rather than hump-shaped, as implied by the life-cycle hypothesis, the saving rate of German households seems to be unaffected by an individual's age [15]. Figure 4.7 shows the saving rate once we correct it, as discussed above, by including contributions to social security and excluding pension benefits from the measure of disposable income. (This correction and the variables used to compute it are discussed in detail in the Appendix posted on our websites). The 'corrected' age-saving profile resembles more closely that predicted by the life-cycle hypothesis. As expected, correcting saving rates boosts the saving rate of those in employment, and causes positive reported saving to become negative for retirees. But since we exclude pensioners from our main sample, we shall proceed using the reported saving rate as this is the margin of total saving which is likely to be affected by any precautionary motives and can be adjusted more directly by household behaviour[16].

Table 4.2 (top panel) shows sample statistics on the reported saving rates (as a percentage of disposable income) by pension status of the head of household. Reported saving

[12]We do not observe social security contributions paid by firms. Consistent with the rules of the German social security system we assume that firms pay a contribution on behalf of their workers equal to that paid by the workers themselves.

[13]To be precise, the mis-reporting does not concern the total pension payments received, since part of these are an implicit return on pension wealth, and therefore are indeed income. We have overlooked this fact. For a discussion of this correction see Jappelli and Modigliani (2005).

[14]We do not observe contributions to private pension plans possibly made by firms and we thus overlook them.

[15]This fact is well known from the work of Borsch-Supan et al. (1991, 2001) and Borsch-Supan (2003). Poterba (1994) makes the same observation for Japan.

[16]Also, in Giavazzi and McMahon (2008) we show that our estimates are robust to the use of corrected saving rates, rather than reported saving rates, as the dependent variable.

rates are generally similar across groups, and all groups display a wide within-group variation. The overall mean reported saving rate, as a percent of disposable income, is 9%: this is slightly higher for civil servants (10%). Though some respondents claim to save almost 90% of their disposable income, the reported saving rate for high savers (90th percentile) is 22%.

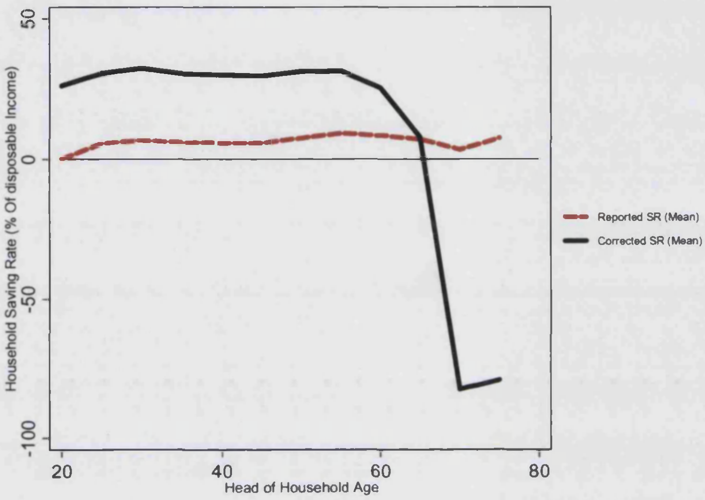


Figure 4.7: Reported and Corrected Saving Rates in Germany in 1998 by age of the head of the household. (Source: authors calculations using all 1998 GSOEP data)

Households differ not only in the level of their savings but also in their trend. Figure 4.8 shows the mean, median and key percentiles of the saving rate by public pension status. Two points are important; first, the average non-CS household has reduced the level of saving over the period in question, while civil servants have (on average) increased their saving slightly. Second, there are numerous non-CS households that have been increasing their saving rate, but also many that have been lowering it; the same is true for households headed by a civil servant. Because fixed effects on levels cannot capture these trend differences we use the first difference of the saving rate as our dependent variable; once we include a fixed effect in such a regression, any trend differences will be eliminated, allowing us to focus on how households have changed their behaviour around their trend.

4.3.2 Hours Worked

The GSOEP survey reports the hours worked by the head and other members of the household each week in their main job and, possibly, in other, secondary, jobs. The question asked is: '*How many hours do your actual working-hours consist of, including*

Table 4.2: Summary Statistics by $treated_{it}$ in 1998: Balanced sample, 1995-2000

Variable		Statistics									
		N	mean	sd	min	max	p10	p25	p50	p75	p90
Reported Saving Rate	All	1924	9	10	0	87	0	0	6	13	23
(% of disp. income)	Non-CS	1757	9	10	0	87	0	0	6	13	23
	Civil Servant	167	10	10	0	59	0	4	8	14	23
	All	1924	38	15	0	80	0	38	40	45	50
Hours	Non-CS	1757	38	15	0	80	0	38	40	45	50
	Civil Servant	167	40	10	0	78	30	39	40	45	50
	All	1924	1	1	0	6	1	1	1	2	2
Workers	Non-CS	1757	1	1	0	6	1	1	1	2	2
	Civil Servant	167	2	1	1	4	1	1	2	2	2
P-time Hours	All	113	21	10	0	70	8	15	21	29	34
(given P-time)	Non-CS	107	21	10	0	70	8	14	21	29	35
	Civil Servant	6	24	5	18	31	20	20	22	29	30
Weekly 2nd-Job Hours	All	1924	0.1	0.3	0.0	7	0.0	0.0	0.0	0.0	0.3
(given employed)	Non-CS	1757	0.1	0.3	0.0	7	0.0	0.0	0.0	0.0	0.4
	Civil Servant	167	0.1	0.2	0.0	3	0.0	0.0	0.0	0.0	0.2

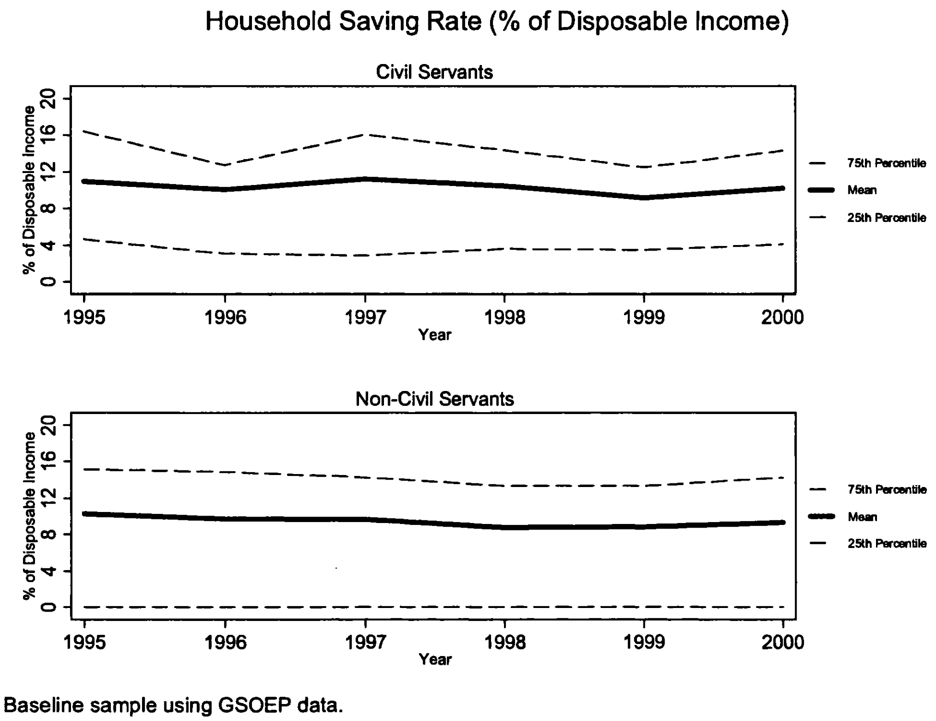


Figure 4.8: Distribution of Household Saving Rate (SR)

possible over time?'. We are able to identify whether a person works, in her main job, full-time, regular part-time or occasionally, from the answer to the question *'Are you currently engaged in paid employment? Which of the following applies best to your status?'.* Finally a related question asks respondents to ignore their main job, and consider additional employment (*'It is possible to work in addition to regular employment, household work, education and also as pensioner. How many days a month do you engage in this additional employment? How many hours on average on these days?');* the answer to this question allows us to construct a measure of hours worked in secondary employment.

Table 4.2 also reports descriptive statistics on the number of weekly hours worked by the head of household (3rd panel), the number of household members who work (4th panel), the average weekly hours of those household heads who works part time in their primary employment (about 10% of all those in employment, displayed in panel 5), and, in the final panel, the average number of hours worked in a 2nd job (by those who also have a main job). About 70% of households contain only a single worker (usually the head of household), and most heads of household work on average 30-40 hours per week. The main earner in a non-CS household is more likely to work part-time, while civil servants are more likely to work in a 2 (or more) workers household. Though some of the non-CS workers are employed for up to 4.5 hours per week in a second job, second jobs are very rare and even the 90th percentile of the distribution works an average of 0.3 hours per week in such employment. In fact only 32 of the 1197 employed non-CS workers in the balanced sample in 1998 engage in 1 hour or more of secondary employment per week (22 of these 32 work full-time in their primary employment; the remainder are part-time employed in their main employment). In the balanced sample of 109 civil servants, only 1 of these engage in secondary employment (in 1998).

4.4 Saving Results

Our baseline regression is

$$\begin{aligned}\Delta sr_{it} &= \beta_t + \theta x_{it} + \eta treated_{i,t} + \psi_1(cs\_reform_t \times cs_{it}) + \psi_2(cs\_reform_t) \\ &\quad + \delta_1 D(Kohl)_t + \delta_2 \left(D(Kohl)_t \times treated_{i,t}\right) \\ &\quad + \tau_1 uncertainty_t + \tau_2 \left(uncertainty_t \times treated_{i,t}\right) + \alpha_i + \varepsilon_{it} \qquad (4.1)\end{aligned}$$

where Δsr_{it} is the change in the saving rate measured in percentage points, α_i and β_t are household and time fixed effects respectively and x_{it} is a vector of controls (for instance the change in household disposable income). The coefficient we are most interested in is τ_2 which captures the differential effect of uncertainty on the treatment group; it tells us whether the behavior of treated households - those affected by the increase in uncertainty - differs from the behavior of our controls. A positive value of τ_2 is a measure of the extent of precautionary saving.

As discussed in the previous section, the saving rates of the individual households in our sample display different trends and therefore to estimate the response of the household saving rate to the treatment, and to separate this effect from the trend behaviour, we use, as dependent variable, the change in the saving rate and include household fixed effects. An additional advantage of using the change in saving rates as our dependent variable is that those households who move from zero to positive saving, or vice versa, can be analysed in the same regression without worrying about the truncation at zero of our dependent variable.

However, we may still have the truncation problem resulting from the fact that some members of sample, whom we record as having zero saving, actually have negative saving. To the extent that these households have zero reported saving, when they are actually running down their wealth, we may overstate or understate the precautionary saving reaction we find. If households begin to report negative saving because of the uncertainty, then we would be overstating the effect. Similarly, if civil servants who report negative saving were to react to the uncertainty period by dissaving less (despite the fact that the main sources of uncertainty do not affect them), then, by continuing to record them as (unchanged) zero savers, we would again overstate the effect of uncertainty. As there is no marked divergence in zero-saving between civil service and non-CS individuals in the uncertainty period, we do not believe that these potential problems are driving the results.

We also discussed above how there had been, prior to the uncertainty associated with the electoral campaign, two pension-related policy changes which may influence the behaviour of household saving of the treated and control groups in a differential way. It is, therefore, necessary to control separately for these changes. For households in which the head of the household is a civil servant, we control for the change in civil service pensions rules using a "reform" variable, and its interaction with a civil service dummy:

$$cs\_reform_t = \begin{cases} 1 & \text{after January 1997} \\ 0 & \text{otherwise} \end{cases}$$

For the all other households, *i.e.* those in which the head-of-household is not a civil servant, we define a variable to control for the year in which the pension reform proposed by Chancellor Kohl was announced:

$$D(Kohl)_t = \begin{cases} 1 & \text{between August 1997 and September 1998} \\ 0 & \text{otherwise} \end{cases}$$

This variable is also interacted with the $treated_{it}$ dummy. The coefficient τ_1 thus captures a more standard effect: the shift in the saving rate resulting from the announcement of Kohl's pension reform by those households who were affected. A positive value of τ_1 indicates that households whose pension status was affected by Kohl's reform increased their savings (more precisely shifted the change in their saving rate up) offsetting the cut in pension wealth.

Our baseline results use the standard definition of saving—reported saving as a percent of disposable income—and are obtained from the balanced panel extending over six years, 1995-2000. The results are presented in Table 4.3[17]. The first column of the table shows the baseline results: along with controls for unemployment and the change in income, the regression includes time and household fixed-effects. The estimate of τ_2 (reported in the second row of Table 4.3) is both statistically (at the 95% level) and economically significant. A coefficient of 3 indicates that the uncertainty induced treated households to, on average, increase the *change* in their saving rate by 3 percentage points per year.

[17]Some of the control variables are dropped automatically by Stata due to multicollinearity; this is especially the case when 0-1 dummies correlate perfectly with fixed effects variables. Such variables are marked with a "-" in the coefficient cells of the tables.

This means, for instance, that a treated household that previously was holding savings constant at 9.8% of disposable income (the average saving rate for the balanced sample in 1998) would, *ceteris paribus*, have a saving rate of about 15.8% by the year 2000.

Column (2) adds controls for the labour market: the included variables are worries about job security (discussed above), an indicator of whether the household lives in one of the new Länder, as well as a dummy variable indicating whether the head of household's employment was in the construction industry. In column (3) we repeat the regression in column 2 but drop observations where the head of household is unemployed; dropping unemployed households ensures that the results are not driven by the presence of unemployed non-CS workers (since there are no unemployed civil servants in the sample).

Column (4) excludes any construction workers from the sample, and column (5) uses only non-construction workers living in the former West Germany; Fuchs-Schündeln (2008) shows that East German households may still be reacting to the large shock of reunification. In all cases our uncertainty effect remains both statistically and economically significant.

In these regressions, our estimates of τ_1 (reported in the first row of Table 4.3) capture a time effect from the entire period of uncertainty and therefore, despite being negative and statistically significant, should not be interpreted in isolation from other year dummies. The estimates of δ_2 indicate that households affected by Kohl's reform do appear to have responded to the news by changing the path of their saving rate so as to offset the cut in pension wealth.[18]

We now run a few robustness tests concerning our uncertainty variable. Column (1) of Table 4.4 reproduces, for comparison, column (2) of Table 4.3 (balanced sample with labour market controls). Column (2) uses $uncertainty_t = 1$ between October 1998 and December 1999 (*later start*), Column (2) uses $uncertainty_t = 1$ between July 1998 and June 2000 (*later end*), and, finally, Column (4) uses $uncertainty_t = 1$ between October 1998 and June 2000 (*both later*). In all cases the uncertainty effect remains statistically significant.

We next ask whether the identified effect on saving is age-dependent. Since our results suggest that greater uncertainty about the future of pensions induces higher precautionary

[18]This substitutability between private and public pension wealth is similar to the findings of Attanasio and Brugiavini (2003). They find that Italian households increased private saving in response to 1992 pension reform which reduced public pension wealth.

Table 4.3: Saving Regressions - Baseline results using the reported saving rate

	(1) ΔSR (% income)	(2) ΔSR (% income)	(3) ΔSR (% income)	(4) ΔSR (% income)	(5) ΔSR (% income)
$uncertainty_t$	-5.0**	-5.0**	-5.1**	-4.9**	-4.8**
	(-2.29)	(-2.29)	(-2.32)	(-2.23)	(-2.23)
$uncertainty_t \times treated_{i,t}$	3.0**	2.9**	3.0**	2.8**	2.7**
	(2.09)	(2.07)	(2.09)	(2.01)	(1.97)
$treated_{i,t}$	-0.1	0.0	-0.2	0.1	-1.0
	(-0.13)	(0.0099)	(-0.14)	(0.069)	(-0.81)
D(unemployed)$_{it}$	-2.6***	-1.7**	-	-1.5**	-
	(-4.75)	(-2.53)		(-2.15)	
Δ income	-0.003***	-0.003***	-0.003***	-0.003***	-0.003***
	(-10.4)	(-10.4)	(-10.1)	(-10.6)	(-8.40)
$D(Kohl)_t$	-3.6	-3.5	-4.1	-3.0	-3.4
	(-1.23)	(-1.21)	(-1.38)	(-1.01)	(-1.17)
$D(Kohl)_t \times treated_{i,t}$	2.7*	2.7*	2.6*	2.5	2.4
	(1.78)	(1.76)	(1.72)	(1.63)	(1.61)
cs_reform_t	-0.4	-0.4	-0.5	-0.3	-0.7
	(-0.69)	(-0.68)	(-0.96)	(-0.58)	(-1.05)
$cs\_reform_t \times cs_{it}$	2.7*	2.6*	2.8**	2.4*	2.5*
	(1.89)	(1.85)	(1.97)	(1.70)	(1.81)
Job Worries$_{it}$		0.3**	0.3**	0.2*	0.4**
		(2.15)	(2.01)	(1.67)	(2.58)
$D(East_{it})$		-1.9	-2.8		
		(-0.88)	(-1.23)		
$D(Construction_{it})$		0.5	0.1		
		(0.80)	(0.21)		
Constant	-0.4	-0.5	-0.1	-0.1	-0.5
	(-0.39)	(-0.41)	(-0.056)	(-0.081)	(-0.38)
Control			Civil servants		
Balanced Sample			1995-2000		
Observations	11594	11594	10963	10602	7444
Number of households	1971	1971	1969	1919	1332

All regressions include household fixed-effects and time fixed-effects.
t statistics in parentheses, *** p¡0.01, ** p¡0.05, * p¡0.1.
"-" in the coefficient cells of the table indicates variables dropped automatically due to multicollinearity.

savings, we are interested in whether it occurs throughout the age distribution; Fuchs-Schündeln (2008) shows that the impact of a change in economic regime, induced by Ger-

Table 4.4: Saving Regression - Robustness Regressions

	(1) ΔSR (% income)	(2) ΔSR (% income)	(3) ΔSR (% income)	(4) ΔSR (% income)
$uncertainty_t$.	-5.0**	-4.4	-4.1**	-3.5*
	(-2.29)	(-0.85)	(-2.52)	(-1.90)
$uncertainty_t \times treated_{i,t}$	2.9**	2.0*	3.0**	2.8**
	(2.07)	(1.84)	(2.18)	(2.02)
$treated_{i,t}$	0.0	0.0	0.0	0.0
	(0.0099)	(0.0022)	(0.035)	(0.026)
D(unemployed)$_{it}$	-1.7**	-1.7**	-1.7**	-1.7**
	(-2.53)	(-2.52)	(-2.53)	(-2.53)
Δ income	-0.003***	-0.003***	-0.003***	-0.003***
	(-10.4)	(-10.4)	(-10.4)	(-10.4)
$D(Kohl)_t$	-3.5	-2.3	-3.1	-2.9
	(-1.21)	(-0.67)	(-1.09)	(-1.02)
$D(Kohl)_t \times treated_{i,t}$	2.7*	1.1	2.6*	2.6*
	(1.76)	(1.06)	(1.79)	(1.72)
cs_reform_t	-0.4	-0.2	-0.3	-0.3
	(-0.68)	(-0.35)	(-0.64)	(-0.61)
$cs\_reform_t \times cs_{it}$	2.6*	1.0	2.6*	2.5*
	(1.85)	(1.13)	(1.90)	(1.79)
Job Worries$_{it}$	0.3**	0.3**	0.3**	0.3**
	(2.15)	(2.14)	(2.13)	(2.13)
$D(East_{it})$	-1.9	-2.0	-2.0	-2.0
	(-0.88)	(-0.92)	(-0.89)	(-0.89)
$D(Construction_{it})$	0.5	0.5	0.5	0.5
	(0.80)	(0.82)	(0.81)	(0.81)
Constant	-0.5	2.8	0.1	-0.0
	(-0.41)	(0.52)	(0.049)	(-0.0053)
Control			Civil servants	
Balanced Sample			1995-2000	
Observations	11594	11594	11594	11594
Number of households	1971	1971	1971	1971

All regressions include household fixed-effects and time fixed-effects.
t statistics in parentheses, *** p¡0.01, ** p¡0.05, * p¡0.1.
"-" in the coefficient cells of the table indicates variables dropped automatically due to multicollinearity.

man reunification, affects different cohorts in a differential way. Gourinchas and Parker

(2001) suggest that the precautionary saving motive should be especially important at young ages, while it should become negligible for older households who, on average, hold large amounts of liquid wealth. Their model however excludes pension wealth. Our data allows to test whether the precautionary saving induced by the uncertainty regarding the future of pensions affects individuals differently depending on their age. Relatively older individuals have a shorter working-life horizon and thus must save relatively more to achieve a given increase in wealth. We investigate whether the effect of uncertainty on saving is age-dependent by estimating:

$$\begin{aligned}\Delta sr_{it} = \beta_t + \theta.x_{it} + \eta.treated_{i,t} + \psi_1(cs\_reform_t \times cs_{it}) + \psi_2(cs\_reform_t)\\ + \delta_1.D(Kohl)_t + \delta_2\,(D(Kohl)_t \times treated_{i,t})\\ + \tau_1.uncertainty_t + \tau_2.\,(uncertainty_t \times treated_{i,t})\\ + \tau_3.\,(Age_{it} \times uncertainty_t) + \tau_4.\,(Age_{it} \times uncertainty_t \times treated_{i,t})\\ + \alpha_i + \varepsilon_{it} \quad (4.2)\end{aligned}$$

The fixed effect regression is reported in column (1) of Table 4.5 and finds no significant effect of age on the extent to which households reacted to the uncertainty. However, including a time-varying age variable with fixed-effects may be problematic; demeaning age, as fixed effects does, would transform this variable in a year-of-birth-specific trend. Therefore, we have tested whether we could drop fixed effects; a Hausman test, which compares the consistent (though not necessarily efficient) fixed-effects model (FE) with a random effects model (RE), fails to reject the null hypothesis that the RE and the FE coefficients are identical ($Prob > \chi^2 = 0.71$). The random effects regression is reported in column 2 and our finding of no significant age effect is unchanged. We cannot reject the hypothesis that the effect of uncertainty on the treated group ($\tau_2 + \tau_4 \times Age_{it}$), for the range of ages within our sample, is 3 percentage points-the same as we find in the earlier regressions.

We also, in column (3) and (4) of Table 4.5, run equation 4.2 using a dummy variable which is 1 if the head of household is older than 50 years of age. We, again, find no differential impact of age on the results reported already.

4.5 Hours Results

As mentioned in the introduction, additional savings can be achieved either by consuming less or by working more. We analyze the effects on labour supply of the uncertainty by considering regressions similar to those just discussed but using, on the left-hand side, labour supply variables rather than the change in the saving rate. The German labour market is relatively rigid: it is unclear the extent to which work contracts allow employees to change their working hours; overtime is also strictly regulated. Workers however can adjust their labour supply using the margin offered to those in part-time employment or by taking 2nd jobs. As discussed above, around 10% of workers in our balanced sample are part-time workers, while very few work significant hours in second jobs - of the 2,046 non-CS workers in full- or part-time employment, only 49 work on average 1 hour or more per week in a 2nd job in 1998 (this number is reasonably constant across years).

Using various measures of hours worked we estimate the following equation using a household fixed effects specification:

$$\begin{aligned} hours_{it} &= \beta_t + \theta . x_{it} + \eta . treated_{i,t} + \psi_1 (cs\_reform_t \times cs_{it}) + \psi_2 (cs\_reform_t) \\ &\quad + \delta_1 . D(Kohl)_t + \delta_2 \left(D(Kohl)_t \times treated_{i,t} \right) \\ &\quad + \tau_1 . uncertainty_t + \tau_2 . \left(uncertainty_t \times treated_{i,t} \right) + \alpha_i + \varepsilon_{it} \end{aligned} \tag{4.3}$$

Relative to the baseline saving equation (equation 4.1), we omit the income control as this is endogenous to the amount of hours worked - the amount of hours worked is both determined by, and determines, the individual's income[19]. We include industry fixed effects to control for industrial differences in hours variables. We report the results in Table 4.6. In columns (1) - (3) , the object of the analysis is the number of hours worked by the head of household (as shown in Table 3, the majority of households contain only a single worker). In column (1) we consider total weekly hours worked by the head of the household in her primary employment. In column (2) we restrict the analysis to heads of household for whom primary employment is part-time. In columns (3) we use all households where the head of household was a part-time worker in 1996; this is designed to capture the effects of part-time workers potentially moving into full-time employment.

The estimate of τ_2, the diff-in-diff effect on hours of the uncertainty, varies depending on whether the head of household works full time or part time. In general (column 1) there is no evidence of a labour supply response - a result which is consistent with the rigidity of German labour contracts. However household heads who work only part-time - and thus presumably have more flexibility - do appear to use this flexibility: following

[19] In the saving regressions above, we worry less about this as the change in saving rates has a much less clear impact on income; the causality runs much more clearly from income changes to savings.

the revocation of the pension reform their hours increase significantly (at the 10% level); see columns (2) and (3). The point estimate, 9.1, means that a head of household working part-time, who previously worked 10 hours per week would have increased her hours to 19 hours per week—an economically significant increase.

In column (4) and (5) of Table 4.6 we shift the focus to the hours worked by other household members (excluding the hours worked by the head of household); column (4) considers all possible households, while column (5) focuses on the households headed by part-time workers (as in column (2)). There is no evidence in either case of a labour supply effect for these workers. We obtained similar, insignificant results (not reported here) when we investigated whether the number of workers increased in households affected by the revocation of the reform. Moreover, there is no evidence that the hours response is dependent on age.

4.6 Conclusions

The results in this paper are of interest from three different perspectives. First, we provide a direct measure of the importance of precautionary saving studying how households respond to an exogenous increase in uncertainty about the path of future income. Our estimates of precautionary savings are the result of a quasi-natural experiment and thus overcome the identification problem that often affects such measures; they also control for individual characteristics and thus for heterogeneity across individuals. Second, we find evidence that faced with an increase in uncertainty households respond adjusting their labour supply: they do so - in a highly regulated labour market - using the only margin that has some flexibility, part-time employment; this effect however is only marginally significant. Finally, while independent of the reasons why uncertainty jumped in the run-up to the 1998 election, our results are suggestive of the economic effects of "wars of attrition", *i.e.* situations in which reforms are delayed because political parties are unable to agree on how the burden of a reform should be shared between various groups in society. Delays in adopting a reform, or the possibility that a reform, after it has been adopted by one government may be revoked by another, raise uncertainty and induce households to save more: consumption may fall and the economy might slow down for no other reason than political uncertainty.

Table 4.5: Looking for an age effect of precautionary saving

	(1) ΔSR (% income)	(2) ΔSR (% income)	(3) ΔSR (% income)	(4) ΔSR (% income)
Fixed effects?	FE	RE	FE	RE
$uncertainty_t$.	-5.9	-6.1*	-5.1**	-4.5**
	(-1.43)	(-1.90)	(-2.28)	(-2.34)
$uncertainty_t \times treated_{i,t}$	4.2	4.7	3.1**	3.3**
	(1.08)	(1.57)	(2.07)	(2.49)
$treated_{i,t}$	-0.0	0.2	-0.0	0.2
	(-0.022)	(0.50)	(-0.0070)	(0.50)
D(unemployed)$_{it}$	-1.7**	-1.2**	-1.7**	-1.2**
	(-2.51)	(-2.45)	(-2.50)	(-2.45)
Δ income	-0.003***	-0.002***	-0.003***	-0.002***
	(-10.4)	(-9.91)	(-10.4)	(-9.90)
$D(Kohl)_t$	-3.5	-3.0	-3.5	-3.0
	(-1.21)	(-1.17)	(-1.22)	(-1.17)
$D(Kohl)_t \times treated_{i,t}$	2.7*	2.7**	2.7*	2.8**
	(1.76)	(2.02)	(1.76)	(2.03)
cs_reform_t	-0.4	-0.4	-0.4	-0.4
	(-0.67)	(-0.96)	(-0.67)	(-0.96)
$cs\_reform_t \times cs_{it}$	2.6*	2.7**	2.6*	2.7**
	(1.85)	(2.17)	(1.85)	(2.18)
Job Worries$_{it}$	0.3**	0.1	0.3**	0.1
	(2.14)	(1.25)	(2.14)	(1.25)
$D(East_{it})$	-1.9	-0.3*	-1.9	-0.3*
	(-0.88)	(-1.71)	(-0.88)	(-1.70)
$D(Construction_{it})$	0.5	0.0	0.5	0.0
	(0.82)	(0.037)	(0.82)	(0.036)
$Age_{it} \times uncertainty_t$	0.018	0.039		
	(0.24)	(0.67)		
$Age_{it} \times uncertainty_t \times treated_{i,t}$	-0.029	-0.035		
	(-0.36)	(-0.57)		
$D(Age_{it}) \times uncertainty_t$			0.181	0.310
			(0.12)	(0.27)
$D(Age_{it}) \times uncertainty_t \times treated_{i,t}$			-0.559	-0.316
			(-0.36)	(-0.27)
Constant	0.633	-0.442	-0.529	1.328
	(0.22)	(-0.19)	(-0.40)	(0.80)
Control	Civil servants			
Balanced Sample	1995-2000			
Observations	11594	11594	11594	11594
Number of households	1971	1971	1971	1971

All regressions include time fixed-effects.

t statistics in parentheses, *** p¡0.01, ** p¡0.05, * p¡0.1.

"-" in the coefficient cells of the table indicates variables dropped automatically due to multicollinearity.

Table 4.6: Labour Hours Regression

	(1)	(2)	(3)	(4)	(5)
		Head			Non-Head
	Hours	*Hours*	*Hours*	*Hours*	*Hours*
	All workers	Part-time	Part-time	All workers	Part-time
$uncertainty_t$.	0.0	-8.4	-12.1	0.8	-0.8
	(0.0092)	(-1.09)	(-1.60)	(0.81)	(-0.12)
$uncertainty_t \times treated_{i,t}$	-0.9	9.1*	9.2*	0.3	1.0
	(-0.78)	(1.72)	(1.81)	(0.53)	(0.21)
$treated_{i,t}$	-2.1**	-2.0	-7.1*	0.2	-0.0
	(-2.24)	(-0.33)	(-1.83)	(0.44)	(-0.0070)
D(unemployed)$_{it}$	-	-	-9.2***	-	-
			(-4.67)		
$D(Kohl)_t$	-4.289*	-7.678	-6.562	1.078	0.184
	(-1.75)	(-1.02)	(-0.87)	(0.76)	(0.027)
$D(Kohl)_t \times treated_{i,t}$	0.3	7.0	6.4	-0.1	0.8
	(0.27)	(1.27)	(1.21)	(-0.18)	(0.16)
cs_reform_t	-0.1	0.2	-0.2	-0.0	-1.4
	(-0.17)	(0.14)	(-0.10)	(-0.061)	(-1.33)
$cs\_reform_t \times cs_{it}$	-1.1	6.1	6.5	0.7	1.4
	(-1.00)	(1.09)	(1.29)	(1.09)	(0.28)
Job Worries$_{it}$	0.4***	0.5	-0.0	-0.1	-0.0
	(3.02)	(1.28)	(-0.0011)	(-1.22)	(-0.13)
$D(East_{it})$	-0.6	-	-	0.5	-
	(-0.31)			(0.48)	
$D(Construction_{it})$	0.2	12.6***	9.2	1.5	0.2
	(0.095)	(2.60)	(1.44)	(1.28)	(0.049)
Constant	45.7***	19.2**	40.8***	-0.8	3.8
	(20.4)	(2.06)	(4.41)	(-0.59)	(0.45)
Control			Civil servants		
Balanced Sample			1995-2000		
Observations	10520	611	629	10520	611
Number of households	1950	263	105	1950	263

All regressions include household fixed-effects, industry fixed effects and time fixed-effects.
t statistics in parentheses, *** p¡0.01, ** p¡0.05, * p¡0.1.
"-" in the coefficient cells of the table indicates variables dropped automatically due to multicollinearity.

Conclusion

As discussed in the introduction, the focus of this thesis is on macroeconomic policy and economic performance. I have made four broad contributions in this thesis:

1. My simple model of inventory-in-motion does reasonably well at matching a number of the stylised facts. However, importantly, the introduction of inventories does, within this framework, generate amplification and propagation of economic shocks.

2. Following from this, although it seems that improved inventory management may have contributed to the behaviour of some of the macroeconomic variables over the past quarter of a century, my model suggests that it is unlikely that it is inventory management alone, or even in a large way, that is responsible for the great stability experienced prior to the "credit crunch".

3. Using the combination of a theoretical model and the voting records of the the Bank of England MPC, it is shown in Chapter 3 that the commonly held intuition for why a mixed committee might outperform other committees does not necessarily hold true. In particular, there is evidence that despite the best attempts of the committee designer, if the committee members are worried about their reputation for various reasons, the gains of having a mixed committee can be reduced or even eliminated.

4. The empirical analysis in Chapter 4 gets around the problems that generally plague studies of precautionary saving by including household fixed effects to control for unobserved heterogeneity, and, at the same time, making use of a quasi-natural experiment around the time of a general election that was difficult to call and was fought on two main policy issues that the parties had different views on. The results indicate that the uncertainty induced by such political uncertainty, and by the subsequent delays in adopting reforms, can have real macroeconomic effects.

The results in this thesis highlight the tight-rope walked by policymakers: the good times may, or may not, have had anything to do with policy; and trying to change institutions for the better may not actually improve decision-making. On the other hand, waiting to decide what to do may actually be very costly.

While these results represent clear contributions to our understanding, there remains yet more to be done.

Beginning with the last Chapter, there is considerable interest in the effects of uncertainty on the macroeconomy and I believe that this paper provides further evidence that uncertainty, and perceptions of it, can have real economic effects. I would like to pursue a further analysis of whether the uncertainty induced changes are necessarily bed for welfare.

An obvious next step for the committee voting research set out in Chapter 3 is to develop a model that explicitly considers career concerns and the economic cycle. This would enable a full theoretical exploration of the potential interactions between the business cycle and reputation effects.

Further, by extending the analysis to other environments, such as corporate boards, this would widen the scope and importance of the results that we have found.

Following the experimental analysis of Blinder and Morgan (2005) and Lombardelli, Proudman, and Talbot (2005), we would like to extend this laboratory environment to allow for internal and external members in order to better understand what aspects of the career concerns are important.

Finally, the analysis in Chapters 1 and 2 presents a number of opportunities for further research which I intend to follow up on.

I aim to extend the model to take account of both demand and supply shocks. Introducing both types of shocks would necessitate overcoming the computational difficulties introduced with a fourth state variable. Nonetheless, this remains a priority for future work as with demand shocks, I could explore the good monetary policy explanation in greater depth.

I also believe that recent papers, such as Van Nieuwerburgh and Veldkamp (2006) and Bullard and Singh (2009), which emphasise the issue of imperfect information may be important for further understanding the role that supply chains and inventories can have when they interact to generate greater volatility. I am beginning a project to explore these issues, and particularly to develop a general equilibrium business cycle model which takes the "bullwhip effect" of inventories seriously. This work could, potentially, reverse some of the results established in this paper about the role of inventories in the Great Moderation. In others words, this would allow me to take more seriously the impact of IT on improved forecasting of sales behaviour, and then see how this affects the volatility of GDP.

In addition, I intend to develop further the time aggregation results explored in my model. One problem with the framework used in Chapters 1 and 2 is that investment and storage inventory are assumed to have the same horizon. This means that the two are substitutes for any output not consumed. To overcome the dominance of the decision to invest in capital, in this paper I have included capital adjustment costs in my model, and I discussed why investment irreversibility was inappropriate. As an alternative, I have started to investigate the situation where the decision to store goods and to invest in goods have different horizons. For example, investment decisions may take one quarter to yield a return (as is standard in RBC quarterly models) while inventory storage is available on a month to month basis. I believe that this may yield important dynamic interactions between investment and stock holding.

Analyses of inventory behaviour at the aggregate level are potentially troublesome; the data has been aggregated across many heterogeneous sectors (see, for example, Imbs, Mumtaz, Ravn, and Rey (2005) for a discussion of the effect of aggregation biases). As such, I would like to carry out some industry, or even firm level analyses of the inventory-in-motion phenomenon discussed in Chapter 1.

The current crisis has not just affected the economy, it has ignited a large debate about the future of business cycle research. While there is clearly a need for a greater understanding of the role of banks in our models, there is a larger debate about whether the current paradigm, including as applied in Chapters 1 and 2 of this thesis, should continue to be the dominant conceptual framework. While I have not tried to answer this within this thesis, I hope to be able to continue to contribute positively to the field and, in doing so, help to tackle not only the challenges that we face now, but also those unforeseen challenges that we will face in the future.

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