ESSAYS IN MONETARY POLICY UNDER HETEROGENEOUS INFORMATION

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Est-ce que, ce qui fait la valeur des pièces, c'est les images qui sont dessus, ou quoi? ces demoiselles, ces femmes nues ou pas nues, les couronnes, les écussons? Ou bien les inscriptions peut-être? Ou bien leurs chiffres, disait-il, les chiffres qu'y met le gouvernement? Les inscriptions, on s'en fout, pas vrai? et les chiffres aussi, on s'en fout. Ça ne serait pas la première fois que le gouvernement vous tromperait sur la valeur et sur le poids, tout aussi bien qu'un particulier. Demandez seulement à ceux qui s'y connaissent. Le gouvernement vous dit: "Cette pièce valait tant; eh bien, maintenant elle vaudra tant..." Ça s'est vu, ça peut se revoir. C'est moins honnête que Farinet, les gouvernements, parce qu'à lui, ce qu'on lui paie, c'est en quoi ses pièces sont faites et, à eux, c'est ce qui est dessus...

Charles Ferdinand Ramuz[1]

[1]Charles Ferdinand Ramuz, *Farinet ou la Fausse Monnaie*, in: Roman II, Gallimard, Coll. "Bibliothèque de la Pléiade", 2005, p. 703.

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Chapter 1

Introduction

1.1 Money nonneutrality and imperfect common knowledge

There is wide agreement today in the economics profession about the role of monetary policy. While economists recognize classical results on the long-run neutrality of money, they agree, at the same time, on the existence of real effects of monetary policy in the short-run, as documented by Phillips (1958). Friedman (1968) was one of the first to express this ambivalent role of monetary policy:

> Monetary policy cannot peg [...] real magnitudes at predetermined levels. But monetary policy can and does have important effects on [...] real magnitudes. The one is in no way inconsistent with the other. (p. 11)

However, many economists at that time considered this dual role of money as paradoxical. For instance, Gurley (1961) parodied the monetary theory of Friedman in these words: "*Money is a veil, but when the veil flutters, real output sputters*" (p. 308). Constructing models that simultaneously account for the short-run Phillips curve and the long-run money neutrality, owing to agents' rationality, has been an important challenge for economists.

It is easy to understand why monetary policy affects nominal magnitudes in an economy. Indeed, classical economic models account for the (long-run) money neutrality. As the Ricardian hypothetical experiment suggests, an announced and fully expected monetary expansion will have a proportional effect on nominal magnitudes, leaving the real economy unaffected. But it is much harder to understand why variations in the nominal quantity of money do not immediately yield proportional variations in all nominal magnitudes such as prices and wages. Economists must think of some frictions that prevent the private sector from instantaneously reacting to variations in nominal magnitudes and that could explain the nonneutrality of monetary policy observed in reality. To address this issue, two fundamentally distinct approaches have been considered.

The first approach, initiated by Phelps (1970), postulates that private agents are not well enough informed about variations in nominal magnitudes to fully respond to them. Phelps develops a theory in which the short-run nonneutrality of money is obtained when transactions are made under incomplete information. Lucas (1972) formalizes this idea in an economy where private agents produce output in separate markets and observe the market-clearing price at which they can sell their own output, but ignore market-clearing prices realized in other markets. The market-clearing price in each market depends on both the nominal aggregate level of expenditure (on all markets) and the relative demand for the particular good produced in each market. Because of information incompleteness, private agents cannot disentangle the rationale behind variations in the market-clearing price. For instance, an increase in nominal aggregate level of expenditure can be interpreted as an increase in the relative demand for the good produced in that particular market. As a result, real magnitudes respond positively to variations in nominal magnitudes in the short run, but not in the long run, once agents have got enough information to distinguish nominal from real variations. Lucas underlines that the short-run "*Phillips curve emerges not as an unexplained empirical fact*" (p. 122) but is consistent with rational expectations in each market since economic agents are free of money illusion.

Appealing though the Lucas model may seem, it has been subjected to some criticisms. In particular, the model does not capture the persistence of business fluctuations observed in reality. Indeed, according to this model, variations in nominal magnitudes have a real effect only in the period in which they occur since they become common knowledge[1] in the subsequent period. Attempts to overcome this criticism led economists to consider richer information structures. For example, Townsend (1983) shows, within an investment model, how higher-order expectations[2] can create an additional source of persistence in real fluctuations when the economic environment is characterized by strategic complementarities and heterogeneous information. This is reminiscent of the beauty contest metaphor by Keynes (1936):

> "[. . .] professional investment may be likened to those newspaper competitions in which the competitors have to pick out the six prettiest faces from a hundred photographs, the prize being awarded to the competitor whose choice most nearly corresponds to the average preferences of the competitors as a whole; so that each competitor has to pick, not those faces which he himself finds prettiest, but those which he thinks likeliest to catch the fancy of the other competitors, all of whom are looking at the problem from the same point of view. It is not a case of choosing those which, to the best of ones judgment, are really the prettiest, nor even those which average opinion genuinely thinks the prettiest. We have reached the third degree where we devote our intelligences to anticipating what average opinion expects the average opinion to be. And there are some, I believe, who practise the fourth, fifth and higher degrees." (p. 156)

But models in which decision makers forecast the forecasts of others were difficult to formalize and to analyze. While Townsend provides a framework that accounts for higher-order expectations, he shows that solving his model yields an infinite-dimensional fixed point problem that has no simple characterized solution. The lack of economic realism of the Lucas model and the complexity of models based on heterogeneous information

[1]There is common knowledge of x among a group of agents when all agents in the group know x, they all know that they know x, they all know that they all know that they know x, and so on *ad infinitum*.

[2]Higher-order expectations are expectations about others' expectations of some variables. For instance, the agent i's first-order expectation of the variable x is its expectation of the variable itself. The agent i's second-order expectation of variable x is its expectation of the average expectation (over all agents) of the variable x, and so on.

incited economists to devote their attention to another source of monetary nonneutrality, the time-contingency of price adjustment.

The second approach postulates that real fluctuations in response to nominal variations arise because adjustment and coordination frictions in price setting prevent private agents to fully respond to variations in nominal magnitudes. This class of models builds on the work of Taylor (1980), Rotemberg (1982), Calvo (1983), and Blanchard and Kiyotaki (1987). One comparative advantage of this approach is its technical simplicity: since economic agents have perfect information, all relevant variables of the economy are common knowledge among them. In sharp contrast to the incomplete information model of Phelps-Lucas, money nonneutrality arises here because of agents' inability to adjust their price in every period (and not because of their incomplete information about economic fundamentals). A second advantage of the sticky-price model is that it captures money nonneutrality over many periods, as long as not all agents have adjusted their price since a monetary shock has occurred. This model, known as the new Keynesian framework, has become the workhorse for monetary policy analysis.[3] However, sticky-price models make counterfactual predictions about the effects of monetary policy. For instance, Ball (1994) shows that sticky-price models predict disinflations to create booms rather than recessions. These models also fail to capture the substantial delay observed in reality between monetary shocks and their maximal impact on inflation.[4]

The lack of empirical plausibility of sticky-price models and new insights into game theory under imperfect common knowledge and heterogeneous information have recently given rise to an increase of interest in incomplete information models. As Woodford (2003a) emphasizes, the "*rejection of the Phelpsian insight that information imperfections play a crucial role in the monetary transmission mechanism may have been premature. For the unfortunate predictions [of low persistence] relate to the specific model presented by Lucas (1972), but not necessarily to alternative versions of the imperfect-information theory.*" This revival of interest in imperfect-information models includes the

[3]See Clarida et al. (1999) for a comprehensive overview of new Keynesian monetary policy analysis.

[4]Counterfactual predictions of sticky-price models are more extensively discussed in chapter 6.

work of Adam (2006), Hellwig (2002), Mankiw and Reis (2002), and Woodford (2003a). All these models depart from the Lucas model in two respects.

First, they allow higher-order expectations to play a crucial role in the decision making of private agents by introducing a monopolistically-competitive pricing framework. In such environment, optimal prices are strategic complements since each agent sets its price according to its expectation of the average price set by others. In the Lucas model, the only variable that matters for private agents – and about which they have imperfect information – is the current value of exogeneous variables (first-order expectations). As underlined by Townsend (1983), the introduction of higher-order expectations in optimal decision making accounts for an additional source of persistence. While observations provide private agents with some insight into variations of exogeneous variables, these observations provide them with a more ambiguous picture of the way others may have changed their own expectations about exogeneous variations, and with an even much more ambiguous picture of the way others may have changed their own expectations about expectations of others. In an environment where individual decisions are made according to expectations of both fundamentals and decisions of others (as is the case in monopolistically-competitive price setting), higher-order expectations are given an essential role in the determination of aggregate outcomes.

Second, this new class of models departs from the model of Lucas by questioning the assumption that shocks become common knowledge in the period subsequent to their occurrence. Such questioning turns out to be a necessary condition for higher-order expectations to play a crucial role in optimal decision making. Accounting for higher-order expectations particularly matters under imperfect common knowledge (when agents have heterogeneous information). Indeed, under perfect common knowledge, all first and higher-order expectations are identical (*i.e.* the law of iterated expectations is satisfied), which makes the distinction between them totally superfluous. By contrast, under imperfect common knowledge, higher-order expectations are order specific and do not collapse to the first-order expectation (*i.e.* the law of iterated expectations fails). This is important because higher-order expectations are slower to adjust in response to shocks as uncertainty is exacerbated by iterations of one's expectations about others' beliefs.

Imperfect-information models of this kind offer an explanation not only for temporary real effects of variations in nominal magnitudes (as the Lucas model), but also for a substantial persistence of real effects over time. Moreover, these models do not seem to suffer from the same counterfactual predictions as sticky-price models. They typically capture the inertial and gradual impact of monetary shocks on inflation. Adam (2006), Hellwig (2002), Mankiw and Reis (2002), and Woodford (2003a) show that their respective model accounts for a considerable delay between the date of an increase in the monetary base and the maximal impact on inflation. As emphasized by Woodford (2003a), while these newly developed class of imperfect-information models tend to rehabilitate the idea of Phelps and Lucas – that imperfect common knowledge is the source of monetary nonneutrality – they would not necessarily lead to the same conclusions for the optimal conduct of monetary policy. For instance, the conclusion derived from the model of Lucas according to which monetary policy can stabilize the economy only to the extent that it takes the private sector by surprise is not generally true in this class of models. Yet, the implications of strategic complementarities under imperfect common knowledge for the optimal conduct of monetary policy remain largely unexplored.

The main aim of this thesis is to address monetary policy issues in an economy where money nonneutrality arises because of imperfect common knowledge and strategic complementarities. In chapter 6, we compare and discuss the optimal conduct of monetary policy in the sticky-price model and the sticky-information model of Mankiw and Reis (2002). We also address central bank's transparency questions in an environment where information plays a key role in the determination of the real effects of money and emphasize the relevance of central bank's communication for the optimal monetary policy in such a context. Transparency issues seem particularly appealing when information is essential to transmission mechanisms because it influences the inflation-output gap trade-off.

1.2 Central bank's transparency

Over the last decades, there has been a switch in central banks' practice from secrecy and opacity to openness and transparency. Generally speaking, central bank's transparency refers to the absence of asymmetric information between the central bank and the private sector. This trend towards greater transparency is evident from casual observations and can be illustrated, for example, by the growing number of publications and declarations of central banks, or by the adoption of an explicit inflation target (that requires a high standard of transparency) by many central banks.[5] The Code of Good Practices on Transparency in Monetary and Financial Policies published by the International Monetary Fund highlights two rationales for transparency (See IMF (1999)): democratic accountability and economic benefits.

First, the increase in transparency can be rationalized by the accountability required from an independent central bank. Indeed, a central bank that becomes independent from its government still needs to be democratically accountable. Some degree of transparency is then a necessary condition for accountability. This rationale for transparency can be seen as a duty for an independent central bank. However, the increase in central banks' transparency has gone beyond the requirement for accountability.

Second, as transparency influences the interaction between the private sector and the central bank, it is likely to influence the economic outcome. The central bank may derive economic benefits from being transparent. Transparency may then be rationalized by central bank's own interest. Yet, while the Code of Good Practices issued by the IMF underlines the benefits of transparency, the welfare effect of transparency is much more controversial in the academic literature. For instance, the Lucas model is widely argued to imply that monetary policy could successfully stabilize the economy only in the extent that the central bank implements its policy by surprise. Hence, transparency would clearly be suboptimal as stabilization would no longer be possible. But the effects of transparency are highly sensitive to the specific context.

We propose here a short classification of the numerous arguments in

[5] See Eijffinger and Geraats (2006) and Poole (2005) for empirical evidence.

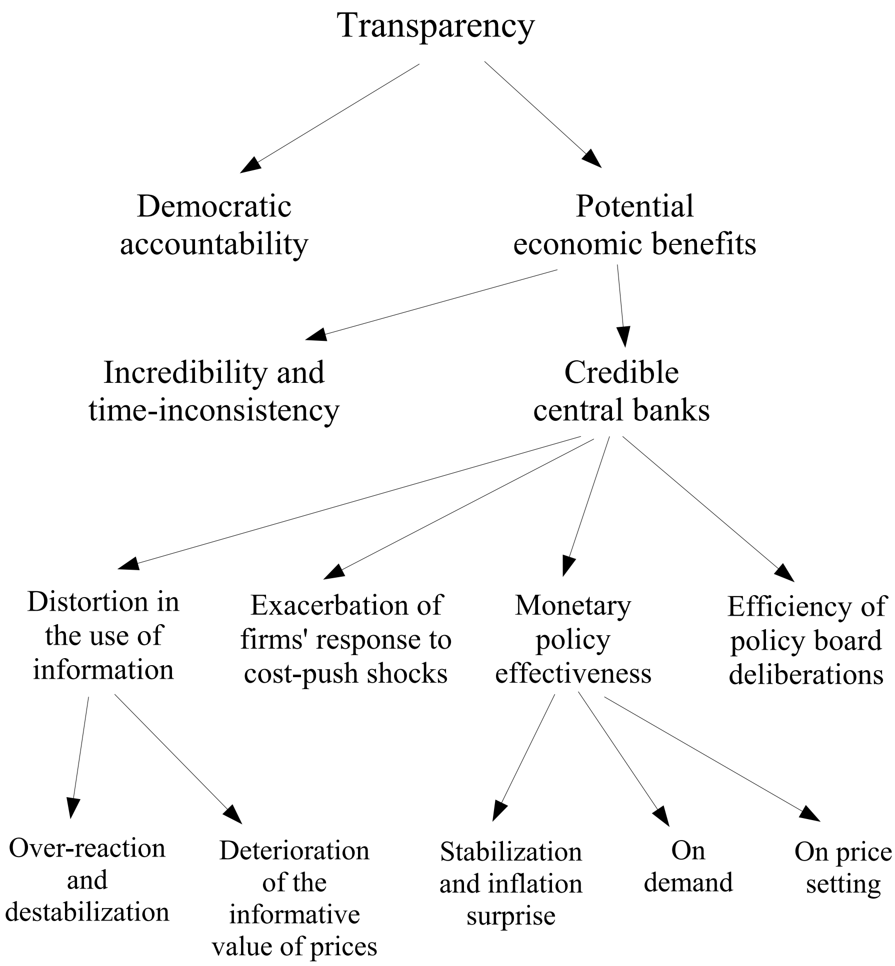

Figure 1.1: Transparency arguments

favour and against transparency in the conduct of monetary policy. We also briefly discuss the contributions of this thesis in this respect. Figure 1.1 proposes an overview of the different arguments. The literature that deals with the pros and cons of transparency from the point of view of its potential economic benefits can be classified into two main groups.

First, most of the literature analyzes the welfare effect of transparency in the time-inconsistency framework *à la* Barro and Gordon (1983). This has been analyzed for example in the pioneer work of Cukierman and Meltzer (1986). As the central bank is presumed to boost the economy above its natural level, this literature examines the extent to which transparency helps to reduce the inflation bias and the time-inconsistency problem and to increase the credibility and flexibility of the central bank.[6]

[6]See Geraats (2002) for an overview.

Second, a much more recent strand of arguments considers different implications of transparency that are not related to the credibility problem linked to time-inconsistency. This literature posits that the central bank is credible and that the private sector perfectly knows its preferences. This thesis contributes to the debate on transparency when the central bank is credible. The focus on credible central banks can be motivated by the two following aspects. First, models where money nonneutrality arises because of strategic complementarities under imperfect common knowledge provide an interesting framework to address transparency issue in the case of credible central banks. Indeed, transparency related questions that one can address in an environment where information is essential for transmission mechanisms are much broader than when information is perfect since communication is crucial for the inflation-output gap trade-off. Addressing transparency issues in sticky-price models where information is perfect narrows the potential impacts of communication on the economic outcome. In such a context, one is strongly inclined to examine the effect of transparency about central bank's preferences on the time-inconsistency problem. That is what the literature has mainly focused on. Yet central banks' communication in imperfect information models has been much less examined and deserves more attention. Second, in the current context of central banks' independence and historically – and durable – low levels of inflation, many central banks have reached a high degree of credibility. On the one hand, the benefit of independence from political interferences is nowadays commonly accepted.[7] On the other hand, central bankers are aware that boosting the output above its natural level would be inflationary and consider that the assumption of inflationary biased central banks does not capture the actual rationale for the conduct of monetary policy. In particular, Blinder (1998), King (1997), and Vickers (1998) argue that the Barro-Gordon argument is not applicable to their respective central banks.[8]

We now present the main transparency effects discussed in the litera-

[7]For example, as politicians gave their opinion about the conduct of monetary policy by the European Central Bank, its president at that time, Wim Duisenberg, stated that it was a "*normal phenomenon*" to observe suggestions from politicians but that "*it would be very abnormal if those suggestions were to be listened to*" (The Economist (1998)).

[8]For a discussion of this issue, see Cukierman (2002). Blinder (2000) also shows that there is a strong consensus among central bankers about the importance and benefit of credibility.

ture and those newly developed in this thesis. We abstract from the transparency debate related to credibility and focus on arguments that apply to well-established central banks. We present transparency arguments that account for the distortion in the use of information, the effectiveness of monetary policy, the exacerbation of firms' response to shocks, and the efficiency of policy board deliberations.

1.2.1 Distortion in the use of information

A first series of arguments emphasizes that transparency, considered as the revelation by the central bank of its own estimation of the fundamentals of the economy,[9] may exacerbate market reaction and distort the economic outcome away from fundamentals.

Overreaction, destabilization, and coordination

In their seminal beauty contest paper, Morris and Shin (2002) argue that, in an environment characterized by imperfect common knowledge and strategic complementarities, more accurate public information may be detrimental to welfare because public information is attributed too large a weight relative to its face value.

This argument is based on two building blocks. First, it emphasizes the relevance of positive externalities that often characterize financial markets and macroeconomic environments (*i.e.* Keynesian beauty contest). Second, it accounts for different types of information – private *vs.* public – that are taken into consideration by each agent according to their predictive power with respect to fundamentals and expectations of others. While private information and public information with identical accuracy have an identical predictive power about fundamentals, public information is much more informative about others' expectations since it is common knowledge. As a result, the combination of strategic complementarities and heterogeneous information gives rise to an overreaction to public information in the sense that private agents assign a larger weight to public information than what would be justified by its face value. This overreaction increases with the

[9] Following Geraats (2002), we call transparency on economic information economic transparency

strength of strategic complementarities.

Morris and Shin argue that overreaction to public information may be detrimental to welfare whenever it is noisy since overreaction to noisy information destabilizes the economy. So, they conclude that it might be better, under some circumstances, to entirely withhold public information.

Their argument has received a great deal of attention in the academic literature, the financial press[10], and central banks[11]. In a closely related work, Amato et al. (2002) interpret the model by Morris and Shin (2002) as a Lucas-Phelps islands economy in which firms try to second-guess the pricing strategies of their competitors.

However, while Morris and Shin see their own argument as an argument against transparency, Svensson (2006) underlines that when the central bank has more accurate information than the private sector (which seems realistic), then the model of Morris and Shin is in favour of rather than against transparency. Indeed, for transparency in the model of Morris and Shin to be welfare detrimental, central bank's information must be less accurate than private information (which is not realistic). Information of public institutions (like central banks) is typically more accurate than privately available information. For instance, in an empirical analysis on US data, Romer and Romer (2000) show that the Fed better forecasts the output and inflation than any single commercial bank.[12]

Nevertheless, Morris et al. (2006) provide a reply to this comment. By integrating correlated signals in the analysis, they show that the result of Morris and Shin (2002) still holds even if the public signal is more precise than private ones. Indeed, with correlated public and private signals, the public signal provides an additional hint on the errors of private agents; it will therefore be more strongly taken into account by private agents in their will to guess the behaviour of others, even for lower levels of relative precision of the public signal. The conceptual framework developed by Morris and Shin (2002) thus appears quite robust.

While the debate between Morris and Shin, and Svensson only considers two extreme cases of disclosure (*i.e.* full transparency *vs.* full opacity),

[10]See The Economist (2004) for instance.

[11]See for example Kohn (2005) and Issing (2005).

[12]See also Peek et al. (1999).

Cornand and Heinemann (2004) show that disclosing information with a limited degree of publicity is welfare improving. Since overreaction occurs because public information is common knowledge, reducing the degree of common knowledge (by limiting the audience) reduces the overreaction and, thereby, improves welfare. They show that public information should always be provided with maximum precision, but under certain conditions not to all agents. Interestingly, reducing the degree of publicity turns out to be optimal even when central bank's information is more accurate than private information for relatively strong strategic complementarities.

Hellwig (2005) analyzes the welfare effects of public information disclosures in a model of monopolistic competition among heterogeneously informed firms. He shows that information heterogeneity leads to potentially important delays in price adjustment and amplifies the real effects of monetary shocks. Public announcements reduce adjustment delays, but come at the cost of higher volatility due to informational noise. As we saw earlier, on this basis, Morris and Shin (2002) have argued that public information disclosures may be harmful. In contrast, Hellwig shows that such announcements always improve welfare because they lead to lower price dispersion.

The different and contrasting welfare results in Morris and Shin and in Hellwig (as well as for example in Angeletos and Pavan (2004)) can be reconciled as being the consequence of the extent to which coordination is valuable at the social level (compared to economic distortion).[13] Public information is a double-edged instrument. On the one hand, it helps coordination between private agents. On the other hand, it may destabilize the economy when it is rather noisy. As a result, when coordination is socially highly valuable, as it is the case in Hellwig with microfounded welfare analysis, transparency is always welfare improving. By contrast, when coordination is less valuable, as in Morris and Shin, the detrimental destabilizing effect of transparency may dominate.

Chapter 3 of this thesis – entitled Central Bank's Action and Communication – contributes to this ongoing debate about the welfare effect of public information. While the above mentioned literature considers communica-

[13]This issue is discussed in chapter 2 of this thesis.

tion as the sole task of the central bank and ignores that communication usually goes with a policy action, we account for the action task of the central bank. In particular, we analyze whether public disclosure is beneficial in the conduct of monetary policy when the central bank primarily tries to stabilize the economy with an instrument that is optimal with respect to its perhaps mistaken view. In this context, our analysis suggests that transparency is particularly welfare improving when the central bank actively shapes the course of the economy with its monetary instrument and when its information is rather noisy. Transparency is beneficial when central bank's information is poorly accurate because the private sector's reaction helps reducing the distortion associated with badly suited policies.

Deterioration of the informative value of prices

One line of criticism that can be made to the literature in the vein of Morris and Shin (2002) and discussed in the previous section is the fact that all the information considered is exogeneous. Yet a central bank typically influences the economy in disclosing information, which affects the fundamental on which the central bank and agents precisely rely to make their decisions. In a comment on Morris and Shin (2002), Atkeson (2001) firstly criticizes the lack of a theory of prices linked with the absence of formalized markets in global games especially applied to currency crises. Atkeson stresses the role of prices to coordinate actions in decentralized markets: prices aggregate information across individuals and then allow the coordination of their actions.[14] The idea that prices serve as an aggregator of information goes back to Hayek (1945). In his article "*The use of knowledge in society*", he emphasizes that the price is "*an aggregator of the dispersed bits of incomplete and frequently contradictory knowledge which all the separate individuals possess*". In practice, central banks cannot directly observe some exogeneous aggregate processes driving the state of the economy. Instead, they devote huge resources to collect data from the economy in order to estimate aggregate

[14]Relying on this criticism, Tarashev (2003), Hellwig et al. (2006) and Angeletos and Werning (2006) show that the results of Morris and Shin can be questioned as soon as prices endogeneously aggregate all the relevant information (*i.e.* when the market is informatively efficient). Those studies mainly focus on the speculative attack game under imperfect common knowledge in the line of Morris and Shin (1998) and more precisely on the key point of multiplicity *vs.* uniqueness of equilibrium in global games, problem that is not addressed in this thesis.

economic outcomes and to understand how close the economy is to capacity. Typically, central banks estimate and forecast the price level to estimate economic imbalances and to decide which policy to implement. The *Inflation Reports* of the Bank of England illustrate well the central role of observing the economic outlook in the conduct of monetary policy (see Bank of England (2005)). This section discusses the main attempts to account for the informative value of prices in a context of strategic complementarities under imperfect common knowledge.

Amato and Shin (2006) emphasize that the central bank entails a dual role in the economy. First, as noticed earlier, as a policy maker, the central bank shapes market expectations. Second, the central bank observes the economy to identify imbalances. While it scrutinizes the economic activity to estimate the state of the economy it has to respond to, its policy making strongly drives economic outcomes. Yet, the more effectively the central bank shapes the economy, the less reliable becomes the economic outcome as an indicator for the state of the economy. From this dilemma arises a trade-off between observing and shaping the economy. Transparency increases the effectiveness of the central bank in shaping market expectations. But the more effective the central bank has been in manipulating the beliefs of the market, the more the central bank will observe its own economic statement.

The deterioration in predictability of economic imbalances presents some empirical evidence. It has especially been documented by Tulip (2005) for the US and by Goodhart (2004) for the UK. For example, Tulip writes: "*whereas the Fed predicted a large share of the fluctuations in output in the 1970s and 1980s, more recent fluctuations have been surprises*". Central banks face a high uncertainty about the economic conditions. This decline in the precision of central banks' forecasts is related to the increase in central banks' transparency.

Amato and Shin (2006) show in this context that the information value of prices decreases with increasing strategic complementarities. The stronger the coordination motive, the stronger the overreaction to central bank's disclosure, and therefore the lower the informative value of prices. Morris and Shin (2005) develop this intuition furthermore and show that prices do no more play their role of informational variable.

Chapter 2 of this thesis – entitled Endogeneous Central Bank's Information and the Optimal Degree of Transparency – analyzes in a different framework the welfare effect of transparency when the central bank gleans information about economic imbalances by observing the price level in the economy. As transparency increases the overreaction of private agents to central bank's disclosure, it deteriorates the informative value of prices, the information quality of the central bank, and, thereby, the precision of central bank's disclosure to which private agents overreact. Interestingly, maximal precision of central bank's disclosure is reached for some limited level of transparency. That is to say that increasing ambiguity in central bank's speech increases its quality since reducing the degree of common knowledge improves the informative value of prices and the precision of information the central bank relies on for its disclosure.

1.2.2 Monetary policy effectiveness

A second strand of arguments dealing with transparency relies on the effectiveness of monetary policy. The link between transparency and monetary policy effectiveness has recently been studied in various ways. Some studies emphasize the relevance of inflation surprise in the Lucas model or the role of transparent monetary policy on demand (especially *via* an arbitrage argument between short-term and long-term rates). By contrast, we insist in this thesis on the role of transparency on price setting by firms.

Stabilization and inflation surprise

Gersbach (2003) and Cukierman (2001) analyze the effect of asymmetric information about shocks hitting the economy. The particularity of their approach is to assume that the central bank directly controls inflation and that it influences the output gap only in the extent that inflation arises as a surprise (Lucas surprise transmission mechanism). As a result, asymmetric information about shocks is necessary for the central bank to stabilize them. If the central bank reveals to the private sector its economic assessment, the private sector anticipates the inflation response of the central bank and stabilization is no longer possible.

Monetary policy effectiveness on demand: overnight to long-term rates

Blinder (1998) and Woodford (2005) emphasize the fact that the central bank only controls an overnight interest rate that is irrelevant to economic decisions. In an environment where the central bank only controls an overnight interest rate that is irrelevant for economic decisions, the central bank can influence the long-term interest rate and asset prices only in the extent that it can influence market expectations about future overnight interest rate. Central bank's transparency helps to predict future target rates and therefore increases the effectiveness of monetary policy on the demand side of the economy. As Woodford points out: *"For monetary policy to be most effective not only do expectations about policy matter, but very little else matters"*. So, managing market expectations plays a key role in the conduct of monetary policy, as *"markets can to a large extent 'do the central bank's work for it', in that the actual changes in overnight rates required to achieve the desired changes in incentives can be much more modest when expected future rates move as well"*.

Empirical analysis shows that transparency increases the impact of monetary policy on market expectations and increases its effectiveness. Demiralp and Jorda (2002) emphasize the relevance of central bank's communication to manipulate market expectations; they show in particular that the publication of the instrument rate targeted by the policy board of the Fed since 1994 has increased the effectiveness of monetary policy in shaping market expectations.

Monetary policy effectiveness on price setting

While Blinder and Woodford emphasize that transparency increases the effectiveness of monetary policy in influencing aggregate demand, we emphasize in chapter 4 – entitled Can Opacity of a Credible Central Bank Explain the Conduct of Monetary Policy in the 70s? – that transparency increases the effectiveness of monetary policy on price stabilization.

We derive the optimal monetary policy in an economy where price setting is characterized by strategic complementarities and imperfect common knowledge. The central bank is fully credible in the sense that it has no inflationary bias *à la* Barro and Gordon (1983) and its preferences are perfectly known to the private sector. We show that the optimal response of the central bank to cost-push shocks is a function of its communication strategy. As cost-push shocks create a trade-off between inflation and output gap stabilization, the central bank chooses whether to accommodate the nominal aggregate demand in order to reduce the negative output gap (at the cost of higher inflation) or to contract the nominal aggregate demand in order to fight inflation (at the cost of larger output gap) according to the effectiveness of its policy to influence inflation and the output gap. When the central bank is opaque with respect to its instrument, fundamental and strategic uncertainty of firms about the monetary instrument is high, which reduces the effectiveness of monetary policy to stabilize inflation. As a result, when uncertainty about its instrument is high because of opacity, the central bank finds it optimal to expand nominal aggregate demand in response to positive cost-push shocks.

Our result suggests that the lack of central bank's credibility is not a necessary condition to explain the excess inflation of the 70s. While most of the literature comments on excess inflation as the result of the permanent inflation bias resulting from time-inconsistency, we propose an alternative view according to which opacity (and not incredibility) could be made accountable for excess inflation. We emphasize that our analysis is robust to the criticisms against the Barro-Gordon argument made by Blinder (1998), Friedman and Kuttner (1996), McCallum (1997), and Taylor (1983).

1.2.3 Exacerbation of response to shocks

In chapter 5 – entitled Monetary Policy and its Informative Value – we present another argument against economic transparency about cost-push shocks. As cost-push shocks create a trade-off between inflation and output gap stabilization, they inevitably generate losses. We underline here that the resulting loss depends on the strength of firms' reaction. When price setting is characterized by strategic complementarities, firms set their price not only according to the own expectations of cost-push shocks but also to their expectations about others' expectations of shocks. The response of each firm depends not only on how each firm is affected by cost-push shocks but also on how each firm expects others to be affected. Transparency about cost-push shocks reduces uncertainty and increases firms' response to them, which turns out to be welfare detrimental. In this context, transparency does not reduce the effectiveness of monetary policy to stabilize shocks but exacerbates firms' response to them.[15]

1.2.4 Efficiency of policy board deliberations

Another argument that is perhaps less related to others underlines the impact of transparency with respect to the minutes of deliberations of the policy board on the quality of deliberations. One of the major recent trends in central banking practice has been the formal adoption of decision-making by Monetary Policy Committees (MPCs) rather than by individual central bank heads.[16] Is such an evolution beneficial in a context where the deliberations of the committees are made public? This issue has recently been under discussion.

In an experiment, Blinder and Morgan (2005) argue that diversification pays off in the form of better decisions. Therefore an individualistic committee, which takes full advantage of the committee's diversity, would seem to have a clear edge over a collegial committee, which exploits diversity much less.

However, Meade and Stasavage (2004) show that since the Fed has published the minutes of deliberations, members of the policy board are much less inclined to reveal their opinions contradicting the position of the chairman. Policy board members avoid expressing their opinions that deviate from the majority since deliberations are made public. And as pointed by Blinder and Wyplosz (2005) (p. 11), several voices potentially create confusion: "*The danger arises if an individualistic committee is undisciplined and speaks with too many voices, especially if those disparate voices carry conflicting messages. In that case, central bank's transparency can degenerate into central bank cacophony, leaving outside observers more befuddled than enlightened*". These arguments are clearly against transparency.

[15]This mechanism is also present in Walsh (2005).

[16]However, committee structures remain highly various. Blinder et al. (2001) provide a detailed typology of these committees. They especially distinguish collegial committees, where decision is made by consensus from individualistic MPCs (e.g., the Bank of England), where each member not only expresses his opinion verbally but also acts by voting; in such a case, unanimity is not necessary. There is also a variety of collegial committees, with two polar cases being the "autocratically-collegial MPC" where the chairman dictates the consensus and the "genuinely collegial MPC" where members argue for their own points but finally compromise on a group decision. The Federal Reserve System is a good example of the former, while the European System of Central Banks can represent the latter.

One observation that contradicts the former argument is that the talk that emanates from the Bank of England's MPC – and which is the expression of many voices[17] – does seem to inform markets much more than it confuses them.

1.3 Summary

This thesis addresses different issues of monetary policy when transmission mechanisms are characterized by strategic complementarities in firms' price setting and imperfect common knowledge. This focus is motivated by the appealing dynamic properties of this class of models[18] and by the crucial role that communication plays when money nonneutrality arises because of imperfect information. Appendix 1.A presents the microeconomic derivation of the pricing rule in an economy characterized by monopolistic competition. This pricing rule, linked to heterogeneous information, is the fundamental equation our work relies on. In this section, we summarize the chapters of this thesis.

Chapter 2: Endogeneous Central Bank's Information and the Optimal Degree of Transparency This chapter accounts for the fact that the central bank, in practice, cannot directly observe some exogeneous aggregate processes driving the state of the economy. Instead, it devotes huge resources to glean information about economic imbalances from the economy itself in order to estimate how close the economy is to capacity. Typically, the central bank estimates and forecasts the price level to identify economic imbalances and to decide which policy to implement. Most of the literature, however, assumes that the central bank has an exogeneous source of information about fundamental shocks, which implies that its information is independent from its policy.

[17]Indeed, the Bank of England publishes the minutes (of MPC discussions) where differences in opinions are an essential part of the information that should be conveyed to the markets.

[18]These properties have been emphasized by Adam (2006), Mankiw and Reis (2002), and Woodford (2003a). See chapter 6 for a discussion on the counterfactual predictions of sticky-price models and the dynamic properties of the sticky-information model of Mankiw and Reis (2002).

Considering the fact that the central bank observes the economy to collect information entails a dual role for the central bank. As a policy maker, a central bank is both an observer and a shaper of the economy. While it scrutinizes the economic activity to estimate the state of the economy it has to respond to, its policy making strongly shapes economic outcomes. Yet, the more effectively the central bank shapes the economy, the less reliable become economic outcomes as indicators for the state of the economy. Since transparency deteriorates the accuracy of central bank's information, the social value of central bank's disclosure is questionable. This chapter presents a simple model that captures the endogeneous nature of central bank's information and addresses welfare issues. While Morris and Shin (2002) underline that transparency generates overreaction to public disclosure, our model with endogeneous information highlights that transparency also reduces the accuracy of central bank's disclosure to which private agents overreact. Transparency does not only raise the weight assigned to higher-order expectation as in Morris and Shin, but also deteriorates the accuracy of first-order (and higher-order) expectations. Interestingly, minimizing the ambiguity of central bank's disclosure does not maximize the precision of its disclosure. It is shown that accounting for the endogeneity of information reduces the optimal degree of central bank's transparency.

Chapter 3: Central Bank's Action and Communication This chapter also contributes to the ongoing debate about the welfare effect of public information. In an environment characterized by imperfect common knowledge and strategic complementarities, Morris and Shin (2002) argue that noisy public information may be detrimental to welfare because public information is attributed too large a weight relative to its face value since it serves as a focal point. This argument considers communication as the sole task of the central bank and ignores that communication usually goes with a policy action. This chapter accounts for the action task of the central bank and analyzes whether public disclosure is beneficial in the conduct of monetary policy when the central bank primarily tries to stabilize the economy with an instrument that is optimal with respect to its perhaps mistaken view. In this context, transparency is particularly beneficial when central bank's information is poorly accurate because it helps reducing the distortion associated with badly suited policies.

Chapter 4: Can Opacity of a Credible Central Bank Explain the Conduct of Monetary Policy in the 70s? While the high inflation episode of the 70s is usually rationalized by the Barro and Gordon (1983) argument, this chapter provides an alternative explanation: the opacity of a credible central bank with respect to its monetary instrument.[19] In a monopolistic competitive economy under imperfect common knowledge, where the central bank has no inflationary bias, the effectiveness of monetary policy to influence the price level depends on the central bank's disclosure regime. Under opacity, as the fundamental and strategic uncertainty of firms about the monetary instrument strongly reduces the effectiveness of monetary policy on the price level, the central bank may find it optimal to stabilize the output gap by expanding the nominal aggregate demand in response to cost-push shocks. This suggests that the central bank's desire to push output above its natural level is not a necessary condition for the expanding monetary policy of the 70s.

Chapter 5: Monetary Policy and its Informative Value This chapter analyzes the welfare effects of economic transparency in the conduct of monetary policy.[20] We propose a model of monopolistic competition with imperfect common knowledge on the shocks affecting the economy (demand and cost-push shocks) where the central bank has no inflationary bias. By contrast to chapter 4, the monetary instrument is common knowledge among firms. But since the economy is affected by two types of shocks, firms are uncertain about the rationale behind the instrument implemented by the central bank. Transparency removes this uncertainty by revealing to firms the central bank's economic assessment. In this context, monetary policy entails a dual role. The instrument of the central bank is both an action that stabilizes the economy and a public signal that partially reveals to firms the central bank's assessment of the state of the economy. Yet, firms are unable to perfectly disentangle the central bank's signals responsible for the instrument and the central bank optimally balances the action and information purposes of its instrument. We derive the optimal monetary policy

[19] This chapter has been developed in collaboration with Camille Cornand.
[20] This chapter has been developed in collaboration with Camille Cornand.

and the optimal central bank's disclosure. We define transparency as an announcement by the central bank that allows firms to identify the rationale behind the instrument. It turns out that transparency is welfare increasing (i) when the degree of strategic complementarities is low, (ii) when the economy is not too affected by cost-push shocks, (iii) when the central bank is more inclined towards price stabilization, (iv) when firms have relatively precise private information, and (v) when the central bank's information is relatively precise on demand shocks and relatively imprecise on cost-push shocks. These results rationalize the increase in transparency in the current context of relative low sensitivity of the economy to cost-push shocks and of strong central bank's preference for price stability.

Chapter 6: Sticky Information and Monetary Policy This chapter compares monetary policy with sticky-price (Calvo (1983)) and sticky-information (Mankiw and Reis (2002)) Phillips curve for a central bank adopting an inflation target. We discuss the dynamic properties of both models in response to monetary shocks and address the extent to which cost-push shocks have a gradual and delayed impact on inflation in the sticky-information economy.

While current inflation depends on current expectations about future inflation in the sticky-price economy, it is past expectations about current inflation that matter for current inflation in the sticky-information economy. This feature has strong implication for the optimal targeting rule. Under commitment, the targeting rule is history-dependent with sticky price but forward-looking with sticky information. As a result, commitment in the sticky-information economy does not imply price stationarity. We underline that, when information is sticky, the central bank must wait that information spreads through the population to benefit from the commitment policy. This sharply contrasts with the sticky-price economy where the central bank reaps benefit from commitment in the initial periods.

Interestingly, in response to cost-push shocks, the central bank of the sticky-information economy first slightly expands the output gap as long as information dissemination is low, and then fights inflation by strongly contracting the output gap once information dissemination is high. This result recalls the conclusions of chapter 4 according to which less information yields accommodating policy response.

1.A Microfoundations

The model is derived from an economy populated by a representative household, a *continuum* of monopolistic competitive firms[21], and a central bank. Two types of stochastic shocks can potentially hit the economy, demand and mark-up (or cost-push) shocks. Nominal aggregate demand is determined by both the demand shock and the monetary instrument set by the central bank. The baseline framework is close to Adam (2006).

Representative household

The representative household chooses its aggregate composite good C and labor supply H in order to maximize its utility subject to its budget constraint,

$$gU(C) - V(H)$$

$$\text{s.t. } WH + \Pi = PC.$$

The parameter g is a stochastic demand shock with $\mathbb{E}(g) = 1$, that induces variations in the nominal aggregate demand. The utility function has the following usual properties: $U' > 0$, $U'' < 0$, $\lim_{C\to\infty} U'(C) = 0$, $V' > 0$, $V'' < 0$, and $V'(0) < U'(0)$. C is the composite good defined by the Dixit and Stiglitz (1977) aggregator

$$C = \Big[\int_0^1 (C_i)^{\frac{\theta-1}{\theta}} di\Big]^{\frac{\theta}{\theta-1}}$$

where $\theta > 1$ is the parameter of price elasticity of demand and where C_i is the good produced by firm i. θ is stochastic with $\mathbb{E}(\theta) = \bar{\theta}$ and induces variations in the desired mark-up of firms. W denotes the competitive wage and Π the profits the household gets from firms. P is the appropriate price index which solves $PC = \int_0^1 P_i C_i di$ and satisfies

$$P = \Big[\int_0^1 P_i^{1-\theta} di\Big]^{\frac{1}{1-\theta}}.$$

Given the overall level of consumption, the household allocates its ex-

[21] See Blanchard and Kiyotaki (1987).

penditure across goods according to

$$C_i = \left(\frac{P_i}{P}\right)^{-\theta} C \tag{1.1}$$

and optimizing the consumption-labor decision leads to the real wage

$$\frac{W}{P} = \frac{V'(H)}{gU'(C)}. \tag{1.2}$$

Firms

Each firm i produces a single differentiated good C_i with one unit of labor H_i according to the simple production function

$$H_i = C_i. \tag{1.3}$$

The profit maximization problem of firm i is given by

$$\max_{P_i} \mathbb{E}[P_i C_i(P_i) - W H_i(P_i) | I_i], \tag{1.4}$$

where I_i is the information set of firm i. Using (1.1), (1.2), and (1.3), the first-order condition of (1.4) becomes

$$\mathbb{E}\Big[(1-\theta)\Big(\frac{P_i}{P}\Big)^{-\theta} + \theta\Big(\frac{P_i}{P}\Big)^{-\theta-1} \frac{V'(C)}{gU'(C)} | I_i\Big] = 0. \tag{1.5}$$

Linearizing (1.5) around the steady state delivers

$$p_i = \mathbb{E}_i[p + \xi c + u], \tag{1.6}$$

where small letters indicate percentage deviation from the steady state and where

$$\begin{aligned} \xi &= -\frac{U''(\bar{C})\bar{C}}{U'(\bar{C})} + \frac{V''(\bar{C})\bar{C}}{V'(\bar{C})} \\ u &= \frac{1}{1-\bar{\theta}} \frac{\theta - \bar{\theta}}{\bar{\theta}}. \end{aligned} \tag{1.7}$$

$\bar{C}$ and $\bar{\theta}$ are the real output and the price elasticity of demand at their steady state level, respectively.

The pricing rule (1.6) states that firms set their price as a function of their expectations of the overall price level p, the real output gap c, and the mark-up shock u. This captures the strategic complementarity of price setting as the price level is the average price set by all firms. Each firm sets its own price according its expectation about the price of others.

The parameter ξ determines the extent to which the optimal price responds to the output gap. Prices strongly respond to the output gap when the competitive real wage (and thereby the costs) is highly sensitive to the output gap. This occurs when ξ is large. As expression (1.7) indicates, the coefficient ξ is large when the household's utility to consume is rather concave and its disutility to work is rather convex. The real wage required for additional production is high since the household derives a low utility from additional consumption while it suffers a high disutility from additional work. As a result, firms strongly adjust their price in response to expected output gap variations since the latter strongly affect the real wage. We call "weakly extensive" an economy with a high value of ξ and "highly extensive" an economy with a low value of ξ.

In this context, ξ also determines whether prices are strategic complements or substitutes. Using the fact that the nominal aggregate demand (deviation) y can be expressed as $y = c + p$, we rewrite the pricing rule (1.6) as

$$p_i = \mathbb{E}_i[(1 - \xi)p + \xi y + u].$$

In the whole thesis, we realistically assume that prices are strategic complements, *i.e.* $0 < \xi \leq 1$.

Chapter 2

Endogeneous Central Bank's Information and the Optimal Degree of Transparency

2.1 Introduction

Over the last decades, the conduct of monetary policy has been characterized by the two following stylized facts: the increase in central bank's transparency and the deterioration of the accuracy of central bank's information. First, the increase in central bank's transparency is evident from casual observations. This can be illustrated by the increasing number of publications of central banks with respect to their monetary policy or by the adoption of an explicit inflation target by many central banks. Second, there is some empirical evidence of a deterioration of central bank's information. This feature has been documented by Tulip (2005) for the US and by Goodhart (2004) for the UK. For instance, Tulip concludes that "*whereas the Fed predicted a large share of the fluctuations in output in the 1970s and 1980s, more recent fluctuations have been surprises.*" The output growth forecast published by the Bank of England also highlights the high uncertainty surrounding economic conditions. The output growth forecast reported in May 2006 on figure 2.1 reveals that assessments of the Bank of England even of the very next future are highly imprecise.[1]

[1]See also Geithner (2006) for a general discussion on central bank's uncertainty and transparency.

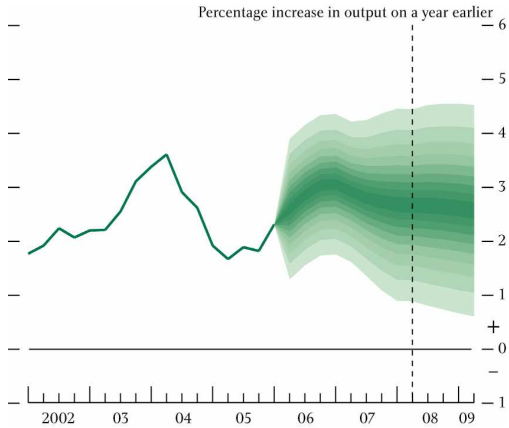

Figure 2.1: Output growth forecast of the Bank of England

This chapter argues that the increase in central bank's transparency can be made accountable for the deterioration of central bank's information. In particular, we emphasize that the accuracy of central bank's information is endogeneous in the sense that it is a function of its disclosure strategy. The aim of this chapter is twofold. First, we develop a simple model with strategic complementarities under imperfect common knowledge that captures the endogeneous nature of central bank's information. Second, we address welfare issues of transparency in this context and derive the optimal disclosure strategy of the central bank.

First, the endogeneity of information arises from the dual role of the central bank in the economy: it is both an observer and a shaper of the economy. On the one hand, for optimizing its policy making, the central bank gleans information about economic conditions by scrutinizing market outcomes to identify shocks. The central bank learns from market expectations. In practice, a central bank cannot directly observe some exogeneous aggregate processes driving the state of the economy. Instead, it devotes huge resources to collect data from economic agents' behaviour in order to estimate aggregate economic outcomes and to understand how close the economy is to capacity. Typically, a central bank forecasts the price level to estimate economic imbalances and to decide which policy to implement. The *Inflation Reports* of the Bank of England well illustrate the role of observing the economic outlook in the conduct of monetary policy. In a prominent article, Hayek (1945) emphasizes the informational role of prices and argues that prices are not just an exchange rate between goods but also an information aggregator. He points out that prices determined by decentralized markets provide an essential source of information since they aggregate the "*dispersed bits of incomplete and frequently contradictory knowledge which all the separate individuals possess*". More recently, Hetzel (1992) argues that gleaning information form private markets may help the central bank to conduct monetary policy. As public's inflation forecast may help a central bank, he calls for issuing both nominal and inflation-indexed bonds that would provide "*a useful 'outside' assessment of the inflationary consequences thought likely to follow from its policy actions*" (p. 13).

On the other hand, by implementing its policy, the central bank influences the economic outcome and particularly the private sector's expectations. Indeed, shaping market expectations plays a key role in the conduct of monetary policy. As pointed out by Woodford (2005), "*for [monetary policy to be most effective] not only do expectations about policy matter, but [...] very little else matters.*" While a central bank observes the aggregate economy to conduct its policy, it also shapes the economic outcomes.

From this ambivalent central bank's role – as an observer and as a shaper – may arise a dilemma for the conduct of monetary policy that has been documented by Amato and Shin (2006) and Morris and Shin (2005).[2] Indeed, the more successfully a central bank influences market expectations, the less reliable become economic outcomes as indicators for the state of the economy. While economic outcomes would reflect the true state of the economy in the absence of central bank's interventions (while the central bank is an observer only), they also partly reflect the central bank's beliefs as the central bank intervenes in the economic development. As soon as central bank's beliefs differ from the true state of the economy because of estimation or forecast errors, economic outcomes may also reflect the mistaken central bank's view. Since the central bank ignores its own errors, it cannot disentangle the state of the economy from its observation. The disclosure

[2]This ambivalent role of the central bank is already present in Bernanke and Woodford (1997) who address the issue of existence and uniqueness of rational expectation equilibrium when the central bank observes and responds to private sector's forecasts. In particular, they show that a central bank cannot at the same time infer the value of the state variable from observing private-sector forecasts and fully stabilize the economy. This arises because "*if inflation equals the target in equilibrium, then the information of the private forecasters is not revealed*" (p. 669).

strategy of the central bank gives rise to a trade-off between the quality of central bank's information and the effectiveness of its policy. In an empirical analysis on US data, Ehrmann and Fratzscher (2005) show that with increasing transparency "*markets attach more importance to the statement and the balance-of-risk assessments at FOMC meetings and less importance to news about macroeconomic fundamentals.*" They also conclude that they "*believe that the reaction of financial markets to the release of macroeconomic fundamentals can be an important source of information for the central bank about the markets' diverse and possible deviating views. Under its new disclosure policy, the Federal Reserve has less such information available*" (p. 9). This chapter provides a simple framework accounting for this feature.

Second, this chapter contributes to the ongoing debate on the welfare effect of central bank's transparency and puts forward the deterioration of central bank's information and disclosure as a potential detrimental effect. This argument is intertwined with that of Morris and Shin (2002) (hereafter M-S). In their seminal beauty contest paper with exogeneous information, the latter highlight the potentially detrimental effect of noisy public information since private agents overreact to the public signal. In an environment of strategic complementarities, central bank's disclosure is given too large a weight relative to what would be justified by its face value because it serves as a focal point. Indeed, as the strength of the coordination motive increases, agents attribute to their expectations about expectations of others a larger weight. Since higher-order expectations are mainly driven by the public disclosure, the increasing weight assigned to higher-order expectations exacerbates the response to disclosure and may destabilize the economy. In this context, reducing the degree of transparency is welfare improving as it reduces the degree of common knowledge of the disclosure and thereby the weight assigned to it in higher-order expectations. This coordination channel also arises in our model with endogeneous information. Yet, in addition to it, our model with endogeneous information addresses the detrimental effect of transparency on the accuracy of central bank's disclosure and thereby of firms' information. With endogeneity, transparency also influences first-order expectations by reducing the accuracy of firms' information. While the coordination channel of M-S focuses on the excessive weight assigned to disclosure in higher-order expectations, our precision channel shows that transparency reduces the accuracy of both first and higher-order expectations. (Indeed, even the precision of the first-order expectation deteriorates as the degree of common knowledge of the central bank's disclosure becomes larger.) Both coordination and precision channels are intertwined since transparency reduces the precision of disclosure in the extent that agents overreact to it because of the coordination motive. Overall, accounting for the endogeneity of information reinforces the detrimental effect of transparency. Our analysis thus shows that the model with endogeneous information always calls for a lower degree of transparency than the model with exogeneous information.

Section 2.2 describes the economy. It is mainly characterized by imperfect common knowledge and the existence of strategic complementarities in pricing decision of firms. Section 2.3 presents the model under exogeneous central bank's information and replicates as a benchmark the analysis of M-S. Section 2.4 derives the model with endogeneous information and discusses the effect of transparency on central bank's information and disclosure. It also compares the optimal degree of transparency under both information regimes and shows that endogeneous information requires a lower degree of transparency. While sections 2.3 and 2.4 address the welfare effect of transparency for a broad class of welfare functions, section 2.5 focuses on microfounded welfare that highly weights coordination at the social level. Finally section 2.6 concludes.

2.2 The economy

The economy is populated by a representative household, a *continuum* of monopolistic competitive firms, and a central bank. The economy is affected by demand shocks. The microfounded market interactions are described in the appendix 1.A of chapter 1.

2.2.1 Firms

The central equation of our model is given by the optimal pricing rule of firms. This is derived from an economy where the representative household consumes a composite good *à la* Dixit and Stiglitz (1977) and where goods are imperfect substitutes. In such a context, the optimal price set by firm i is

$$p_i = \mathbb{E}_i[p + \xi c], \tag{2.1}$$

where $\mathbb{E}_i$ is the expectation operator of firm i conditional on its information, p is the overall price level, and c is the real output gap. The pricing rule (2.1) says that each firm sets its price according to both its own belief about the real output gap and its belief about the overall price level. We assume that the nominal aggregate demand defined as $y = c + p$ is determined by a stochastic demand shock $g \in \mathbb{R}$. So, one can write the pricing rule as

$$p_i = \mathbb{E}_i[(1 - \xi)p + \xi g]. \tag{2.2}$$

The parameter ξ captures the impact of the real output gap on prices (through wages). A large ξ means that the representative household is highly risk averse and that output gaps imply large variations in wages and thereby in prices. ξ also describes whether prices are strategic complements or substitutes. We shall assume in this thesis that $0 < \xi < 1$, which implies that prices are strategic complements, meaning that firms tend to raise their price whenever they expect the others to do so. This assumption seems very natural and captures the concept of beauty contest introduced by Keynes: firms base their decision not only on their own expectations of fundamentals but also on the so-called higher-order expectations, *i.e.* expectations of the average expectations of fundamentals, up to an infinite number of iterations.

Substituting successively the average price level with higher-order expectations about the demand shock, the pricing rule becomes

$$\begin{aligned} p_i &= \mathbb{E}_i[(1 - \xi)p + \xi g] \\ &= \mathbb{E}_i\Big[\xi g + (1 - \xi)\Big[\bar{\mathbb{E}}[\xi g + (1 - \xi)[\bar{\mathbb{E}}[\xi g + \ldots]]]\Big]\Big]. \end{aligned} \tag{2.3}$$

This chapter considers an economy under imperfect common knowledge where firms have differential information. With heterogeneous information, the law of iterated expectations fails and expectations of higher-order do not collapse to the average expectation of degree one.[3] This yields the pricing

[3]See Morris and Shin (2002).

rule

$$p_i = \xi \sum_{k=0}^{\infty} (1-\xi)^k \mathbb{E}_i \Big[\bar{\mathbb{E}}^{(k)}(g) \Big],$$

and averaging over firms, we get

$$p = \xi \sum_{k=0}^{\infty} (1-\xi)^k \Big[\bar{\mathbb{E}}^{(k+1)}(g) \Big], \tag{2.4}$$

where k is the degree of higher-order iteration, $\bar{\mathbb{E}}$ is the population average expectation operator such that $\bar{\mathbb{E}}(.) = \int_i \mathbb{E}_i(.)di$, and we use the following notation of higher-order expectations: $\bar{\mathbb{E}}^{(0)}(x) = x$ is the expected variable x itself, $\bar{\mathbb{E}}^{(1)}(x) = \bar{\mathbb{E}}(x)$ is the average expectation of x, $\bar{\mathbb{E}}^{(2)}(x) = \bar{\mathbb{E}}\bar{\mathbb{E}}^{(1)}(x) = \bar{\mathbb{E}}\bar{\mathbb{E}}(x)$ is the average expectation of the average expectation of x, and so on.

2.2.2 Welfare

One can show that in an economy characterized by imperfect competition, the welfare of the representative household is decreasing in both the dispersion of prices across firms $\int_i (p_i - p)^2 di$ and the variability of the output gap $c = y - p$. So, we define the social loss as

$$L = \int_i (p_i - p)^2 di + \lambda (g - p)^2, \tag{2.5}$$

where λ is the weight assigned to the output gap variability. The welfare function used in the transparency debate of M-S is a matter of controversy since the detrimental effect of transparency is driven by the relative relevance of coordination and stabilization at the social level. The application of the M-S argument to different welfare functions may lead to different conclusions. For example, Hellwig (2005) and Woodford (2005) show that when coordination is socially highly valuable, transparency is welfare improving as it helps coordinating firms' price setting. In their model, the potential destabilizing effect of transparency is neglected. The welfare function (2.5) is generic since the coefficient λ describes the relative importance of coordination for the society as a whole.

We leave λ unrestricted (free from other parameters) in sections 2.3 and

2.4 in order to discuss the argument of M-S in an environment where coordination is socially not very valuable and to emphasize the effect of endogeneous information in this context. We show in section 2.3.3 that the welfare in M-S given by $-\int_i (p_i - g)^2 di$ can be expressed by (2.5) with the parameter $\lambda = 1$. This means that the welfare in M-S equally weights coordination and stabilization at the social level.

Then, in section 2.5, following Hellwig (2005) and Woodford (2005) we consider the welfare function that is consistent with a microfounded economy. Adam (2006) derives the microfounded welfare of the representative household and shows that the weight assigned to output gap stabilization is given by $\lambda = \frac{\xi}{\theta}$, where $\theta > 1$ is the degree of substitutability in the Dixit-Stiglitz aggregator. Since $0 < \xi < 1$, the weight λ is typically much smaller in the microfounded welfare function than in the analysis of M-S.

2.2.3 The central bank

The central bank discloses information to firms about the fundamental demand shock g. We will discuss the welfare effect of the central bank's disclosure in two different informational contexts.

First, we consider the case where the central bank directly observes the stochastic demand shock g with some noise. The precision of central bank's information is then exogeneously determined (section 2.3).

Second, we assume that the central bank cannot directly observe the demand shock g but watches instead the economic activity to estimate the state of the economy. In this case, we show that the precision of central bank's information is endogeneous as it depends upon its disclosure policy (section 2.4).

2.3 Exogeneous central bank's information

This section analyzes the welfare effect of central bank's disclosure when the central bank has a direct source of information about the demand shock. The aim of this section is to illustrate the much debated result by M-S where central bank's information is exogeneous. The present section must be seen as a benchmark case that replicates the results by M-S in a slightly less stylized context and allows a better suited comparison.

We describe the information structure and derive the equilibrium. Then, we discuss the optimal information disclosure first when the central bank chooses between full transparency and full opacity (*i.e.* the central bank either perfectly reveals its opinion or totally withholds it), and second when the central bank can choose its optimal degree of transparency (*i.e.* the central bank speaks with some ambiguity).

2.3.1 Information structure

Firms' information

To make its pricing decision, each firm receives two signals. First, each firm gets a private signal about the demand shock. The private signal is centred on the true value of g and has a normally distributed error term:

$$g_i = g + \varepsilon_i \qquad \text{with } \varepsilon_i \sim N(0, \sigma_\varepsilon^2),$$

where ε_i are identically and independently distributed across firms.

Second, the central bank provides firms with its viewpoint about the demand shock. The central bank communicates its information D with more or less ambiguity. We capture this ambiguity with the transparency of its disclosure. For the sake of generality, we write the signal disclosed by the central bank and received by firm i as

$$D_i = D + \phi_i \qquad \text{with } \phi_i \sim N(0, \sigma_\phi^2).$$

The dispersion of individual noises σ_ϕ^2 determines the degree of transparency of the central bank. Under transparency, every firm gets the same univocal signal ($\sigma_\phi^2 = 0$). Then, the central bank's information D is a public signal that is common knowledge among firms. Under opacity, the individual signal got by each firm has an infinite idiosyncratic noise ($\sigma_\phi^2 \to \infty$). The central bank's information thus does not contain any valuable information. One can imagine any intermediate situation where the central bank provides firms with more or less equivocal information.

The introduction of idiosyncratic noise in central bank's disclosure reduces its degree of common knowledge among firms. Heinemann and

Illing (2002) address the issue of central bank disclosing information to every agent in private but within a game of speculative attack. Cornand and Heinemann (2004) propose another disclosure strategy that also reduces the degree of common knowledge: the disclosure of a public signal D to a fraction S of firms. The disclosure D thus becomes semi-public as the fraction $1 - S$ of firms does not receive it but only gets its private signal g_i.[4] Appendix 2.B shows that both disclosure strategies – *i.e.* limited transparency *vs.* limited publicity – are strictly equivalent in terms of welfare. More precisely, this appendix shows that the equivalence relationship between the degree of transparency σ_ϕ^2 and the degree of publicity S is given by

$$\sigma_\phi^2 = \frac{1-S}{S}(\sigma_\varepsilon^2 + \sigma_\eta^2) \qquad \text{or} \qquad S = \frac{\sigma_\varepsilon^2 + \sigma_\eta^2}{\sigma_\varepsilon^2 + \sigma_\eta^2 + \sigma_\phi^2}.$$

In the remainder of the chapter, we will however only address the question of optimal degree of transparency.

Central bank's information

The central bank imperfectly observes the demand shock: it receives a signal on the demand shock that is centred on its true value and contains an error term:

$$D = g + \eta \qquad \text{with } \eta \sim N(0, \sigma_\eta^2).$$

Note that the precision of central bank's information is exogeneously determined. Figure 2.2 illustrates the informational structure discussed in this section.

2.3.2 Equilibrium

This section derives the perfect Bayesian equilibrium behaviour of firms. To determine the optimal price rule (2.4), we build the first and higher-order expectations of firm i about the demand shock g conditional on its informa-

[4]Some other way to disclose fragmented information is introduced in Morris and Shin (2006).

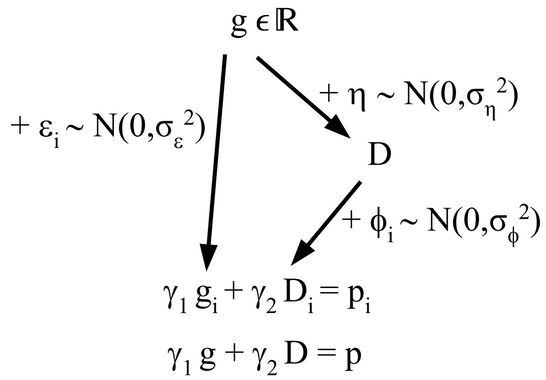

Figure 2.2: Exogeneous central bank's information

tion. The expectation of degree one about the demand shock $\mathbb{E}_i(g)$ yields

$$\mathbb{E}(g|g_i, D_i) = \frac{\sigma_\eta^2 + \sigma_\phi^2}{\sigma_\varepsilon^2 + \sigma_\eta^2 + \sigma_\phi^2} g_i + \frac{\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + \sigma_\eta^2 + \sigma_\phi^2} D_i = \Omega_{11} g_i + \Omega_{12} D_i. \tag{2.6}$$

The best estimate of the demand shock by firm i is an average of its both signals whose weighting depends upon their relative precision. To compute the higher-order expectations of firm i, one needs also to know the expectation of degree one of the central bank's average disclosure $\mathbb{E}_i(D)$. This delivers

$$\mathbb{E}(D|g_i, D_i) = \frac{\sigma_\phi^2}{\sigma_\varepsilon^2 + \sigma_\eta^2 + \sigma_\phi^2} g_i + \frac{\sigma_\varepsilon^2 + \sigma_\eta^2}{\sigma_\varepsilon^2 + \sigma_\eta^2 + \sigma_\phi^2} D_i = \Omega_{21} g_i + \Omega_{22} D_i. \tag{2.7}$$

Note that under transparency (when $\sigma_\phi^2 = 0$), the central bank's disclosure is univocal and $\Omega_{21} = 0$ which means that the private signal g_i does not help guessing D (since $D_i = D$). Under opacity, when the idiosyncratic noise is infinite ($\sigma_\phi^2 \to \infty$), the central bank's disclosure is of no use to estimate the demand shock g and the best estimate is the private signal g_i itself ($\Omega_{11} = 1$).

Using these results, we can express the higher-order expectation of degree k as

$$\bar{\mathbb{E}}^{(k)} \begin{pmatrix} g \\ D \end{pmatrix} = \begin{pmatrix} \Omega_{11} & \Omega_{12} \\ \Omega_{21} & \Omega_{22} \end{pmatrix}^k \begin{pmatrix} g \\ D \end{pmatrix}.$$

Plugging this into the price rule (2.4), we get

$$p = \begin{pmatrix} \xi & 0 \end{pmatrix} \sum_{k=0}^{\infty} (1-\xi)^k \begin{pmatrix} \Omega_{11} & \Omega_{12} \\ \Omega_{21} & \Omega_{22} \end{pmatrix}^{k+1} \begin{pmatrix} g \\ D \end{pmatrix}. \tag{2.8}$$

The price rule is a linear combination of the demand shock and the central bank's disclosure. Appendix 2.A shows that the price rule is given by

$$\begin{aligned} p &= \gamma_1 g + \gamma_2 D \qquad \text{with} \\ \gamma_1 &= \frac{\Omega_{11}\xi + (1-\xi)\Omega_{21}}{1-(1-\xi)(\Omega_{11}-\Omega_{21})} = \frac{\xi\sigma_\eta^2 + \sigma_\phi^2}{\sigma_\varepsilon^2 + \xi\sigma_\eta^2 + \sigma_\phi^2} \\ \gamma_2 &= \frac{\xi\Omega_{12} + (1-\xi)\Omega_{12}\Omega_{21}}{\xi - (1-\xi)[\Omega_{11}\xi - (1+\xi)\Omega_{21} - (1-\xi)(\Omega_{21}-\Omega_{11})\Omega_{11}]} = \frac{\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + \xi\sigma_\eta^2 + \sigma_\phi^2}. \end{aligned} \tag{2.9}$$

γ_1 and γ_2 sum up to 1. The equilibrium firms' action can be interpreted as a weighted average of the fundamental g and the average disclosure D. Note however that the weight assigned to the central bank's disclosure is larger in the equilibrium action (γ_2) than in the best estimate of g given in (2.6): $\gamma_2 > \Omega_{12}$. This discrepancy arises because of the coordination motive in the pricing rule. While ε_i and ϕ_i are idiosyncratic noises, the central bank's error term η is commonly observed by all firms through the disclosure D_i. The weight assigned to the central bank's error (and thereby to D_i) increases as the coordination motive strengthens: strategic complementarities raise the incentive of firms to coordinate their action around the central bank's disclosure. When the degree of strategic complementarities $1-\xi$ increases, the weight assigned to the private signal g_i declines ($\frac{\partial\gamma_1}{\partial\xi} > 0$) while the weight assigned to central bank's disclosure increases ($\frac{\partial\gamma_2}{\partial\xi} < 0$). When the degree of transparency increases (σ_ϕ^2 falls), the weight put on the central bank's disclosure D_i increases since its interpretation becomes less ambiguous and better conducive to guess the action of others ($\frac{\partial\gamma_1}{\partial\sigma_\phi^2} > 0$ and $\frac{\partial\gamma_2}{\partial\sigma_\phi^2} < 0$). Signals are also given a higher weight when their precision increases: $\frac{\partial\gamma_1}{\partial\sigma_\varepsilon^2} < 0$ and $\frac{\partial\gamma_2}{\partial\sigma_\eta^2} < 0$.

2.3.3 Welfare

We now examine the welfare given by (2.5) in the current informational context. On the one hand, the equilibrium firms' behaviour (2.9) implies that the unconditional expected price dispersion across firms satisfies

$$\mathbb{E}\Big(\int_i (p_i - p)^2 di\Big) = \mathbb{E}\Big(\int_i (\gamma_1 g_i + \gamma_2 D_i - \gamma_1 g - \gamma_2 D)^2 di\Big) = \gamma_1^2\sigma_\varepsilon^2 + \gamma_2^2\sigma_\phi^2.$$

On the other hand, the unconditional output gap expectation is

$$\mathbb{E}(c^2) = \mathbb{E}(g-p)^2 = \mathbb{E}(g - \gamma_1 g - \gamma_2 D)^2 = \gamma_2^2\sigma_\eta^2.$$

So, the unconditional expected social loss can be written as

$$\begin{aligned}\mathbb{E}(L) &= \gamma_1^2\sigma_\varepsilon^2 + \gamma_2^2\sigma_\phi^2 + \lambda\gamma_2^2\sigma_\eta^2 \\ &= \frac{\sigma_\varepsilon^2(\lambda\sigma_\eta^2 + \sigma_\phi^2) + (\xi\sigma_\eta^2 + \sigma_\phi^2)^2}{(\sigma_\varepsilon^2 + \xi\sigma_\eta^2 + \sigma_\phi^2)^2}\sigma_\varepsilon^2.\end{aligned} \tag{2.10}$$

Let us now discuss the welfare considered in M-S and given by $-\int_i (p_i - g)^2 di$. We write the corresponding loss as

$$\begin{aligned}\mathbb{E}(L_{MS}) &= \mathbb{E}\Big(\int_i (p_i - g)^2 di\Big) \\ &= \mathbb{E}\Big(\int_i (\gamma_1(g+\varepsilon_i) + \gamma_2(g+\eta+\phi_i) - g)^2 di\Big) \\ &= \gamma_1^2\sigma_\varepsilon^2 + \gamma_2^2\sigma_\phi^2 + \gamma_2^2\sigma_\eta^2.\end{aligned}$$

This implies that the welfare in M-S is a particular case of our general formulation (2.10) where $\lambda = 1$. This means that the model of M-S equally weights coordination and stabilization at the social level.

The welfare effect of the central bank's disclosure is analyzed in the next sections. We first restrict the discussion to the binary case of transparency *vs.* opacity. This is the perspective of M-S where the central bank either discloses a public signal (that is common knowledge) or withholds its information. Then, we allow for intermediate level of transparency and derive the optimal degree of transparency.

2.3.4 Transparency *versus* opacity

Opacity The welfare is calculated when the central bank withholds its information, *i.e.* $\sigma_\phi^2 \to \infty$. Under opacity, firms set their price equal to their private signal g_i, *i.e.* $\gamma_1 = 1$ and $\gamma_2 = 0$. The resulting expected loss is

$$\mathbb{E}(L_O) = \mathbb{E}\Big(\int_i (\gamma_1(g+\varepsilon_i) - \gamma_1 g)^2 di + \lambda(g - \gamma_1 g)^2\Big) = \sigma_\varepsilon^2.$$

The overall price level p is equal to the fundamental g. The price dispersion across firms is given by the variance of the idiosyncratic noise ε_i.

Transparency Under transparency, disclosure of the central bank is common knowledge ($\sigma_\phi^2 = 0$) and the pricing rule of firms becomes

$$p = \frac{\xi\sigma_\eta^2}{\sigma_\varepsilon^2 + \xi\sigma_\eta^2} g + \frac{\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + \xi\sigma_\eta^2} D.$$

The resulting expected loss is

$$\mathbb{E}(L_T) = \Big(\frac{\xi\sigma_\eta^2}{\sigma_\varepsilon^2 + \xi\sigma_\eta^2}\Big)^2 \sigma_\varepsilon^2 + \lambda\Big(\frac{\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + \xi\sigma_\eta^2}\Big)^2 \sigma_\eta^2.$$

Transparency is welfare improving when the loss under opacity L_O is larger than the loss under transparency L_T. When the precision of central bank's information is exogeneous, it turns out that full transparency is preferable to opacity when

$$\lambda - 2\xi < \frac{\sigma_\varepsilon^2}{\sigma_\eta^2}. \tag{2.11}$$

This finding is in line with M-S: transparency is welfare detrimental whenever public information is too noisy relative to private information ($\frac{\sigma_\varepsilon^2}{\sigma_\eta^2}$ small) and when the degree of strategic complementarities is rather high (ξ small). When complementarities are sufficiently low such that $\lambda - 2\xi < 0$, transparency is always beneficial since variances of error terms are positive by definition ($\sigma_.^2 \geq 0$).

The general framework developed in this chapter shows the extent to which the welfare effect of transparency is related to the social value of coordination. In the case of M-S, as $\lambda = 1$, private information must be more accurate than public information for transparency to be detrimental. The left-hand side of inequation (2.11) is always smaller than one. For the right-hand side to be smaller than the left-hand one, the central bank's noise σ_η^2

must be larger than the private noise σ_ε^2. Since information of public institutions (like central banks) is typically more accurate than information privately available[5], Svensson (2006) argues that the detrimental effect of transparency emphasized in the beauty contest framework of M-S arises under unrealistic conditions.

But if the social value of coordination is smaller than in M-S ($\lambda > 1$), opacity may be superior even when public information is more accurate than private information (this arises when $\lambda - 2\xi > 1$). This means that the pertinence of the critique of Svensson strongly depends on the coordination value at the social level.

2.3.5 Optimal degree of transparency

In the former section, the central bank could either disclose its noisy information with perfect precision or withhold it. In reality, however, central bankers are known for mumbling with ambiguity. This makes central bank's disclosures open to interpretation. The more a central bank speaks in an equivocal manner, the higher the uncertainty about the interpretation of the disclosure (fundamental uncertainty) and the higher the uncertainty about its interpretation by others (strategic uncertainty). When full transparency is detrimental to welfare relative to opacity, reducing transparency may improve welfare. But even when full transparency is preferable to opacity, partial transparency may yield a superior outcome. What is the optimal degree of transparency for a central bank to disclose its information?

To determine the optimal degree of transparency σ_ϕ^{2*}, we minimize the loss (2.10) with respect to σ_ϕ^2 and set it equal to zero:

$$\begin{aligned}
\frac{\partial \mathbb{E}(L)}{\partial \sigma_\phi^2} &= 2\gamma_1 \frac{\partial \gamma_1}{\partial \sigma_\phi^2}\sigma_\varepsilon^2 + \gamma_2^2 + 2\gamma_2 \frac{\partial \gamma_2}{\partial \sigma_\phi^2}\sigma_\phi^2 + 2\lambda\gamma_2 \frac{\partial \gamma_2}{\partial \sigma_\phi^2}\sigma_\eta^2 \\
&= \frac{(\sigma_\varepsilon^2 + (3\xi - 2\lambda)\sigma_\eta^2 + \sigma_\phi^2)\sigma_\varepsilon^4}{(\sigma_\varepsilon^2 + \xi\sigma_\eta^2 + \sigma_\phi^2)^3} \\
&= 0 \qquad \Leftrightarrow \qquad \sigma_\phi^2 = (2\lambda - 3\xi)\sigma_\eta^2 - \sigma_\varepsilon^2. \qquad (2.12)
\end{aligned}$$

[5]For instance, in an empirical analysis on US data, Romer and Romer (2000) show that the Fed better forecasts the output and inflation than any single private commercial bank.

Since the variance of idiosyncratic noise is nonnegative, the optimal degree of transparency is described by

$$\sigma_\phi^{2*} = \max[0, (2\lambda - 3\xi)\sigma_\eta^2 - \sigma_\varepsilon^2]. \tag{2.13}$$

We show in appendix 2.B that full transparency is always superior to full opacity when σ_ϕ^{2*} is not defined as the right-hand side of equation (2.12) is negative. This analysis calls for partial transparency when coordination is not very valuable at the social level (λ large), when the degree of strategic complementarities is high (ξ small), and/or when the central bank's information is rather noisy (σ_η^2 large).

Implementing the optimal degree of transparency (2.13) yields the following expected welfare:

$$\mathbb{E}(L^*) = \min\Big[\frac{(\lambda\sigma_\varepsilon^2 + \xi^2\sigma_\eta^2)\sigma_\varepsilon^2\sigma_\eta^2}{(\sigma_\varepsilon^2 + \xi\sigma_\eta^2)^2}, \frac{4\sigma_\eta^2(\xi - \lambda) + \sigma_\varepsilon^2}{4\sigma_\eta^2(\xi - \lambda)}\sigma_\varepsilon^2\Big].$$

The first panel of figure 2.3 illustrates the unconditional expected loss under transparency (dotted line), under opacity (dashed line), and under optimal degree of transparency (solid line). The parameter values are $\sigma_\eta^2 = 0.25$, $\xi = 0.1$, and $\lambda = 1$. As (2.11) shows, full opacity is superior to full transparency when $\sigma_\varepsilon^2 < (\lambda - 2\xi)\sigma_\eta^2 = 0.2$. The optimal degree of transparency is represented in the second plot below. As (2.13) states it, reducing the degree of transparency is optimal when $\sigma_\varepsilon^2 < (2\lambda - 3\xi)\sigma_\eta^2 = 0.425$. Interestingly, for $0.2 < \sigma_\varepsilon^2 < 0.425$, reducing the degree of transparency is optimal even if full transparency is superior to full opacity.

2.4 Endogeneous central bank's information

In this section, we relax the assumption that the central bank directly observes the exogeneous aggregate shock g underlying the economy. Since the central bank has no direct source of information about stochastic aggregate economic conditions, it must observe the aggregate activity of firms to infer the demand shock. In reality, the central bank learns about aggregate shocks by collecting data from the aggregate economic outcome and not by observing an exogeneous fundamental process.The model developed

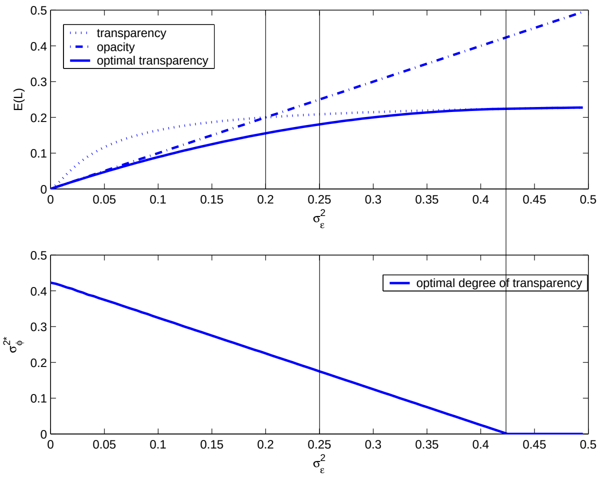

Figure 2.3: Unconditional expected loss and optimal degree of transparency

in the current section accounts for the feature that the central bank learns about economic conditions from watching the economy itself. But the central bank, as a policy maker, also strongly shapes market expectations and thereby drives the path of economic activity. While the central bank only shapes the economy with its disclosure in the case of exogeneous information, it also observes the economy when information is endogeneous. The dual role of the central bank entails a dilemma: the better the central bank succeeds in influencing the economic activity, the more the economy reflects the central bank's assessment and the less accurate becomes the observation of aggregate economic outcomes as indicators of imbalances.

The next sections describe the information structure and derive the equilibrium. We then discuss the properties of the model and the effect of the central bank's disclosure on the accuracy of its information and of that of firms. Finally, we examine the optimal disclosure strategy and compare it to the benchmark case of exogeneous information.

2.4.1 Information structure

Firms

Each firm receives two signals, as in the case of exogeneous central bank's information. First, each firm faces a particular demand condition that reflects the particularity of its own industry or business. Each firm has its own "window on the world". Overall, the mean of these individual shocks is the aggregate demand shock g and individual shocks have some dispersion around their mean:

$$g_i = g + \varepsilon_i, \quad \text{with} \quad \varepsilon_i \sim N(0, \sigma_\varepsilon^2).$$

Second, each firm i observes the central bank's disclosure given by

$$D_i = D + \phi_i, \quad \text{with} \quad \phi_i \sim N(0, \sigma_\phi^2).$$

ε_i and ϕ_i are identically and independently distributed across firms.

The central bank

The central bank has no direct access to information on the underlying shock. In particular, it cannot observe the aggregate demand shock g because it is not a tangible quantity. Instead, the central bank bases its estimation of the demand shock on its observations of the overall price level. As pointed by Hayek (1945), prices play a crucial informational role by aggregating individual information. By observing the average action of firms, the central bank obtains information about the state of the economy.

We postulate that the central bank observes the price level p with some noise η

$$D = p + \eta, \quad \text{with} \quad \eta \sim N(0, \sigma_\eta^2).$$

The variance σ_η^2 denotes, as in the case of exogeneous information, the imprecision of central bank's observation (estimation). As we discuss below, since firms base their pricing decision partly on the central bank's disclosure, the precision of central bank's information is a function of its disclosure strategy.

Figure 2.4 summarizes the information structure of our model with endogeneous central bank's information.

2.4.2 Equilibrium

This section solves the perfect Bayesian equilibrium price setting of firms. We determine the first and higher-order expectations of firm i about the de-

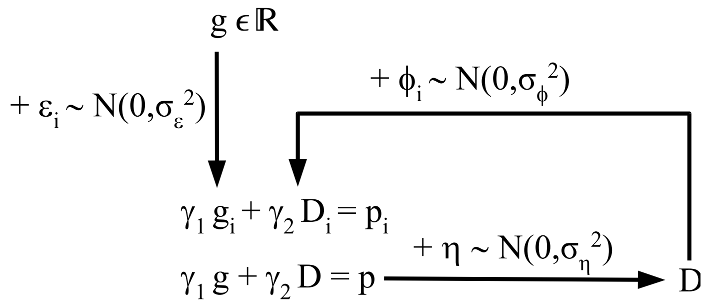

Figure 2.4: Endogeneous central bank's information

mand shock g and the central bank's disclosure D conditional on its information g_i and D_i. The equilibrium pricing rule of firm i is a linear combination of its signals

$$p_i = \gamma_1 g_i + \gamma_2 D_i.$$

Using this and the fact that $\gamma_1 + \gamma_2 = 1$, we rewrite the disclosure D_i as

$$\begin{aligned} D_i &= D + \phi_i = p + \eta + \phi_i = \gamma_1 g + \gamma_2 D + \eta + \phi_i \\ &= g + \frac{1}{1-\gamma_2}\eta + \phi_i. \end{aligned}$$

Note that the precision of the signal disclosed by the central bank is a function of γ_2, the firms' reaction to this signal. Its precision decreases with the strength of the firms' response. When their reaction to the central bank's disclosure is weak (γ_2 small), the factor of the central bank's noise η is small. The precision is maximal when firms do not react to the disclosure ($\gamma_2 = 0$). The stronger their reaction, the more noisy is the disclosure. This relation captures the main trade-off of our model. As the central bank's influence on the firms' pricing decision increases, the accuracy of its information (and disclosure) is reduced. In this sense, the central bank's information is endogeneous: it is a function of its disclosure strategy.

Expectations of degree one yield

$$\begin{aligned} \mathbb{E}\left(\begin{array}{c} g \\ D \end{array} \middle| \; g_i, D_i \right) &= \mathbf{\Omega} \begin{pmatrix} g_i \\ D_i \end{pmatrix} = \begin{pmatrix} \Omega_{11} & \Omega_{12} \\ \Omega_{21} & \Omega_{22} \end{pmatrix} \begin{pmatrix} g_i \\ D_i \end{pmatrix} \\ &= \begin{pmatrix} \frac{(1-\gamma_2)^{-2}\sigma_\eta^2 + \sigma_\phi^2}{\sigma_\varepsilon^2 + (1-\gamma_2)^{-2}\sigma_\eta^2 + \sigma_\phi^2} & \frac{\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + (1-\gamma_2)^{-2}\sigma_\eta^2 + \sigma_\phi^2} \\ \frac{\sigma_\phi^2}{\sigma_\varepsilon^2 + (1-\gamma_2)^{-2}\sigma_\eta^2 + \sigma_\phi^2} & \frac{\sigma_\varepsilon^2 + (1-\gamma_2)^{-2}\sigma_\eta^2}{\sigma_\varepsilon^2 + (1-\gamma_2)^{-2}\sigma_\eta^2 + \sigma_\phi^2} \end{pmatrix} \begin{pmatrix} g_i \\ D_i \end{pmatrix}. \end{aligned} \tag{2.14}$$

The best estimate of the demand shock is a weighted average of signals g_i and D_i. The weight assigned to each signal increases with its relative precision. As just discussed, the precision of the disclosure D_i depends on the equilibrium pricing rule (on γ_2). In sharp contrast to the model with exogeneous information (see equations (2.6) and (2.7)), the precision of first-order expectations depends on the strength of firms' reaction to central bank's disclosure γ_2.

Using this solution to solve firms' inference problem, we write (2.4) as

$$\begin{aligned} p &= \xi \sum_{k=0}^{\infty} (1-\xi)^k \left[\bar{\mathbb{E}}^{(k+1)}(g) \right] \\ &= \begin{pmatrix} \xi & 0 \end{pmatrix} \sum_{k=0}^{\infty} (1-\xi)^k \left[\mathbf{\Omega^{k+1}} \begin{pmatrix} g \\ D \end{pmatrix} \right]. \end{aligned}$$

The resulting price rule is described by

$$\begin{aligned} p &= \gamma_1 g + \gamma_2 D && (2.15) \\ \gamma_1 &= \frac{(1-\xi)\Omega_{21}\gamma_2 + \xi\Omega_{11}}{1-(1-\xi)\Omega_{11}} = \frac{\xi(1-\gamma_2)^{-2}\sigma_\eta^2 + \sigma_\phi^2}{\sigma_\varepsilon^2 + \xi(1-\gamma_2)^{-2}\sigma_\eta^2 + \sigma_\phi^2} \\ \gamma_2 &= \frac{(1-\xi)\Omega_{12}\gamma_1 + \xi\Omega_{12}}{1-(1-\xi)\Omega_{22}} = \frac{\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + \xi(1-\gamma_2)^{-2}\sigma_\eta^2 + \sigma_\phi^2}. \end{aligned}$$

Similarly to the case of exogeneous information presented in section 2.3 (see equations (2.6) and (2.9)), the equilibrium price rule is distorted towards the central bank's disclosure compared to the first-order expectation of g given in (2.14). This distortion increases with the degree of strategic complementarities $1-\xi$.

2.4.3 Bayesian update and equilibrium action

This section compares the Bayesian update and the equilibrium action in both cases of exogeneous and endogeneous information. Figure 2.5 illustrates the weight assigned to the central bank's disclosure both in the first-order expectation of the demand shock g and in the equilibrium pricing rule as a function of the degree of transparency σ_ϕ^2. This is computed with $\xi = 0.1$ and $\sigma_\eta^2 = \sigma_\varepsilon^2 = 0.25$.[6]

For the case of exogeneous information, the dash-dotted and dotted lines represent the weight assigned to D_i in the Bayesian update (Ω_{12} in equation (2.6)) and in the equilibrium price rule (γ_2 in equation (2.9)), respectively. We see that both weights increase with the degree of transparency: higher transparency increases the degree of common knowledge of central bank's disclosure and its focal role for price setting. The weight in the pricing rule is also larger than that in the Bayesian update ($\gamma_2|_{\sigma_\phi^2} > \Omega_{12}|_{\sigma_\phi^2}, \forall \sigma_\phi^2$).

For the case of endogeneous information, the solid line represents Ω_{12} in the first-order expectation (2.14) and the dashed line γ_2 in the optimal pricing equation (2.15). As in the case of exogeneous information, firms overreact to the central bank's disclosure in the sense that the weight assigned to it in the pricing rule (γ_2) is larger than that in the Bayesian update (Ω_{12}). But with endogeneous information, the effect of central bank's transparency (σ_ϕ^2) on firms' estimation is ambiguous: while a reduction in the degree of transparency (that is to say an increase of the idiosyncratic noise) reduces the accuracy of the disclosure, it increases the precision of the average disclosure D as firms respond less strongly to it. Ω_{12} does not monotonously increase in the degree of transparency. When σ_ϕ^2 falls, the degree of common knowledge of the central bank's disclosure D_i increases and the weight assigned to it in the pricing rule (γ_2) rises. The impact of a fall in σ_ϕ^2 on the precision of the disclosure D_i (and consequently on Ω_{12}) is twofold. On the one hand, the precision of disclosure increases because the idiosyncratic noise is reduced. On the other hand, as firms respond more strongly to the disclosure, the precision of both central bank's information and disclosure decreases. The combination of both mechanisms gives rise to the ambiguous effect of transparency on Ω_{12} that is particular to the model with endogeneous information.

The next section addresses the effect of transparency on the accuracy of prices and central bank's information as indicators of the state of the economy.

[6]We use the methodology of Ulrich Doraszelski to solve this nonlinear model. We are grateful to him for making his codes available. See Doraszelski and Markovich (2005) for example.

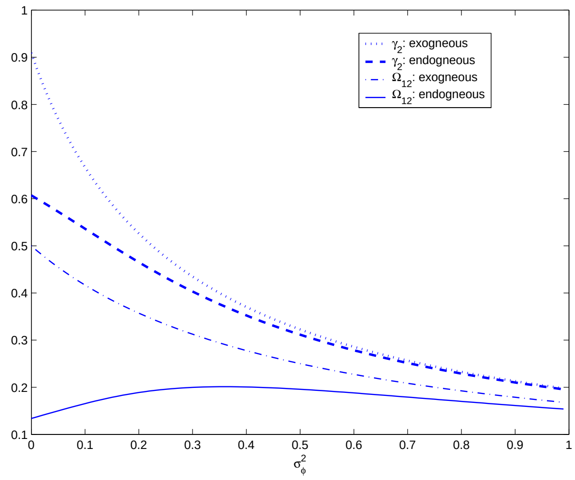

Figure 2.5: Bayesian update and equilibrium action

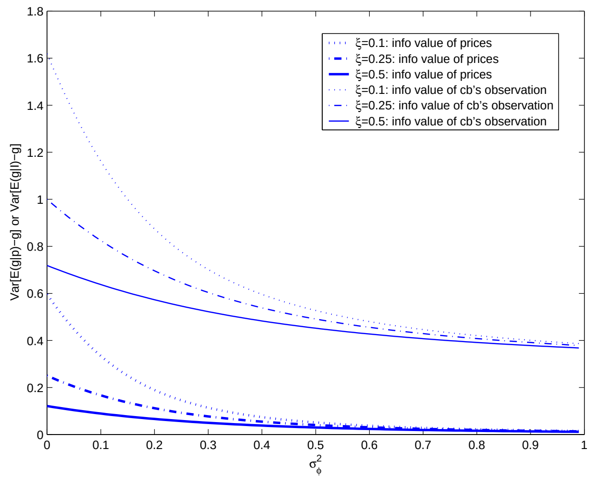

Figure 2.6: Informative value of prices and central bank's observation

2.4.4 Information value of prices and precision of central bank's information

Figure 2.6 illustrates the accuracy of prices and central bank's information as indicators of economic conditions. The computation is done with $\sigma_\eta^2 = \sigma_\varepsilon^2 = 0.25$. The information value is evaluated as the variance of the error of demand shock estimations conditional either on the price level p or on central bank's information D.

The information value of the price level p is given by

$$\text{Var}[\mathbb{E}(g|p) - g] = \text{Var}\Big[\mathbb{E}\Big(g|g + \frac{\gamma_2}{1-\gamma_2}\eta\Big) - g\Big] = \frac{\gamma_2^2}{\gamma_1^2}\sigma_\eta^2 = \frac{\gamma_2^2}{(1-\gamma_2)^2}\sigma_\eta^2,$$

while the information value of the central bank's observation D is given by

$$\text{Var}[\mathbb{E}(g|D) - g] = \text{Var}\Big[\mathbb{E}\Big(g|g + \frac{1}{1-\gamma_2}\eta\Big) - g\Big] = \frac{1}{\gamma_1^2}\sigma_\eta^2 = \frac{1}{(1-\gamma_2)^2}\sigma_\eta^2.$$

The figure 2.6 shows that the information about the state of the economy contained in the price level and in central bank's observation decreases with the degree of central bank's transparency. In the limit of opacity, γ_2 converges to zero (firms don't react to the disclosure) and the price level becomes a perfect indicator for the demand shock g. The accuracy of central bank's observation also increases with opacity. But as the central bank observes the price level with an error term η, it is always less accurate than the price level itself.

The accuracy of the price level as an indicator for economic conditions decreases with the weight assigned to central bank's disclosure. This weight is high either when the idiosyncratic noise of the disclosure is low (high degree of transparency or common knowledge) or when strategic complementarities are strong (ξ small). The degree of strategic complementarities affects the information value of prices because it drives the overreaction to central bank's disclosure. When complementarities are high (dotted lines), the central bank's disclosure is given a large weight in the pricing rule. This increases the impact of the noise η on the price level.

This clearly highlights the endogeneous nature of central bank's information. The more effectively the central bank influences the pricing behaviour of firms (γ_2 large), the less accurate is its estimation of demand shocks.

2.4.5 Firms' information

We now turn to the information accuracy of individual firms. While opacity increases the precision of central bank's observation and thereby of average disclosure D, it increases the idiosyncratic noise at the same time (σ_ϕ^2). The overall impact of opacity is therefore ambiguous on the accuracy of the disclosure received by an individual firm i. On the one hand, a rise in opacity increases the precision of central bank's observation and average disclosure. This tends to increase the precision of individual disclosure D_i as well. On the other hand, a rise in opacity requires a larger idiosyncratic noise ϕ_i that reduces the precision of the individual disclosure. By contrast to the case of exogeneous information where increasing idiosyncratic noise always reduces the precision of firms' information, it may increase the precision of firms' information with endogeneous information.

The precision of firms' information is captured by the variance of the error term of the demand shock first-order expectation conditional on the private signal g_i and disclosure D_i. This is given by

$$\begin{aligned}\text{Var}[\mathbb{E}(g|g_i, D_i) - g] &= \text{Var}\Big[\mathbb{E}\Big(g|g+\varepsilon_i, g+\frac{1}{1-\gamma_2}\eta+\phi_i\Big) - g\Big] \\ &= \Omega_{11}^2\sigma_\varepsilon^2 + \Big(\frac{\Omega_{12}}{1-\gamma_2}\Big)^2\sigma_\eta^2 + \Omega_{12}^2\sigma_\phi^2 = \frac{\sigma_\varepsilon^2[(1-\gamma_2)^{-2}\sigma_\eta^2+\sigma_\phi^2]}{\sigma_\varepsilon^2+(1-\gamma_2)^{-2}\sigma_\eta^2+\sigma_\phi^2}.\end{aligned}$$

Figure 2.7 illustrates this variance for three degrees of strategic complementarities as a function of the degree of transparency. The solid line shows that when complementarities are low reducing the degree of transparency always deteriorates firms' information. This arises because transparency does not distort central bank's information too much as the coordination motive is weak (see Figure 2.6 in section 2.4.4). The increasing idiosyncratic noise of opacity is not overcome by the rise in the precision of central bank's information.

When the degree of transparency is high and complementarities are strong, the dotted and dashed lines show that reducing the degree of transparency increases the precision of firms' information. The gain in the precision of central bank's information overcomes the rise in idiosyncratic noise as long as transparency is sufficiently high. Below a certain threshold of transparency, lowering it further reduces the precision of firms' information.

The effect of transparency on the first-order expectation of firms is particular to endogeneous information. The case of exogeneous information emphasizes the effect of transparency on expectations of higher orders: transparency may be detrimental because expectations of higher orders are given too large a weight into the pricing rule. Our case of endogeneous information highlights a new effect of transparency since even the first-order expec-

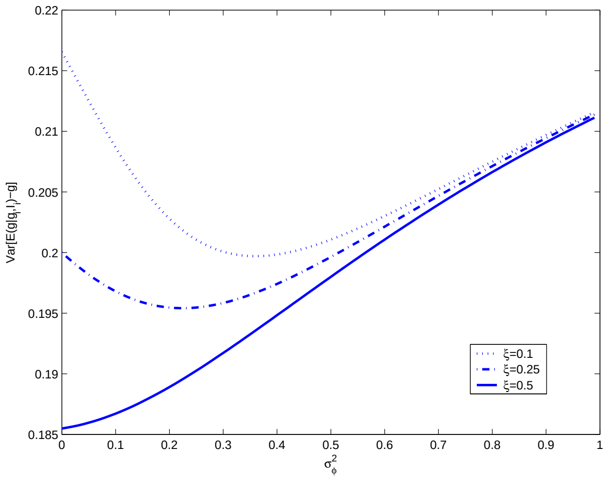

Figure 2.7: Precision of firms' information

tation of firms is affected by the degree of transparency.

2.4.6 Welfare

We now examine the welfare given by (2.5) in the context of endogeneous information. As with exogeneous information, the equilibrium firms' behaviour (2.15) implies that the expected price dispersion across firms satisfies

$$\mathbb{E}\Big(\int_i (p_i - p)^2 di\Big) = \mathbb{E}\Big(\int_i (\gamma_1 g_i + \gamma_2 D_i - \gamma_1 g - \gamma_2 D)^2 di\Big) = \gamma_1^2\sigma_\varepsilon^2 + \gamma_2^2\sigma_\phi^2.$$

But now the unconditional output gap expectation is expressed by

$$\mathbb{E}(c^2) = \mathbb{E}(g - p)^2 = \mathbb{E}(g - \gamma_1 g - \gamma_2 D)^2 = \frac{\gamma_2^2}{(1-\gamma_2)^2}\sigma_\eta^2.$$

So, the unconditional expected social loss can be written as

$$\mathbb{E}(L) = \gamma_1^2\sigma_\varepsilon^2 + \gamma_2^2\sigma_\phi^2 + \lambda\frac{\gamma_2^2}{(1-\gamma_2)^2}\sigma_\eta^2. \tag{2.16}$$

The welfare effect of the central bank's disclosure is analyzed in the next sections. We first restrict the discussion to the binary case of transparency *vs.* opacity. This is the perspective of M-S where the central bank either discloses a public signal (that is common knowledge) or withholds its information. Then, we allow for intermediate levels of transparency and derive the optimal degree of transparency.

2.4.7 Transparency *versus* opacity

Opacity Under opacity, firms do not respond to the central bank's disclosure and set their price equal to their private signal g_i, *i.e.* $\gamma_1 = 1$ and $\gamma_2 = 0$. The resulting expected loss is

$$\mathbb{E}(L_O) = \sigma_\varepsilon^2.$$

The overall price level p is equal to the fundamental g. The price dispersion across firms is given by the variance of the idiosyncratic noise ε_i.

Transparency Under transparency, disclosure of the central bank is common knowledge ($\sigma_\phi^2 = 0$) and the resulting expected loss is

$$\mathbb{E}(L_T) = \gamma_1^2\sigma_\varepsilon^2 + \lambda\frac{\gamma_2^2}{(1-\gamma_2)^2}\sigma_\eta^2.$$

Transparency is welfare improving when the expected loss under opacity $\mathbb{E}(L_O)$ is larger than the expected loss under transparency $\mathbb{E}(L_T)$.

Qualitatively, transparency is welfare improving for the same configuration as in the case of exogeneous information presented in equation (2.11). Namely, transparency is welfare improving when strategic complementarities are weak (ξ large), when private signals are noisy (σ_ε^2 large), when the central bank's error term σ_η^2 is small, and when the weight assigned to output gap deviation λ is small. Figure 2.8 illustrates the unconditional expected loss under transparency relative to that under opacity $\mathbb{E}(L_T)/\mathbb{E}(L_O)$ as a function of the precision of private signals for three levels of complementarities. This is computed with $\sigma_\eta^2 = 0.25$ and $\lambda = 1$. The solid line shows that transparency is beneficial when complementarities are weak. But transparency is welfare detrimental when complementarities are strong (dashed and dotted lines) because it deteriorates the accuracy of central bank's information and enhances the destabilizing effect of transparency.

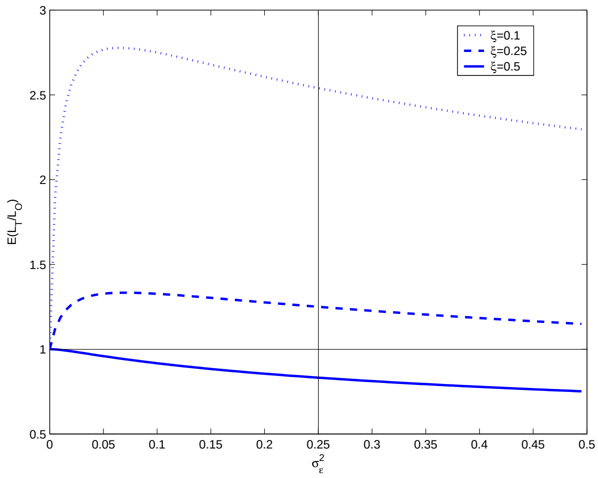

Figure 2.8: Unconditional expected loss under transparency *vs.* under opacity

2.4.8 Optimal degree of transparency

Endogeneous information This section derives the optimal degree of transparency. The first panel of figure 2.9 represents the unconditional expected loss (2.16) as a function of the degree of transparency for three values of strategic complementarities. The parameter values are $\sigma_\eta^2 = \sigma_\varepsilon^2 = 0.25$ and $\lambda = 1$.

The expected loss is minimal at some intermediate level of transparency, the optimal degree of transparency. Under full opacity, the loss is given by $\sigma_\varepsilon^2 = 0.25$ whatever the degree of strategic complementarities. When complementarities are strong (dotted and dashed lines), full transparency yields a larger loss than that under full opacity. But increasing transparency from full opacity reduces the expected loss up to the optimal degree of transparency that minimizes the expected loss. When complementarities are weak (solid line), the loss under full transparency is lower than that under full opacity. But even in this case, reducing the degree of transparency yields a superior outcome. Partial transparency is thus also optimal.

Exogeneous *vs.* endogeneous information The second panel of figure 2.9 compares the effect of transparency with exogeneous information (presented in section 2.3) and endogeneous information. Parameter values are $\sigma_\eta^2 = \sigma_\varepsilon^2 = 0.25$ and $\lambda = 1$. Note that under full opacity both mod-

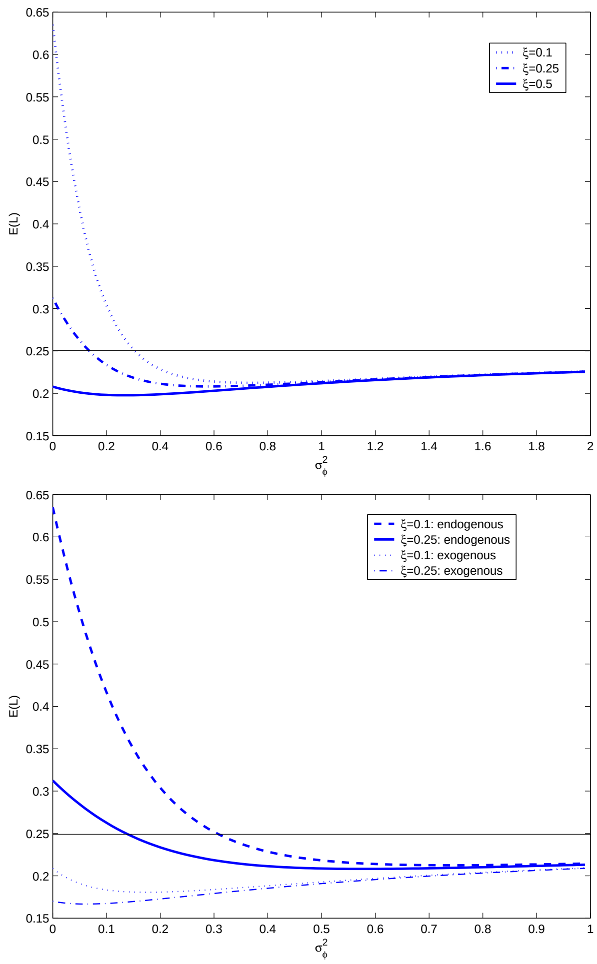

Figure 2.9: Unconditional expected loss

els are strictly identical: as central bank's disclosure does not contain any valuable information, firms set their price according to their private signal exclusively, the price level is a perfect indicator for the demand shock, and central bank's information has a noise with variance σ_η^2. But as the degree of transparency increases, the differential between both models is brought out. The second panel of figure 2.9 points out two features. First, the welfare improving effect of transparency is weaker with endogeneous than exogeneous information. And second, with endogeneous information, the minimal loss is reached at higher level of idiosyncratic noise σ_ϕ^2: the optimal degree of transparency is lower with endogeneous than exogeneous information.

The impact of transparency in the model with exogeneous information is twofold. First, higher transparency has a clear-cut effect on fundamental uncertainty of firms (first-order expectations): it raises the accuracy of firms' information. Second, higher transparency reduces strategic uncertainty of firms (higher-order expectations) and leads to an overreaction to central bank's disclosure. While the effect of transparency on fundamental uncertainty is welfare improving, the effect on strategic uncertainty is detrimental as it may destabilize the economy.

By contrast, the impact of transparency with endogeneous central bank's information is threefold. First, transparency has an ambiguous effect on fundamental uncertainty of firms. While higher transparency increases the accuracy of individual central bank's disclosure as idiosyncratic noise falls, the precision of central bank's information (and thereby that of average disclosure) decreases. This is the detrimental effect of transparency particular to the model with endogeneous information that has been discussed in section 2.4.5. Second, transparency reduces strategic uncertainty of firms as in the model with exogeneous information and involves overreaction to central bank's disclosure. Consequently, the welfare improving effect of transparency is weaker with endogeneous information and the minimal loss is reached at higher σ_ϕ^2: the optimal degree of transparency is lower.

Figure 2.10 compares the optimal degree of transparency with exogeneous (solid line) and endogeneous (dashed line) central bank's information. The optimal degree of transparency with exogeneous information is given by (2.13). As expected, the optimal degree of transparency is always lower in the model with endogeneous information than in that of exogeneous information. This arises because the endogeneity of information gives rise to an additional detrimental effect of transparency, namely the deterioration of the accuracy of central bank's information and disclosure. The parameter values set by default are $\sigma_\eta^2 = 0.25$, $\sigma_\varepsilon^2 = 0.25$, $\xi = 0.25$, and $\lambda = 1$. The first graph illustrates the impact of σ_η^2, the variance of the error term of central bank's observation, on the optimal degree of transparency. As it rises, the optimal degree of transparency decreases because the precision of the disclosure falls and this increases the potential distortion.

The second graph shows the impact of σ_ε^2, the variance of the error term of private signals. With exogeneous information, an increase in σ_ε^2 leads to a higher optimal degree of transparency because the coordination potential of private signals decreases. The degree of transparency has no impact on

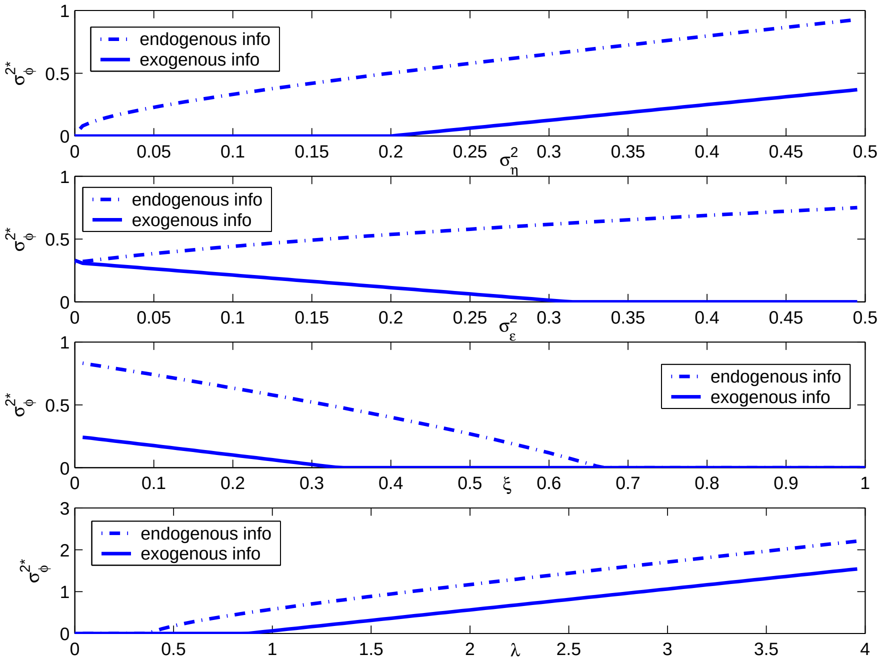

Figure 2.10: Optimal degree of transparency with exogeneous and endogeneous information

the relative precision of the disclosure ($\sigma_\varepsilon^2/\sigma_\eta^2$). The level of coordination among firms falls as private signals are more dispersed. More transparency and thereby a higher degree of common knowledge of the disclosure partially compensates the lack of coordination. By contrast, with endogeneous information, the degree of transparency affects the relative precision of the disclosure $\sigma_\varepsilon^2/((1-\gamma_2)^{-2}\sigma_\eta^2)$: a lower degree of transparency increases the relative precision of the average disclosure since γ_2 falls with opacity. Optimal transparency is driven by two opposite effects. First, an increase in σ_ε^2 leads to a much smaller increase in the relative precision of the disclosure because γ_2 rises as the precision of private information falls. This means that the precision of central bank's information falls when firms' private information becomes less accurate. This effect calls for a lower level of transparency in order to confine the deterioration of central bank's average disclosure. Second, as with exogeneous information, less accurate private information reduces the coordination success of firms what favours more transparency on central bank's disclosure. It turns out that the loss due to the deterioration of disclosure accuracy dominates the loss due to the lack of coordination. Consequently, the optimal degree of transparency declines as the precision of private information shrinks.

The third graph shows the impact of the degree of strategic complementarities $1 - \xi$ on the optimal degree of transparency. An increase in complementarities reduces the optimal degree of transparency in both models. As the coordination motive strengthens, the distorting effect of the noisy disclosure becomes more relevant and the optimal degree of transparency falls.

And finally, the fourth graph illustrates the impact of λ, the weight assigned to output gap deviation. When the weight assigned to price dispersion falls, the distorting effect of the disclosure is more costly and the optimal degree of transparency becomes lower.

2.5 Microfounded welfare function

This section examines the welfare effect of transparency when the weight assigned to output gap deviation λ is consistent with other parameters of the model ($\lambda = \frac{\xi}{\theta}$).[7] As discussed in section 2.2.2, the microfounded welfare is given by

$$L = \int_i (p_i - p)^2 di + \frac{\xi}{\theta}(g - p)^2, \tag{2.17}$$

where $0 < \xi < 1$ and $\theta > 1$. The relative weight assigned to coordination is high since price dispersion reduces utility of households. This increases the welfare improving effect of central bank's disclosure because it helps coordinating firms' price decisions. The potential destabilizing effect of transparency is disregarded in a large extent. We may therefore expect that the optimal degree of transparency is higher than when coordination and stabilization are equally weighted as in M-S ($\lambda = 1$). One may however question whether this microfounded analysis fits the benefits of coordination and costs of destabilization that occur in reality.

We first show that considering the microfounded welfare renders full transparency always optimal under exogeneous information since coordination is given a larger weight at the social level. Second, we turn to endogeneous information. Even if the optimal degree of transparency under

[7]See Adam (2006) for complete derivation.

endogeneity is systematically lower than under exogeneous information, coordination is socially so valuable in (2.17) that full transparency turns to be the best disclosure strategy as well.

2.5.1 Exogeneous information

This section briefly discusses the optimal disclosure strategy of the central bank when its information is exogeneous. We rewrite the optimal disclosure strategy derived in section 2.3 and substitute the unrestricted weight λ with its microfounded value.

When we confine the disclosure strategy to either full transparency or full opacity, the optimality condition (2.11) becomes

$$\mathbb{E}(L_T) < \mathbb{E}(L_O) \qquad \Leftrightarrow \qquad 0 > \frac{\xi}{\theta} - 2\xi < \frac{\sigma_\varepsilon^2}{\sigma_\eta^2}.$$

Since the condition is always satisfied, we conclude that disclosing information is always optimal. This result coincides with that of Hellwig (2005).

Allowing transparency to be intermediate, we rewrite condition (2.13) as

$$\sigma_\phi^{2*} = \max[0, \underbrace{(2\frac{\xi}{\theta} - 3\xi)\sigma_\eta^2 - \sigma_\varepsilon^2}_{<0}] = 0.$$

Again, the new optimal degree of transparency implies that full transparency is always optimal.

2.5.2 Endogeneous information

Figure 2.11 computes the unconditional expected loss with the following parameter values: $\sigma_\eta^2 = \sigma_\varepsilon^2 = 0.25$ and $\theta = 1.2$ for three values of strategic complementarities. Reducing the degree of transparency never increases the unconditional expected welfare. This arises because the microfounded welfare function assigns an extremely large weight to coordination and neglects stabilization. The consideration of endogeneous central bank's information does not change the conclusion of Hellwig (2005).

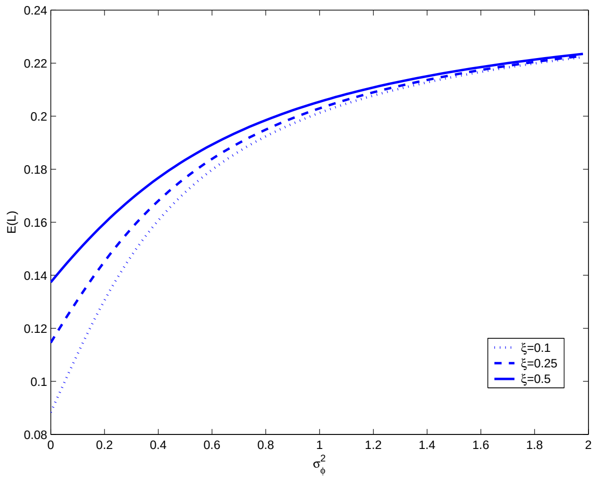

Figure 2.11: Unconditional expected loss with endogeneous information and microfounded welfare function

2.6 Conclusion

This chapter has developed a model with endogeneous central bank's information that gives rise to a trade-off between shaping and learning from market expectations. As transparency increases the effectiveness of central bank's disclosure on firms' behaviour, it reduces the accuracy of prices as an indicator for the underlying shocks and at the same time the accuracy of central bank's information. Considering endogeneous central bank's information enables us to address some new issues with respect to the welfare effect of central bank's transparency.

Morris and Shin (2002) underline the potential detrimental effect of transparency when higher-order expectations are given a large weight because of a coordination motive. As transparency reduces *strategic* uncertainty, it exacerbates the overreaction to central bank's disclosure. Our model with endogeneous information captures an additional – but somehow intertwined – detrimental effect of transparency: the deterioration of central bank's information and disclosure. Transparency generates overreaction to noisy information and deteriorates thereby the accuracy of central bank's disclosure to which private agents overreact. This increases *fundamental* uncertainty of firms.

While the overreaction in M-S occurs because higher-order expectations overweight public information, the deterioration of accuracy affects both first and higher-order expectations as it enhances fundamental uncertainty of firms about shocks. For instance, we show an ambiguous effect of the degree of transparency on the precision of firms' information. Surprisingly, raising a low idiosyncratic noise increases the precision of central bank's disclosure because it strongly improves central bank's information.

Since both overreaction and deterioration effects of transparency combine, accounting for the endogeneity of central bank's information calls for a lower optimal degree of transparency than in the case where the accuracy of central bank's information is exogeneous. However, the welfare effect of transparency strongly depends on how valuable coordination is to society.

2.A Appendix I: Linear pricing rule for exogeneous information

This appendix solves the rational expectations equilibrium for the pricing rule of firms given by equation (2.3).

We first postulate that the optimal price of firm i is a linear combination of its two signals

$$p_i = \gamma_1 g_i + \gamma_2 D_i. \tag{2.18}$$

The optimal weights γ_1 and γ_2 depend on firms' expectations about the pricing behaviour of other firms. The conditional estimate of the average price is therefore given by

$$E_i(p) = \gamma_1 E_i(g) + \gamma_2 E_i(D). \tag{2.19}$$

Plugging $E_i(p)$ in the pricing rule (2.3) and replacing the expectations of firm i about g and D yields

$$\begin{aligned} p_i &= (1-\xi)[\gamma_1 E_i(g) + \gamma_2 E_i(D)] + \xi E_i(g) \\ &= (1-\xi)[\gamma_1(\Omega_{11} g_i + \Omega_{12} D_i) + \gamma_2(\Omega_{21} g_i + \Omega_{22} D_i)] + \xi(\Omega_{11} g_i + \Omega_{12} D_i). \end{aligned}$$

Rearranging gives

$$\begin{aligned} p_i &= g_i[(1-\xi)(\Omega_{11}\gamma_1 + \Omega_{21}\gamma_2) + \xi\Omega_{11}] \\ &\quad + D_i[(1-\xi)(\Omega_{12}\gamma_1 + \Omega_{22}\gamma_2) + \xi\Omega_{12}]. \end{aligned}$$

Identifying the coefficients, we get

$$\begin{aligned} \gamma_1 &= \frac{(1-\xi)\Omega_{21}\gamma_2 + \xi\Omega_{11}}{1-(1-\xi)\Omega_{11}} \\ \gamma_2 &= \frac{(1-\xi)\Omega_{12}\gamma_1 + \xi\Omega_{12}}{1-(1-\xi)\Omega_{22})}. \end{aligned}$$

And solving this system of equations yields

$$\gamma_1 = \frac{\xi\Omega_{11} + (1-\xi)\Omega_{21}}{1-(1-\xi)(\Omega_{11}-\Omega_{21})} = \frac{\xi\sigma_\eta^2 + \sigma_\phi^2}{\sigma_\varepsilon^2 + \xi\sigma_\eta^2 + \sigma_\phi^2}$$

$$\gamma_2 \quad = \quad \frac{\xi\Omega_{12} + (1-\xi)\Omega_{12}\Omega_{21}}{\xi - (1-\xi)[\xi\Omega_{11} - (1+\xi)\Omega_{21} - (1-\xi)(\Omega_{21} - \Omega_{11})\Omega_{11}]} = \frac{\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + \xi\sigma_\eta^2 + \sigma_\phi^2}.$$

This solution is equivalent to equations (2.9) in the text.

2.B Appendix II: Limited publicity *versus* limited transparency

As Morris and Shin (2002) show, firms overreact to the public signal because it is common knowledge among them. Consequently, limiting the degree of common knowledge reduces the overreaction and may improve welfare. Which disclosure strategies can reduce the degree of common knowledge? This appendix compares two strategies and shows that they are strictly equivalent for a large class of coordination games.

First, the central bank can reduce the *degree of transparency* by disclosing its information with idiosyncratic noise to each firm. This strategy has been proposed by Heinemann and Illing (2002) and is discussed in section 2.3. The disclosure received by firm i is given by

$$I_i = I + \phi_i = g + \eta + \phi_i \qquad \text{with } \phi_i \sim N(0, \sigma_\phi^2).$$

Each firm receives the central bank's disclosure in private. This disclosure strategy captures the so-called mystique of central banks' speech, *i.e.* the ambiguity surrounding the interpretation of central banks' message. Indeed, central banks are known for speaking with some ambiguity that gives rise to fundamental and strategic uncertainty about the interpretation of their speeches.

Second, the central bank can reduce the *degree of publicity* by disclosing its information with perfect precision but not to all agents. This strategy has been proposed by Cornand and Heinemann (2004). In this set-up, a fraction S of agents receives the semi-public signal $D = g+\eta$ in addition to its private signal $g_i = g + \varepsilon_i$ while the other fraction $1 - S$ only gets its private signal.

Information structure

We allow now the central bank to dispose of both disclosure strategies simultaneously. So, we have

- a fraction S of firms who gets a private signal and a central bank's disclosure
  - $g_i = g + \varepsilon_i$ with $\varepsilon_i \sim N(0, \sigma_\varepsilon^2)$
  - $D_i = g + \eta + \phi_i$ with $\eta \sim N(0, \sigma_\eta^2)$ and $\phi_i \sim N(0, \sigma_\phi^2)$.

  σ_ϕ^2 captures the degree of transparency of the central bank's disclosure and drives the degree of common knowledge among the fraction S of firms that gets the disclosure.

- a fraction $1 - S$ of firms who only get a private signal
  - $g_i = g + \varepsilon_i$.

Equilibrium action

The average equilibrium action of the fraction $1 - S$ receiving only a private signal is given by

$$p_{1-S} = g$$

since private signals g_i are centred on the true value g.

The average equilibrium action of the fraction S receiving both a private signal and a central bank's disclosure is given by

$$\begin{aligned} p_S &= \gamma_1 g + \gamma_2 D \\ &= \frac{(1-(1-\xi)S)\sigma_\eta^2 + \sigma_\phi^2}{\sigma_\varepsilon^2 + (1-(1-\xi)S)\sigma_\eta^2 + \sigma_\phi^2} g + \frac{\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + (1-(1-\xi)S)\sigma_\eta^2 + \sigma_\phi^2} D. \end{aligned}$$

The overall average equilibrium action (over both fractions of firms with and without central bank's disclosure) can be written as

$$\begin{aligned} p &= \Gamma_1 g + \Gamma_2 D \\ &= S \cdot p_S + (1-S) \cdot p_{1-S} \end{aligned}$$

$$
\begin{aligned}
&= S(\gamma_1 g + \gamma_2 D) + (1-S)g \\
&= (S\gamma_1 + 1 - S)g + S\gamma_2 D \\
&= \frac{(1-S)\sigma_\varepsilon^2 + (1-(1-\xi)S)\sigma_\eta^2 + \sigma_\phi^2}{\sigma_\varepsilon^2 + (1-(1-\xi)S)\sigma_\eta^2 + \sigma_\phi^2} g + \frac{S\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + (1-(1-\xi)S)\sigma_\eta^2 + \sigma_\phi^2} D.
\end{aligned}
$$

Welfare

We consider the general form of social loss

$$
L = \int_i (p_i - p)^2 di + \lambda (g-p)^2, \tag{2.20}
$$

where λ describes the extent to which coordination is socially valuable. Using equilibrium actions of our set-up, we express the unconditional expected loss as

$$
\begin{aligned}
\mathbb{E}(L) &= \mathbb{E}\Big[S\int_S (\gamma_1 g_i + \gamma_2 D_i - \Gamma_1 g - \Gamma_2 D)^2 di + (1-S)\int_{(1-S)} (g_i - \Gamma_1 g - \Gamma_2 D)^2 di \\
&\quad + \lambda(g - \Gamma_1 g - \Gamma_2 D)^2\Big] \\
&= S[\gamma_1^2\sigma_\varepsilon^2 + (1-S)^2\gamma_2^2\sigma_\eta^2 + \gamma_2^2\sigma_\phi^2] + (1-S)[\sigma_\varepsilon^2 + \Gamma_2\sigma_\eta^2] + \lambda\Gamma_2^2\sigma_\eta^2 \\
&= S[\gamma_1^2\sigma_\varepsilon^2 + (1-S+\lambda S)\gamma_2^2\sigma_\eta^2 + \gamma_2^2\sigma_\phi^2] + (1-S)\sigma_\varepsilon^2.
\end{aligned} \tag{2.21}
$$

As discussed in section 2.3.3, the welfare in M-S given by $-\int_i (p_i - g)^2 di$ is a particular case of (2.20) where $\lambda = 1$. The corresponding unconditional expected loss with full publicity (*i.e.* $S = 1$) and full transparency (*i.e.* $\sigma_\phi^2 = 0$) is

$$
\begin{aligned}
\mathbb{E}(L_{MS}) &= \gamma_1^2\sigma_\varepsilon^2 + \gamma_2^2\sigma_\eta^2 \\
&= \frac{\sigma_\varepsilon^2\sigma_\eta^2(\sigma_\varepsilon^2 + \xi^2\sigma_\eta^2)}{(\sigma_\varepsilon^2 + \xi\sigma_\eta^2)^2}.
\end{aligned}
$$

Optimal transparency

Transparency *versus* opacity

We address the question whether full transparency ($\sigma_\phi^2 = 0$) is superior to full opacity ($\sigma_\phi^2 \to \infty$) in terms of welfare (2.21). It is straightforward to show that transparency is superior to opacity if

$$\frac{S^2\lambda - 2 + 3S - S^2 - 2S\xi}{2 - S} < \frac{\sigma_\varepsilon^2}{\sigma_\eta^2}. \quad (2.22)$$

In the particular case where the degree of publicity is maximal (S=1), we get condition (2.11) in the text.

Optimal degree of transparency

General case We derive the optimal degree of transparency σ_ϕ^{2*}. The degree of publicity S is considered as given. The first derivative of the unconditional expected loss (2.21) with respect to σ_ϕ^2 is

$$\begin{aligned} \frac{\partial \mathbb{E}(L)}{\partial \sigma_\phi^2} &= \frac{(\sigma_\varepsilon^2 + (1 - S - 2\lambda S + 3\xi S)\sigma_\eta^2 + \sigma_\phi^2)S\sigma_\varepsilon^4}{(\sigma_\varepsilon^2 + (1 - S(1-\xi)\sigma_\eta^2 + \sigma_\phi^2)^3} \\ &= 0 \qquad \Leftrightarrow \qquad \sigma_\phi^2 = (S - 1 + 2S\lambda - 3S\xi)\sigma_\eta^2 - \sigma_\varepsilon^2. \quad (2.23) \end{aligned}$$

We ensure that extrema yield minimum losses. The second derivative of the expected loss with respect to σ_ϕ^2 leads to

$$\begin{aligned} \frac{\partial^2 \mathbb{E}(L)}{\partial (\sigma_\phi^2)^2} &= \frac{-2S\sigma_\varepsilon^4(\sigma_\varepsilon^2 + (1 - S - 3S\lambda + 4S\xi)\sigma_\eta^2 + \sigma_\phi^2)}{(\sigma_\varepsilon^2 + (1 - (1-\xi)S\sigma_\eta^2 + \sigma_\phi^2)^4} \\ &> 0 \qquad \Leftrightarrow \qquad \sigma_\phi^2 < (S - 1 + 3S\lambda - 4S\xi)\sigma_\eta^2 - \sigma_\varepsilon^2. \quad (2.24) \end{aligned}$$

To show that reducing the degree of transparency according to (2.23) always leads to a minimum expected loss, we plug (2.23) into (2.24). The second derivative of the expected loss is then positive only if $\xi < \lambda$, which turns to be a necessary condition for the optimal variance σ_ϕ^2 of (2.23) to be positive (the expression $(S - 1 + 2S\lambda - 3S\xi)$ is larger than zero only if $\xi < \lambda$). This means that when (2.23) calls for increasing σ_ϕ^2 (*i.e.* reducing transparency), the resulting expected loss is a minimum.

One can show that when the right hand side (RHS) of (2.23) is negative, condition (2.22) is always satisfied. So, full transparency is always superior to opacity when the (RHS) of equation (2.23) is negative.

For the sake of generality, the optimal degree of transparency is given by

$$\sigma_\phi^{2*} = \max[0, (S - 1 + 2S\lambda - 3S\xi)\sigma_\eta^2 - \sigma_\varepsilon^2]. \quad (2.25)$$

Reducing the degree of transparency is optimal improving when the precision of central bank's information $1/\sigma_\eta^2$ is low, when the weight λ assigned to economic stabilization is large, when complementarities are strong (ξ small), and when the degree of publicity is large.

$$\sigma_\phi^{2*} > 0 \Leftrightarrow S(1 + 2\lambda - 3\xi) > \frac{\sigma_\varepsilon^2 + \sigma_\eta^2}{\sigma_\eta^2}.$$

Full publicity For the particular case of full publicity (*i.e.* $S = 1$) discussed in section 2.3 we have:

$$\frac{\partial \mathbb{E}(L)}{\partial \sigma_\phi^2} = 0 \quad \Leftrightarrow \quad \sigma_\phi^2 = (2\lambda - 3\xi)\sigma_\eta^2 - \sigma_\varepsilon^2 \tag{2.26}$$

$$\frac{\partial^2 \mathbb{E}(L)}{\partial (\sigma_\phi^2)^2} > 0 \quad \Leftrightarrow \quad \sigma_\phi^2 < (3\lambda - 4\xi)\sigma_\eta^2 - \sigma_\varepsilon^2 \tag{2.27}$$

To show that reducing the degree of transparency according to (2.26) always leads to a minimum expected loss, we plug (2.26) into (2.27). The second derivative of the expected loss is then positive only if $\xi < \lambda$, which turns to be a necessary condition for the optimal variance σ_ϕ^2 of (2.26) to be positive (the expression $(2\lambda - 3\xi)$ is larger than zero only if $\xi < \lambda$). This means that when (2.26) calls for increasing σ_ϕ^2 (*i.e.* reducing transparency), the resulting expected loss is a minimum.

We now check whether transparency is superior to opacity when the RHS of equation (2.26) is negative. We distinguish two cases. First, when $\xi < \lambda$, the condition $(2\lambda - 3\xi) < \frac{\sigma_\varepsilon^2}{\sigma_\eta^2}$ (for negative RHS of (2.26)) implies $(\lambda - 2\xi) < \frac{\sigma_\varepsilon^2}{\sigma_\eta^2}$, which calls for full transparency according to (2.11). Second, when $\xi > \lambda$, condition (2.11) is always satisfied and full transparency optimal. As a result, full transparency is always superior to opacity when the RHS of equation (2.26) is negative.

The optimal degree of transparency is given by

$$\sigma_\phi^{2*} = \max[0, (2\lambda - 3\xi)\sigma_\eta^2 - \sigma_\varepsilon^2]. \tag{2.28}$$

This is equation (2.13) in the text.

Optimal publicity

Full *versus* zero publicity

Again, we address the question whether full publicity ($S = 1$) is superior to zero publicity ($S = 0$). One can show that full publicity is superior to zero publicity in terms of welfare (2.21) if

$$(\lambda - 2\xi) < \frac{\sigma_\varepsilon^2 + \sigma_\phi^2}{\sigma_\eta^2}. \tag{2.29}$$

In the particular case where the central bank's disclosure is fully transparent ($\sigma_\phi^2 = 0$), the condition for full publicity is identical to the condition for full transparency (under full publicity) (2.11) in the text. In other words, the condition for full publicity under full transparency is identical to the condition for full transparency under full publicity.

Optimal degree of publicity

General case We derive the optimal degree of publicity S^*. The central bank seeks to determine the optimal degree of publicity for a given degree of transparency σ_ϕ^2. The first and second derivatives of the unconditional expected loss (2.21) are given by

$$\frac{\partial \mathbb{E}(L)}{\partial S} = 0 \qquad \Leftrightarrow \qquad S = \frac{\sigma_\varepsilon^2 + \sigma_\eta^2 + \sigma_\phi^2}{(1 + 2\lambda - 3\xi)\sigma_\eta^2} \tag{2.30}$$

$$\frac{\partial^2 \mathbb{E}(L)}{\partial S^2} > 0 \qquad \Leftrightarrow \qquad (\lambda - 1 + S + 2S\lambda - 2(2+\lambda)S\xi + 3S\xi^2)\sigma_\eta^2 + (\lambda - 1)(\sigma_\varepsilon^2 + \sigma_\phi^2) > 0. \tag{2.31}$$

Substituting (2.30) into (2.31), we see that the extrema yield a minimum expected loss if and only if $\lambda > \xi$. This is however a necessary condition for the RHS of (2.30) to be positive.

For the case where the RHS of (2.30) is negative, we see that $(1 + 2\lambda - 3\xi) < 0$ implies $(\lambda - 2\xi) < 0$, which calls for zero publicity according to (2.29). For the case where the RHS of (2.30) is greater than 1, we rewrite it as $(2\lambda - 3\xi) < \frac{\sigma_\varepsilon^2 + \sigma_\phi^2}{\sigma_\eta^2}$ and see that it implies the condition for full publicity (2.29) when $\lambda > \xi$, which turns to be a necessary condition for the RHS of (2.30) to be greater than 1 (or even positive).

For the sake of generality, the optimal degree of publicity is given by

$$S^* = \min[1, \max(0, \frac{\sigma_\varepsilon^2 + \sigma_\eta^2 + \sigma_\phi^2}{(1+2\lambda-3\xi)\sigma_\eta^2})]. \tag{2.32}$$

Reducing the degree of publicity is optimal when the precision of central bank's information $1/\sigma_\eta^2$ is low, when the weight assigned to stabilization λ is large, when complementarities are strong (ξ small), and when the degree of transparency is large (σ_ϕ^2 small).

$$S^* < 1 \Leftrightarrow 2\lambda - 3\xi > \frac{\sigma_\varepsilon^2 + \sigma_\phi^2}{\sigma_\eta^2}.$$

Full transparency When the central bank's disclosure is common knowledge among receivers ($\sigma_\phi^2 = 0$), the condition for limiting publicity becomes

$$S^* < 1 \Leftrightarrow 2\lambda - 3\xi > \frac{\sigma_\varepsilon^2}{\sigma_\eta^2}. \tag{2.33}$$

Note that the RHS of (2.30) is negative when

$$S^* < 0 \Leftrightarrow 1 + 2\lambda - 3\xi < 0,$$

what must be foreclosed because it has no economic sense. Since Cornand and Heinemann (2004) consider the case where $\lambda = 1$ (as in M-S), the RHS of (2.30) is never negative in their analysis.

Welfare under optimal degree of publicity *vs.* transparency

We analyze the welfare (2.21) when the central bank implements the optimal degree of transparency (2.25) or the optimal degree of publicity (2.32).

It turns out that the loss under both disclosure strategies is strictly identical and is given by

$$\mathbb{E}(L^*) = \sigma_\varepsilon^2 + \frac{\sigma_\varepsilon^4}{4\sigma_\eta^2(\xi - \lambda)}.$$

Publicity-transparency equivalence

Since implementing a limited degree of publicity or a limited degree of transparency yields the same welfare, the central bank can indifferently implement one of both disclosure strategies to reduce the degree of common knowledge about its disclosure. The relation between the degree of publicity S and the degree of transparency σ_ϕ^2 is

$$\sigma_\phi^2 = \frac{1-S}{S}(\sigma_\varepsilon^2 + \sigma_\eta^2) \qquad \text{or} \qquad S = \frac{\sigma_\varepsilon^2 + \sigma_\eta^2}{\sigma_\varepsilon^2 + \sigma_\eta^2 + \sigma_\phi^2}.$$

Interestingly, while the weight λ assigned to economic stabilization in the welfare drives the optimal degree of publicity or transparency (optimal publicity or transparency are low when coordination is given a small weight at the social level), it does not challenge the publicity-transparency equivalence result.

Chapter 3

Central Bank's Action and Communication

3.1 Introduction

The conduct of monetary policy has been characterized by an important switch from secrecy to transparency over the last decades. Central banks talk much more openly about their policy decisions today than they used to do in the last decades. While central bankers thought they could better achieve their target by acting in secret and taking the markets by surprise, it seems that transparency has nowadays become the new paradigm.

This trend in central banking has given rise to a growing literature about the pros and cons of higher transparency. In particular, the literature has recently raised questions about the value of having central banks provide more and better information to the public. For decisions made under uncertainty, more accurate information usually permits that decisions are better suited to the underlying fundamental. But macroeconomic environments also often entail strategic complementarities in decision making. As Keynes pointed out in his beauty contest example, decision makers face the dilemma of matching some fundamental of the economy and coordinating with the decision of others. While both public information and private information play an equivalent role in guessing the fundamental, public information plays a preponderant role in guessing the decision of others because it is common to all agents and better helps predicting their expectations. So, individual agents assign a higher weight to public information than justified by its informative value since it serves as a focal point. Public information is therefore extremely effective in shaping market outcomes.

In their seminal beauty contest paper, Morris and Shin (2002) (henceforth M-S) highlight that the disclosure of noisy public information may be detrimental to welfare because the overreaction to it may distort the market outcome away from the fundamental. They conclude that, if there is some upper bound in the precision of its information, the central bank may be better off withholding its information. Their argument has received a great deal of attention in central banks[1] and in the financial press[2] because it seems to contradict the general presumption that transparency is beneficial.

Yet, the literature in the vein of M-S analyzes the welfare effect of public information when the only task of the central bank is to communicate with the public, *i.e.* to disclose or withhold its information. Typically it ignores that the primarily task of a central bank is to take action by implementing a monetary instrument. While communication is certainly a key component of monetary policy, the action implemented by a central bank must not be ignored for all that. This chapter argues that information policy must be thought within a framework that also considers the primarily task of the central bank, namely its action. Indeed, information disclosure – if any – rarely occurs alone but usually goes with policy implementation. More importantly, one must be aware that the action implemented by a central bank is chosen according to its perhaps noisy information. When the central bank has a mistaken view about the economic outcome (because of inevitable forecast errors) its stabilization policy may well turn out to be rather distorting. Thus, the question of transparency must account for the fact that the central bank's action suffers from the same distortion as its disclosure. One may thus ask how a central bank should communicate with the public when the monetary instrument it implements is distorted by noisy information. Should the central bank implement its instrument in secret to avoid the private sector's overreaction to its mistaken view? Or should it, on the contrary, bring its viewpoint to light?

This chapter contributes to the ongoing debate about the welfare effect of public information when disclosure goes with action. It especially develops the idea that – as opposed to M-S – transparency reduces the distortion of

[1]See for example Kohn (2005) and Issing (2005).
[2]See The Economist (2004).

monetary policy. We consider a model of monopolistic competition with imperfect common knowledge where firms' prices are strategic complements. The economy is hit by demand shocks and firms set their price according to their own belief about the output gap and their expectations about the belief of others. Our analysis is constructed into two steps.

First, we discuss in section 3.3 the transparency effect in the case where information disclosure is the only purpose of the central bank. Under transparency, the central bank publishes its viewpoint on the state of the economy (while under opacity, it withholds it). Central bank's disclosure reduces the fundamental and strategic uncertainty. This set-up not surprisingly yields the same conclusion as M-S, namely that the central bank should withhold its information whenever it is rather noisy and when the degree of strategic complementarities is high. In this context, we introduce the concept of partial transparency. While M-S consider two extreme kinds of disclosure, transparency and opacity, we argue that some intermediate level of transparency better describes the reality and may be welfare improving. It is not necessarily true that central bank's disclosures are common knowledge among the whole population. Indeed, central banks are known for speaking with mystique. This makes their disclosures equivocal, open to interpretation, and prevents them from becoming common knowledge. Greenspan's testimony to the US Congress in 1987 illustrates the willingness of central bankers to speak in equivocal manners: "*Since I have become a central banker, I have learned to mumble with great incoherence. If I seem unduly clear to you, you must have misunderstood what I said*." More recently (in December 2002), Mike Moskow, the president of the Federal Reserve Bank of Chicago, claimed that "*[the Fed speak] is a language in which it is possible to speak, without ever saying anything*." Imperfect or partial transparency can be well rationalized in this context. Since a central bank's disclosure may be detrimental to welfare when it is common knowledge, introducing some uncertainty about its interpretation reduces its focal role and improves the outcome. This argument is close to that of Cornand and Heinemann (2004) who introduce the notion of partial publicity. They show that disclosing public information to a limited audience reduces the overreaction to it which can be welfare increasing. Depriving some agents of receiving public information prevents it from becoming common knowledge among the whole population. But while under partial publicity the disclosure is common knowledge among the limited audience (only), under partial transparency the disclosure is private to each firm. In this respect, partial transparency is similar to Heinemann and Illing (2002) who argue – within a game of speculative attack – that central banks should provide information to each agent in private with some idiosyncratic noise to avoid common knowledge (and yields equilibrium uniqueness).

Second, section 3.4 presents the case where the central bank tries to stabilize the economy by implementing a monetary instrument. As discussed below, central banks have become much more transparent about their instrument over the last decades. We show that full transparency is then preferable to partial transparency. The intuition behind this finding is as follows. Since the central bank tries to stabilize the economy based on its information, central bank's errors influence the economic outcome even if central bank's information remains unknown to firms. The central bank's mistaken view distorts the economy even under opacity. The disclosure policy of the central bank however influences firms' reaction and the price level because the monetary instrument is part of the output gap, the fundamental firms have to respond to. Under transparency, firms' response accounts for the monetary instrument and this reduces the distorting effect of central bank's action. For instance, if the central bank contracts the economy by mistake, prices better offset the mistaken policy action when firms' reaction to the instrument is maximal, *i.e.* when the instrument is common knowledge among firms. Opacity is however optimal in this setup for a very small and rather unrealistic range of parameter values. But interestingly, we show that the case for opacity shrinks when central bank's information becomes less accurate: while the monetary instrument increasingly distorts the output gap, transparency, by strengthening the response of firms to central bank's action, attenuates the distortion. Transparency is therefore particularly beneficial when the central bank has a very mistaken view of the state of the economy.

Section 3.5 compares the optimal disclosure in our two frameworks and emphasizes the benefit of transparency when the central bank tries to stabilize the economy. As a result, taking the action task of the central bank into consideration strongly contrasts with M-S according to which transparency is welfare detrimental when the central bank's information is poorly accurate. And finally, section 3.6 concludes.

3.2 The economy

The model is derived from an economy with flexible prices, populated by a *continuum* of monopolistic competitive firms and a central bank. The economy is hit by stochastic demand shocks. When the central bank does not implement any action but solely discloses information, the nominal aggregate demand is determined by the demand shock exclusively. By contrast, in the case where the central bank also implements a monetary policy, the nominal aggregate demand is determined by both the demand shock *and* the monetary instrument set by the central bank.

3.2.1 Firms

In a monopolistic competitive economy, the optimal price setting of firm i is

$$p_i = \mathbb{E}_i[p + \xi c], \tag{3.1}$$

where $\mathbb{E}_i$ is the expectation operator of firm i conditional on its information, p is the overall price level, and c is the real output gap. The pricing rule (3.1) says that each firm sets its price according to both its own belief about the real output gap and its belief about the overall price level.[3] The parameter ξ determines the extent to which the optimal price responds to the output gap. Firms strongly respond to the output gap when it has a strong impact on the competitive real wage. This occurs when the household's utility and disutility functions are very concave and convex, respectively, *i.e.* when ξ is large. In this case, the real wage required for additional production is high (since the household derives a low utility from additional consumption while it suffers a high disutility from additional work) and firms strongly adjust their price to the output gap.

Per definition, the nominal aggregate demand y is defined as the sum of the real output gap and the price level: $y = c + p$. So, one can write the

[3] See chapter 1 section 1.A for the derivation of the pricing rule 3.1.

pricing rule as

$$p_i = \mathbb{E}_i[(1-\xi)p + \xi y]. \tag{3.2}$$

The parameter ξ also determines whether prices are strategic complements or substitutes. In the whole thesis, we assume that prices are strategic complements, *i.e.* that $\xi \leq 1$. Small values of ξ stands for high degree of strategic complementarities in the economy.

3.2.2 Welfare

The welfare is decreasing in both the dispersion of prices across firms $\int_i (p_i - p)^2 di$ and the variability of the output gap $c = y - p$. Since there is currently no consensus about how coordination is socially valuable relative to macroeconomic distortion, we define a generic welfare function that accounts for alternative weights assigned to coordination. The social loss is given by

$$L = \int_i (p_i - p)^2 di + \lambda (y - p)^2, \tag{3.3}$$

where λ is the weight assigned to the output gap distortion. As discussed in the previous chapter in section 2.3.3, the welfare function derived in the seminal beauty contest paper by M-S is captured by the loss (3.3) when the weight assigned to coordination is equal to that assigned to output gap distortion, that is to say when $\lambda = 1$. The loss (3.3) can also replicate the microfounded welfare that assigns a much strong weight on coordination at the social level. Adam (2006) shows that the weight assigned to the output gap distortion when the welfare is microfounded amounts to $\lambda = \frac{\xi}{\theta}$, where $\theta > 1$ is the degree of substitutability in the Dixit-Stiglitz aggregator.

3.2.3 The central bank

The current chapter underlines the relevance of two central bank's tasks, namely information disclosure and policy implementation. In section 3.3, the central bank is supposed to influence the economy with the disclosure of its information about demand shocks exclusively. By contrast, section 3.4 additionally accounts for the monetary policy I implemented by the central bank. The monetary instrument is then supposed to partially determined the nominal aggregate demand up to the demand shock g. The nominal aggregate demand y is the sum of the central bank's instrument and of the demand shock g, *i.e.* $y = I + g$.

3.3 Pure information disclosure

This section analyzes the welfare effect of public information when the central bank does not influence the economy except with its information disclosure. The aim of this section is to illustrate the much debated result by M-S where information disclosure is the only task of the central bank. Since the central bank does not implement any action, we set $I = 0$ and rewrite the pricing rule (3.2) as

$$p_i = \mathbb{E}_i[(1-\xi)p + \xi g]. \tag{3.4}$$

One may worry about the fact that the central bank does not offset demand shocks in the present economy and claim that this is not optimal. However, the aim of this chapter is not to address the merits of having a central bank stabilizing the economy but to compare the welfare effect of disclosure in the case where the central bank does not stabilize the economy to the case where it does. So, the present section must be seen as a benchmark case that replicates the results by M-S and allows a better suited comparison.

We describe the information structure in the next section. Then, we discuss the optimal information disclosure first when the central bank chooses between full transparency and opacity (*i.e.* the central bank either perfectly reveals its opinion or totally withholds it), and second when the central bank can choose its optimal degree of transparency (*i.e.* the central bank speaks with some ambiguity).

3.3.1 Information structure

Each firm sets its price according to its information about the demand shock g and the expectations of other firms about it (the so-called higher-order expectations). The demand shock is drawn from a uniform distribution over the real line: $g \in \mathbb{R}$. Each firm receives a private signal about the demand shock. The private signal is centred on the true value of g and has a normally distributed error term:

$$g_i = g + \varepsilon_i \qquad \text{with } \varepsilon_i \sim N(0, \sigma_\varepsilon^2).$$

Firms additionally get a signal disclosed by the central bank. The central bank itself receives a signal on the demand shock that is centred on its true value and has a normally distributed error term:

$$D = g + \eta \qquad \text{with } \eta \sim N(0, \sigma_\eta^2).$$

The central bank provides firms with its assessment of the demand shock. As discussed in the introduction, there are different ways for the central bank to communicate. Indeed, the central bank may be fully transparent by disclosing a public signal D common knowledge among firms. Or the central bank may also be opaque and withhold its information. This is the case where the central bank provides each firm with an individual signal whose idiosyncratic noise is infinite. One can imagine any intermediate situation where the central bank provides firms with more or less equivocal information. For the sake of generality, we write the signal disclosed by the central bank and received by firm i as

$$D_i = g + \eta + \phi_i \qquad \text{with } \phi_i \sim N(0, \sigma_\phi^2).$$

The individual noise ϕ_i captures the degree of transparency of a central bank. Under transparency, every firm gets the same univocal signal (when $\sigma_\phi^2 = 0$), while under opacity, the individual signal got by each firm is so noisy that its interpretation is impossible ($\sigma_\phi^2 \to \infty$).

3.3.2 Equilibrium

The economy described above is similar to that of chapter 2 section 2.3. We refer to this section for the resolution of the equilibrium behaviour of firms and recall the main results for convenience.

The price rule is a linear combination of the demand shock and the central bank's disclosure and is given by

$$\begin{aligned} p &= \gamma_1 g + \gamma_2 D \qquad \text{with} \\ \gamma_1 &= \frac{\xi\sigma_\eta^2 + \sigma_\phi^2}{\sigma_\varepsilon^2 + \xi\sigma_\eta^2 + \sigma_\phi^2} \\ \gamma_2 &= \frac{\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + \xi\sigma_\eta^2 + \sigma_\phi^2}. \end{aligned}$$

The corresponding unconditional expected social loss can be written as

$$\mathbb{E}(L) = \gamma_1^2\sigma_\varepsilon^2 + \gamma_2^2\sigma_\phi^2 + \lambda\gamma_2^2\sigma_\eta^2. \tag{3.5}$$

We present the optimal disclosure strategy in the subsequent sections. Since the optimal disclosure has been derived in the previous chapter, we simply recall the main results.

3.3.3 Transparency *versus* opacity

As discussed in section 2.3.4, transparency is welfare improving when the loss under opacity L_O is larger than the loss under transparency L_T. The welfare analysis of transparency yields the following proposition:

Proposition 1: *When the central bank's unique task is information disclosure, full transparency is preferable to opacity when*

$$\lambda - 2\xi < \frac{\sigma_\varepsilon^2}{\sigma_\eta^2}. \tag{3.6}$$

It turns out that transparency is welfare detrimental whenever public information is too noisy relative to private information (σ_η^2 large), when strategic complementarities are rather strong (ξ small), and when the weight assigned to output gap stabilization (λ) is large.

3.3.4 Optimal degree of transparency

Again, we report the optimal degree of transparency analyzed in section 2.3.5. Deriving the optimal degree of transparency in the framework described above, we get the following proposition:

Proposition 2: *When the central bank's unique task is information disclosure, the optimal degree of transparency is given by*

$$\sigma_\phi^{2*} = \max[0, (2\lambda - 3\xi)\sigma_\eta^2 - \sigma_\varepsilon^2]. \tag{3.7}$$

.

This analysis calls for partial transparency when central bank's information is rather noisy (σ_η^2 large), when the degree of strategic complementarities is high (ξ small), and when the weight assigned to output gap stabilization (λ) is large.

3.4 Action and information disclosure

We now deal with the main aim of this chapter. We analyze the optimal disclosure policy when the central bank's primarily task is to stabilize the economy. The economy is hit by demand shocks g and the central bank tries to offset them by implementing its monetary instrument I. The nominal aggregate demand is composed of the demand shock and the monetary instrument, *i.e.* $y = g + I$. Thus firms set their price according to their first and higher-order expectations about both the demand shock and the monetary instrument. The central bank's action is part of the "fundamental" firms respond to. We rewrite the pricing rule (3.2) for convenience:

$$p_i = \mathbb{E}_i[(1-\xi)p + \xi g + \xi I]. \tag{3.8}$$

We describe the information structure and derive the equilibrium. We discuss then the optimal information disclosure when the central bank chooses between full transparency and opacity, and then whether partial transparency is optimal.

3.4.1 Information structure

Each firm sets its price according to its own belief about both the demand shock g and the central bank's instrument I, and its belief about others' belief about them. Again, the demand shock is drawn form the real line: $g \in \mathbb{R}$. Each firm receives a private signal $g_i = g + \varepsilon_i$ about the demand shock that has the same properties as in the former section.

Based on its own information $D = g + \eta$, the central bank sets its instrument to offset demand shocks: $I = -g - \eta$.

The central bank then provides firms with information about its instrument (or economic assessment). When the central bank is transparent, its instrument is a public signal (common knowledge among firms). Conversely, when it is opaque, firms' observation of the instrument does not contain any valuable information at all. In intermediate situations, the central bank provides firms with more or less ambiguous information about its instrument. For the sake of generality, we write the signal disclosed by the central bank and received by firm i as

$$I_i = I + \phi_i = -g - \eta + \phi_i \qquad \text{with } \phi_i \sim N(0, \sigma_\phi^2).$$

As in the former section, the individual noise ϕ_i captures the degree of transparency of the central bank. Full transparency is reached when $\sigma_\phi^2 = 0$ and full opacity when the central bank withholds information about its instrument ($\sigma_\phi^2 \to \infty$).

3.4.2 Equilibrium

To determine the equilibrium behaviour of firms, we proceed as before. Substituting successively the average price level with higher-order expectations about the demand shock and the monetary instrument into (3.8) yields

$$p_i = \xi \sum_{k=0}^{\infty} (1-\xi)^k \mathbb{E}_i \Big[\bar{\mathbb{E}}^{(k)} (g + I) \Big],$$

and averaging over firms, we get

$$p = \xi \sum_{k=0}^{\infty} (1-\xi)^k \Big[\bar{\mathbb{E}}^{(k+1)} (g + I) \Big]. \tag{3.9}$$

The optimal pricing rule of firm i is a weighted average of its first and higher-order expectations about the demand shock g and the central bank's instrument I conditional on its information. Its first-order expectations yield

$$\begin{aligned}
\mathbb{E}(g|g_i, I_i) &= \frac{\sigma_\eta^2 + \sigma_\phi^2}{\sigma_\varepsilon^2 + \sigma_\eta^2 + \sigma_\phi^2} g_i - \frac{\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + \sigma_\eta^2 + \sigma_\phi^2} I_i = \alpha g_i + (\alpha - 1) I_i \\
E(I|g_i, I_i) &= -\frac{\sigma_\phi^2}{\sigma_\varepsilon^2 + \sigma_\eta^2 + \sigma_\phi^2} g_i + \frac{\sigma_\varepsilon^2 + \sigma_\eta^2}{\sigma_\varepsilon^2 + \sigma_\eta^2 + \sigma_\phi^2} I_i = \beta g_i + (1 + \beta) I_i.
\end{aligned}$$

Plugging this result into (3.9), we have

$$p = \begin{pmatrix} \xi & \xi \end{pmatrix} \sum_{k=0}^{\infty} (1-\xi)^k \begin{pmatrix} \alpha & (\alpha - 1) \\ \beta & (1+\beta) \end{pmatrix}^{k+1} \begin{pmatrix} g \\ I \end{pmatrix}$$

and rewriting in a linear form leads to

$$\begin{aligned}
p &= \gamma_1 g + \gamma_2 I \qquad \text{with} \qquad (3.10) \\
\gamma_1 &= \frac{\xi(\alpha - \beta)}{1 - (1-\xi)(\alpha - \beta)} = \frac{\xi \sigma_\eta^2}{\sigma_\varepsilon^2 + \xi \sigma_\eta^2 + \sigma_\phi^2} = \gamma_2.
\end{aligned}$$

The derivation of this equilibrium pricing rule is given in appendix 3.A. When the central bank stabilizes the economy with its monetary instrument, firms equally weight their private signal g_i and the central bank's disclosure I_i into their pricing decision ($\gamma_1 = \gamma_2$). This arises because firms respond to the nominal aggregate demand that is composed of both the demand shock and the monetary instrument.

Since the central bank tries to stabilize the economy, it is common knowledge among firms (even under opacity) that the nominal aggregate demand expected by the central bank is equal to zero. In the particular case where the central bank has perfect information about demand shocks ($\sigma_\eta^2 = 0$), the monetary instrument perfectly offsets demand shocks and firms set their price equal to zero. For the more realistic case where central bank's information is noisy, the demand shock is less likely to be precisely offset by the central bank and thus the nominal aggregate demand to be zero. Firms then rely more strongly on their private information g_i and disclosure I_i to set their optimal price ($\frac{\partial \gamma_1}{\partial \sigma_\eta^2} > 0$).

When the degree of strategic complementarities increases, firms respond less strongly to their private signal g_i and to the instrument disclosure I_i, and assign a higher weight to the nominal aggregate demand expected by the central bank (that is to say zero) since the latter is common knowledge ($\frac{\partial\gamma_1}{\partial\xi} > 0$).

When private noises increase, fundamental and strategic uncertainty increases as well. Hence, firms less strongly respond to their private signal and disclosure and higher weight the nominal demand of zero expected by the central bank ($\frac{\partial\gamma_1}{\partial\sigma_\varepsilon^2} < 0$ and $\frac{\partial\gamma_1}{\partial\sigma_\phi^2} < 0$).

3.4.3 Welfare

We now turn to the welfare analysis in the current context. First, the equilibrium firms' behaviour (3.10) implies that the price dispersion across firms satisfies

$$\mathbb{E}\Big(\int_i (p_i - p)^2 di\Big) = \mathbb{E}\Big(\int_i (\gamma_1 g_i + \gamma_2 I_i - \gamma_1 g - \gamma_2 I)^2 di\Big) = \gamma_1^2\sigma_\varepsilon^2 + \gamma_2^2\sigma_\phi^2.$$

Second, with the central bank stabilizing the economy, the output gap is

$$\mathbb{E}(c^2) = \mathbb{E}\Big((g + I - p)^2\Big) = \mathbb{E}\Big((g + (-g-\eta) - \gamma_1 g - \gamma_2(-g-\eta))^2\Big) = (\gamma_2 - 1)^2\sigma_\eta^2.$$

So, since $\gamma_1 = \gamma_2$, the unconditional expected loss can be written as

$$\begin{aligned}\mathbb{E}(L) &= \gamma_1^2\sigma_\varepsilon^2 + \gamma_1^2\sigma_\phi^2 + \lambda(\gamma_1 - 1)^2\sigma_\eta^2 \\ &= \frac{\lambda(\sigma_\varepsilon^2 + \sigma_\phi^2) + \xi^2\sigma_\eta^2}{(\sigma_\varepsilon^2 + \xi\sigma_\eta^2 + \sigma_\phi^2)^2}(\sigma_\varepsilon^2 + \sigma_\phi^2)\sigma_\eta^2. \end{aligned} \tag{3.11}$$

3.4.4 Transparency *versus* opacity

Opacity The welfare is now computed when the central bank is opaque and implements its instrument in secret, *i.e.* $\sigma_\phi^2 \to \infty$. Under opacity, firms set their price equal to zero since $\gamma_1 = 0$ and $\gamma_2 = 0$. In so far as firms know that the central bank stabilizes the economy but have no information about the instrument, their private information g_i does not help them guessing the nominal aggregate demand. Their best nominal aggregate demand estimation is therefore zero and the resulting unconditional expected loss is

$$\mathbb{E}(L_O) = \lambda\sigma_\eta^2.$$

Transparency When the central bank is transparent, its monetary instrument is common knowledge: $\sigma_\phi^2 = 0$. Under transparency, the pricing rule of firms becomes

$$p_i = \frac{\xi\sigma_\eta^2}{\sigma_\varepsilon^2 + \xi\sigma_\eta^2} g_i + \frac{\xi\sigma_\eta^2}{\sigma_\varepsilon^2 + \xi\sigma_\eta^2} I_i,$$

and the resulting unconditional expected loss yields

$$\mathbb{E}(L_T) = \Big(\frac{\xi\sigma_\eta^2}{\sigma_\varepsilon^2 + \xi\sigma_\eta^2}\Big)^2 \sigma_\varepsilon^2 + \lambda\Big(\frac{\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + \xi\sigma_\eta^2}\Big)^2 \sigma_\eta^2.$$

Transparency is welfare improving when the loss under opacity L_O is larger than the loss under transparency L_T. Comparing both expected losses, we get the following proposition.

Proposition 3: *When the central bank tries to offset demand shocks with its monetary instrument, full transparency is preferable to opacity when*

$$\lambda > \frac{\xi\sigma_\varepsilon^2}{2\sigma_\varepsilon^2 + \xi\sigma_\eta^2}. \tag{3.12}$$

Whether transparency is beneficial depends on the value of four parameters, the relevance of output gap stabilization at the social level λ, the noise of central bank's information σ_η^2, the noise of firms' private information σ_ε^2, and the degree of strategic complementarities $1 - \xi$. Note first that transparency is particularly welfare improving when the weight assigned to the output gap stabilization λ is large. Transparency increases firms' response to both their private signal and the monetary instrument what reduces the output gap but increases the price dispersion. When the central bank actively shapes the nominal aggregate demand with its monetary instrument and assigns a large weight to output stabilization, transparency reduces the potential detrimental effect of the policy owing firms to account for it in their price setting.

Second, transparency improves welfare when central bank's information is rather noisy (the derivative of the right-hand side (RHS) of inequation (3.12) is negative with respect to central bank's noise σ_η^2). When the monetary instrument implemented by the central bank is very likely not to precisely offset the demand shock, transparency helps reducing the possible distortion generated by the policy.

Third, switching from opacity to transparency increases the price dispersion since prices are all homogeneous under opacity ($\gamma_1 = 0$).[4] The loss linked to the rise in dispersion depends on the precision of firms' private information. High precision of firms' private information reduces the cross section price dispersion. Hence, transparency is welfare improving when firms' private information is rather precise (the derivative of the RHS of inequation (3.12) is positive with respect to firms noise σ_ε^2).

Fourth, transparency is beneficial when strategic complementarities are strong (ξ small) because strong complementarities reduces the weight assigned to private signals and thereby the cross sectional price dispersion (the derivative of the RHS of inequation (3.12) is positive with respect to ξ).

It is worth underlining here that welfare effects of transparency fundamentally depends on whether the central bank tries to offset demand shocks with its monetary instrument or not. As discussed in section 3.3.3, when the central bank does not influence the nominal aggregate demand, transparency is welfare increasing (compared to opacity) when (i) the output gap stabilization is socially not very valuable (λ small), (ii) the central bank's information is quite accurate (σ_η^2 small), (iii) the firms' private information is rather noisy (σ_ε^2 large), and (iv) strategic complementarities are strong (ξ small). The qualitative conditions for transparency in an economy where the central bank does not influence the nominal aggregate demand (section 3.3) are simply the opposite to that in an economy where the central bank partially determines the nominal aggregate demand with its monetary instrument (this section).

3.4.5 Optimal degree of transparency

In this section, we allow the central bank to disclose more or less equivocal information about its instrument and derive the optimal degree of transparency. The recent development of the US Federal Reserve disclosure about

[4]This mechanism is similar to that of Kondor (2004). He shows that when the fundamental is split into two parts (as it is the case in this section) more information increases the disagreement between agents.

its monetary policy provides a good illustration of various degrees of transparency. Before 1994, the Federal Reserve did not publicly announce the federal funds rate it was targeting. The private sector had to observe the market operations implemented by the trading desk of the Fed to guess the policy decisions of the Federal Open Market Committee. This lack of transparency was a source of fundamental uncertainty about the rate targeted by the Fed and of strategic uncertainty about the beliefs of others about this target. Since February 1994, the Fed has been publishing the new target after each meeting of the FOMC. While such a publication reduces uncertainty about the numerical target, uncertainty still remains about how restrictive or expansive the Fed considers its policy decision to be. Hence, from 1998 on, the FOMC has decided to indicate after each meeting its current bias with respect to possible changes in the future policy. And even more recently, the FOMC has made the release of the minutes of its deliberations available to the public.[5] This process clearly increases the degree of common knowledge about the impact of monetary policy on the aggregate nominal demand among firms. While the previous subsection has compared the welfare under both extreme cases of full transparency and opacity, we focus now on intermediate level of transparency and determine the optimal degree of transparency.

To determine the optimal degree of transparency σ_ϕ^{2*}, we set the first derivative of the loss (3.11) with respect to σ_ϕ^2 equal to zero:

$$\begin{aligned}
\frac{\partial \mathbb{E}(L)}{\partial \sigma_\phi^2} &= 2\gamma_1 \frac{\partial \gamma_1}{\partial \sigma_\phi^2}\sigma_\varepsilon^2 + \gamma_1^2 + 2\gamma_1 \frac{\partial \gamma_1}{\partial \sigma_\phi^2}\sigma_\phi^2 - 2\lambda \frac{\partial \gamma_1}{\partial \sigma_\phi^2}\sigma_\eta^2 + 2\lambda\gamma_1 \frac{\partial \gamma_1}{\partial \sigma_\phi^2}\sigma_\eta^2 \\
&= \frac{[(2\lambda - \xi)\sigma_\varepsilon^2 + \xi^2\sigma_\eta^2 + (2\lambda - \xi)\sigma_\phi^2]\xi\sigma_\eta^4}{(\sigma_\varepsilon^2 + \xi\sigma_\eta^2 + \sigma_\phi^2)^3} \\
&= 0 \qquad \Leftrightarrow \qquad \sigma_\phi^2 = \frac{\xi^2}{\xi - 2\lambda}\sigma_\eta^2 - \sigma_\varepsilon^2. \qquad (3.13)
\end{aligned}$$

To ensure that extrema lead to minimum expected losses, the second derivative of the loss with respect to σ_ϕ^2 yields

$$\begin{aligned}
\frac{\partial^2 \mathbb{E}(L)}{\partial (\sigma_\phi^2)^2} &= \frac{2[(\xi - 2\lambda)\sigma_\varepsilon^2 + \xi(\lambda - 2\xi)\sigma_\eta^2 + (\xi - 2\lambda)\sigma_\phi^2]\xi\sigma_\eta^4}{(\sigma_\varepsilon^2 + \xi\sigma_\eta^2 + \sigma_\phi^2)^4} \\
&> 0 \qquad \Leftrightarrow \qquad (\xi - 2\lambda)\sigma_\phi^2 > (2\lambda - \xi)\sigma_\varepsilon^2 + \xi(2\xi - \lambda)\sigma_\eta^2. (3.14)
\end{aligned}$$

[5] See Poole (2005).

We show that limiting the degree of transparency is never optimal. Substituting equation (3.13) into (3.14), we observe that inequation (3.14) is satisfied when $\lambda > \xi$. That is to say that implementing the degree of transparency given by the RHS of (3.13) yields a minimum expected loss only if $\lambda > \xi$. But this condition implies that the RHS of (3.13) is negative what has no economic interpretation since the variance cannot be negative. In other words, the extrema described as in equation (3.13) are maximum expected losses. As a result, the optimal disclosure strategy consists of choosing between full transparency and full opacity according to Proposition 3.

This yields the following proposition:

Proposition 4: *When the central bank tries to offset demand shocks with its monetary instrument, partial transparency is never optimal.*

In sharp contrast to the economy where the central bank does not stabilize the nominal aggregate demand, reducing the degree of transparency does not improve welfare when the central bank actively influences the nominal aggregate demand with its policy. As we bring it up in the next section, the framework where the central bank stabilizes the economy with its instrument calls for full transparency under realistic parameter conditions.

3.5 Discussion

This section compares the optimal information disclosure when the only task of the central bank is to disclose information with the case where it also stabilizes the economy. The optimal disclosure in both situations is a function of the degree of strategic complementarities $1 - \xi$, the weight assigned to output gap variability λ, and the relative precision of firms' private information $\frac{\sigma_\varepsilon^2}{\sigma_\eta^2}$.

Figure 3.1 illustrates the optimal disclosure when firms' private information is as precise as central bank's information, *i.e.* $\frac{\sigma_\varepsilon^2}{\sigma_\eta^2} = 1$. Figure 3.2 considers the more realistic case where firms' private information is less accurate than central bank's information, *i.e.* $\frac{\sigma_\varepsilon^2}{\sigma_\eta^2} = 2$.

The optimal disclosure derived in section 3.3 where the unique central bank's task is to disclose is as follows. The dotted line in both figures is

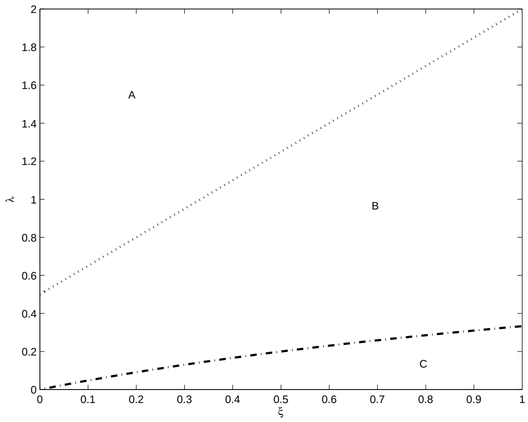

Figure 3.1: Optimal information disclosure with $\frac{\sigma_\varepsilon^2}{\sigma_\eta^2} = 1$

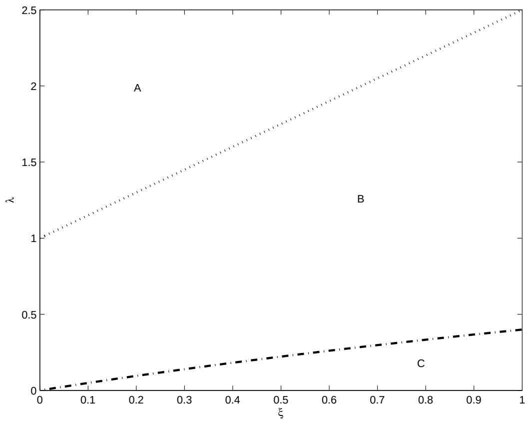

Figure 3.2: Optimal information disclosure with $\frac{\sigma_\varepsilon^2}{\sigma_\eta^2} = 2$

given by $\lambda = (\frac{\sigma_\varepsilon^2}{\sigma_\eta^2} + 3\xi)/2$ (see Proposition 2). As discussed in section 3.3.4, full transparency is optimal when $\lambda < (\frac{\sigma_\varepsilon^2}{\sigma_\eta^2} + 3\xi)/2$ while partial transparency is optimal otherwise. The optimal disclosure is partial transparency for parameter combinations of λ and ξ given by the area called A in both figures. Full transparency is optimal for parameter combinations in areas B and C. Partial transparency is beneficial when the degree of strategic complementarities $1 - \xi$ is high and when firms' private information is relatively accurate. As shown above, opacity is never optimal.[6] This arises because of the coordination motive: public information (or more information) allows private agents to better coordinate. The optimal degree of transparency (3.7)

[6]This finding is consistent with Cornand and Heinemann (2004) who show that partial dissemination of public information is always preferable to withholding public information.

indicates that full opacity is optimal only in the extent that coordination does not matter at all at the social level. Indeed, when the weight assigned to output gap stabilization λ goes to infinity, the variance of idiosyncratic noise σ_ϕ^2 goes to infinity as well (meaning full opacity). Withholding central bank's information is optimal when there is no concern for coordination.

We now turn to the case described in section 3.4 where the central bank stabilizes the economy with its instrument. The dashed line is given by $\lambda = \frac{\xi\sigma_\varepsilon^2}{2\sigma_\varepsilon^2+\xi\sigma_\eta^2}$ (see Proposition 3). As discussed in the previous section, full transparency is optimal for values of λ larger than the dashed line. So, full transparency is optimal for parameter combinations in areas A and B, while opacity is optimal for area C. The framework of section 3.4 that accounts for the stabilization purpose of the central bank makes a case for full transparency in almost all parameter configurations unless price dispersion is assigned a much higher weight than output gap stabilization. There is no price dispersion when the central bank withholds its information since every firm sets a price of zero under opacity ($\gamma_1 = \gamma_2 = 0$). But opacity creates however higher cost in terms of output gap variability.

Yet, the case for opacity is extremely unlikely. For instance, when firms' private information is as accurate as central bank's information and $\xi = 0.25$, opacity would be optimal if the weight assigned to price dispersion would be more than 9 times higher than that assigned to output gap variability (from Proposition 3, we obtain $\lambda < \frac{\xi}{2+\xi} = 0.11$). It is interesting to emphasize that when central bank's information becomes less accurate (the relative precision $\frac{\sigma_\varepsilon^2}{\sigma_\eta^2}$ decreases) transparency becomes beneficial for a larger range of parameter combinations. Since the central bank's instrument is part of the fundamental firms respond to, an increase in central bank's uncertainty makes transparency more beneficial.

Following the discussion of section 2.5 of chapter 2, we briefly discuss the case of microfounded welfare function. As shown by Adam (2006), the microfounded welfare function is given by equation (3.3) with $\lambda = \frac{\xi}{\theta}$ where $\theta > 1$ is the degree of substitutability in the Dixit-Stiglitz aggregator. When the central bank does not stabilize the economy with its instrument, section 2.5.1 shows that full transparency is always optimal for the microfounded welfare function. This has been underlined by Hellwig (2005): when coordination is socially highly valuable transparency is welfare improving since it helps coordinating. The linear function $\lambda = \frac{\xi}{\theta}$ can be represented on figures 3.1 and 3.2 with a slope smaller than one. We clearly see that the $\xi - \lambda$ combinations are in areas B and C: full transparency is always optimal.

By contrast, when the central bank tries to stabilize the nominal aggregate demand with its instrument, the microfounded welfare function can lead to full opacity. As Proposition 3 indicates, opacity is superior to transparency when coordination is socially highly valuable (λ small). For large value of θ, the weight λ becomes arbitrarily small and may call for opacity (area C in figures 3.1 and 3.2).

3.6 Conclusion

Can a central bank speak too much? This question has been the subject of a very controversial literature over the last years. While transparency has been an important point of central banks' agenda, the argument by Morris and Shin (2002) has received a great deal of attention because it seems to contradict the general presumption that transparency is always beneficial. According to their analysis, the disclosure of central bank's noisy information can be welfare detrimental and destabilizing since it serves as a focal point in a context of strategic complementarities. The current chapter contributes to this ongoing debate by highlighting the dual tasks of monetary policy: action and communication. While the literature in the vein of M-S considers the case where the sole task of the central bank is to provide the private sector with information, we also account for the action task of the central bank and draw opposite conclusions: when central bank's information is poorly accurate, transparency reduces the distorting effect of the monetary instrument.

This finding challenges the stabilizing role of public disclosure under imperfect information. Our analysis highlights the beneficial effects of transparency when the stabilization policy of the central bank is implemented on the base of imprecise information. Yet, in monetary policy, decisions under imperfect information are rather the rule than the exception. Indeed, since monetary policy affects the economy with a substantial delay, central banks must act in advance and make their decisions according to their forecasts. The *Inflation Reports* of the Bank of England provide a good example of the information accuracy a central bank bases its decision on. As an inflation targeter, the Bank of England mainly conducts its policy in compliance with its expected inflation and output growth that are published in its *Inflation Report*. The uncertainty surrounding central bank's forecasts is surprisingly high. As pointed out by Morris and Shin (2005) for the August 2005 Report, the "fan chart" for output growth looks rather like a "hammer" than a "fan". Under these circumstances, the instrument set by the central bank may well be proved inadequate for the actual state of the economy.

Our analysis addresses the question of central bank's communication when the conduct of monetary policy suffers from inaccurate information and shows that transparency helps reducing the distortion associated with poorly suited policies. This result supports the recent development in central banking towards more transparency with respect to policy implementations.

3.A Appendix: Linear pricing rule

This appendix solves the rational expectations equilibrium for the pricing rule of firms given by equation (3.8).

We first postulate that the optimal price of firm i is a linear combination of its two signals

$$p_i = \gamma_1 g_i + \gamma_2 I_i. \tag{3.15}$$

The optimal weights γ_1 and γ_2 depend on firms' expectations about the pricing behaviour of other firms. The conditional estimate of the average price is therefore given by

$$\mathbb{E}_i(p) = \gamma_1 \mathbb{E}_i(g) + \gamma_2 \mathbb{E}_i(I). \tag{3.16}$$

Plugging $\mathbb{E}_i(p)$ in the pricing rule (3.8) and replacing the expectations of firm i about g and I yields

$$\begin{aligned} p_i &= (1-\xi)[\gamma_1 \mathbb{E}_i(g) + \gamma_2 \mathbb{E}_i(I)] + \xi \mathbb{E}_i(g) + \xi \mathbb{E}_i(I) \\ &= (1-\xi)[\gamma_1(\alpha g_i + (\alpha - 1) I_i) + \gamma_2(\beta g_i + (1+\beta) I_i)] \\ &\quad + \xi(\alpha g_i + (\alpha - 1) I_i) + \xi(\beta g_i + (1+\beta) I_i). \end{aligned}$$

Rearranging gives

$$\begin{aligned} p_i &= g_i[(1-\xi)(\alpha\gamma_1+\beta\gamma_2)+\xi(\alpha+\beta)] \\ &\quad +I_i[(1-\xi)((\alpha-1)\gamma_1+(1+\beta)\gamma_2)+\xi(\alpha+\beta)]. \end{aligned}$$

Identifying the coefficients, we get

$$\begin{aligned} \gamma_1 &= \frac{(1-\xi)\beta\gamma_2+\xi(\alpha+\beta)}{1-(1-\xi)\alpha} \\ \gamma_2 &= \frac{(1-\xi)(\alpha-1)\gamma_1+\xi(\alpha+\beta)}{1-(1-\xi)(1+\beta)}. \end{aligned}$$

And solving this system of equations yields

$$\begin{aligned} \gamma_1 &= \frac{\xi(\alpha+\beta)}{1-(1-\xi)(\alpha+\beta)} = \frac{\xi\sigma_\eta^2}{\sigma_\varepsilon^2+\xi\sigma_\eta^2+\sigma_\phi^2} \\ \gamma_2 &= \frac{\xi\sigma_\eta^2}{\sigma_\varepsilon^2+\xi\sigma_\eta^2+\sigma_\phi^2}. \end{aligned}$$

This solution is equivalent to equation (3.10) in the text.

Chapter 4

Can Opacity of a Credible Central Bank Explain the Conduct of Monetary Policy in the 70s?[1]

4.1 Introduction

During the 1970s, many countries experienced long lasting average inflation rates that clearly exceeded the rate that seems to be socially desirable. This feature has been usually explained within the framework of Barro and Gordon (1983), which presumes that the central bank desires to push output above its natural level. Indeed, under discretion, the central bank's incentive to boost the output above its potential level gives rise to a persistent inflationary bias that supports the monetary outcome in the 1970s.

Yet, the inflationary bias argument is a matter of controversy. Three strands of criticism have been developed. First, Taylor (1983) and McCallum (1997) question the plausibility of the inflationary bias argument since any rational central bank should recognize that the renouncement to cheat the private sector yields a superior outcome. In its comment to Barro and Gordon (1983), Taylor (p. 125) writes that "*[...] the superiority of the zero inflation policy is obvious [...]. It is therefore difficult to see why the zero inflation policy would not be adopted*" by the central bank. Second, Blinder (1998) (p. 40) points out the particular economic context of the 1970s and argues that "*Barro and Gordon ignored the obvious practical explanations for the observed up-*

[1]This chapter has been developed with the collaboration of Camille Cornand.

surge in inflation – the Vietnam War, the end of the Bretton-Woods system, two OPEC shocks, and so on – and sought instead a theoretical explanation for what they believed to be a systematic inflationary bias in the behaviour of central banks". And third, as the Barro-Gordon literature calls for institutional changes in order to cope with inflation, Friedman and Kuttner (1996) (p. 79) emphasize that "*not only have most countries succeeded in slowing their economy's inflation, in most cases they have done so under monetary policymaking institutions no different than they had before*".

This chapter provides an alternative explanation to the time-inconsistency literature for the high inflation episode of the 1970s that is consistent with the three aforesaid criticisms.[2] We show that central bank's opacity can account for an expansive monetary policy in response to oil shocks, even when the central bank is fully credible. This sharply contrasts with the standard monetary policy literature that calls – according to the *lean against the wind* principle – for taking restrictive action whenever inflation is above target.[3]

We do not claim, however, that the Barro-Gordon model does not capture a real phenomenon in central banking. For instance, we believe that institutional changes in the central bank of New Zealand (adoption of an explicit inflation target and independence from the government) and their impacts on inflation fit the Barro-Gordon argument pretty well. We highlight instead that even a central bank with no inflationary bias and whose preferences are perfectly known to the private sector may find it optimal to accommodate monetary policy in response to cost-push shocks when it is opaque with respect to its monetary instrument. So, our model rather applies to central banks that are traditionally independent, credible and well-established, and rationalizes the high inflation episode of the 1970s in countries like Germany, Switzerland, or the US. In some sense, our model provides an analysis for inflation time-series in some particular countries, while Barro-Gordon explains cross-sectional inflation between some countries.

[2] Orphanides (2002) alternatively argues that policy decisions during the 70s can be reconciled with an optimal approach accounting for the errors in the real time assessments of the natural rate of unemployment by the Fed.

[3] Note that some authors adopt other definitions of the *lean against the wind* principle. For instance, Schwartz (2003) (p. 1025) argues that "*the Fed should 'lean against the wind', by taking restrictive action during periods of economic expansion and expansionary action during periods of economic contraction*". By contrast, Clarida et al. (1999) (p. 1672) say that "*the central bank pursues a 'lean against the wind' policy: Whenever inflation is above target, contract demand below capacity (by raising the interest rate).*"

Our analysis emphasizes the relevance of strategic complementarities in price setting and of information disclosed by the central bank for the effectiveness of monetary policy to stabilize the price level. The effectiveness of monetary policy on the pricing rule of firms is driven by the disclosure of the central bank since it determines the fundamental and strategic uncertainty surrounding its monetary instrument. As cost-push shocks create a trade-off between price and output gap stabilization, the central bank may find it optimal to stabilize rather the output gap than the price level when its policy is relatively ineffective to influence the price level, *i.e.* when the central bank is opaque with respect to its policy.

In an empirical analysis on US data, Romer and Romer (2000) show that the observation of the monetary instrument highly influences the formation of market expectations. Moreover, Demiralp and Jorda (2002) emphasize the relevance of central bank's communication to manipulate market expectations. They show, in particular, that the publication of the instrument rate targeted by the policy board of the Fed since 1994 has increased the effectiveness of monetary policy to shape market expectations (announcement effect).

We propose a monetary policy model under monopolistic competition with imperfect common knowledge on the cost-push shocks affecting the economy where the central bank has no inflationary bias and the private sector perfectly knows its preferences. Both the central bank and firms are uncertain about the true state of the economy and receive private signals on cost-push shocks. Firms also get some signal on the monetary instrument of the central bank according to the degree of transparency of the central bank with respect to its policy. While the central bank's disclosure does not contain any valuable information under opacity, the monetary instrument is common knowledge among firms under transparency.

The mechanism of the model is the following. The information disclosed by the central bank influences the reaction of the price level to monetary policy and thus influences the extent to which the central bank can deal with the trade-off generated by cost-push shocks. Under transparency, as the monetary instrument is common knowledge among firms, the optimal monetary policy always satisfies the *lean against the wind* principle. By contrast, opacity increases fundamental and strategic uncertainty about the central bank's action and thereby reduces the effectiveness of monetary policy on the price level. Under opacity, the central bank's influence on the price level is limited as firms do not observe its instrument. So, contracting the nominal demand is ineffective to reduce the price level and the central bank may find it optimal to reduce the output gap by expanding its instrument.[4] But opacity is not a sufficient condition for the optimal monetary policy to be accommodating. The sign of the policy coefficient depends on the relation between the degree of strategic complementarities, the preference of the central bank for output gap stabilization, and the relative precision of firms' private information.

The three strands of criticism raised against the Barro-Gordon model do not apply to our argument. First, our central bank does not have an incentive to push output above its potential level. Second, our model accounts for the response of monetary policy to cost-push shocks. And third, while no significant institutional changes occurred in the central bank of most OECD countries, the switch from opacity to transparency is an obvious development in the recent conduct of monetary policy that accounts for the decrease in inflation.

Note that most of the literature rationalizes the case for transparency as a mean to reach credibility. For example, King (2001) argues that "*a degree of openness was not only desirable but also necessary for any degree of credibility*" (p. 375). Interestingly, our analysis emphasizes the relevance of transparency even when central banks are credible.

The remaining of the chapter is structured as follows. Section 4.2 outlines a monopolistic competition economy, in which firms' pricing decisions represent strategic complements. Section 4.3 considers a benchmark case under perfect common knowledge that recalls standard findings in monetary policy analysis and gives useful insights for the intuition behind our main result. Section 4.4 examines the case of imperfect common knowledge and shows that the optimal monetary policy under opacity may violate the *lean against the wind* principle. We also show that small changes in the degree of transparency or in preferences may have large effects on the optimal monetary policy. Finally section 4.5 concludes.

[4]While Goodfriend and King (2005) and Svensson (2002) argue that the lack of central bank's credibility increases the cost of disinflation, our analysis emphasizes the role of central bank's transparency as a determinant of the costs of inflation stabilization.

4.2 The economy

The model is derived from an economy with flexible prices, populated by a *continuum* of monopolistic competitive firms and a central bank. The economy is affected by stochastic cost-push shocks. Nominal aggregate demand is determined by the monetary instrument set by the central bank.

4.2.1 Firms

The behaviour of firms consists in choosing a price. Under monopolistic competition *à la* Dixit-Stiglitz, firms set their price as a function of their expectations of the overall price level p, the real output gap c, and the cost-push shock u.[5] One can show that the optimal price of firm i is given by

$$p_i = \mathbb{E}_i[p + \xi c + u]. \tag{4.1}$$

The pricing rule (4.1) captures the strategic complementarities of prices. Indeed, each firm i sets its price according to its expectation about both fundamentals (the output gap c and the cost-push shock u) and the average action of others, the overall price level p.

The parameter ξ determines the extent to which the optimal price responds to the output gap. As we assume below, the central bank determines the nominal aggregate demand through its monetary instrument. Using the fact that the nominal aggregate demand (deviation) y is by definition equal to $c + p$, we rewrite the pricing rule (4.1) as

$$p_i = \mathbb{E}_i[(1 - \xi)p + \xi y + u]. \tag{4.2}$$

We realistically assume that prices are strategic complements and impose $0 < \xi < 1$. When ξ decreases, the optimal price setting responds less strongly to fundamentals (y and u) and more strongly to the strategic term, the overall price level p: the degree of strategic complementarities increases.

While prices are flexible in our model, imperfect common knowledge among firms and strategic complementarities may account for nonneutral effects of monetary policy. Indeed, Hellwig (2002) or Woodford (2003a)

[5] For the microfounded derivation, see Adam (2006) or Woodford (2003a).

show that the lack of information about each other's expectations (higher-order uncertainty) yields nominal adjustment delays of prices.

4.2.2 The central bank

The central bank minimizes the deviation of both the output gap c and the price level p from their respective target owing to its monetary instrument I. The central bank's optimization problem consists in minimizing its loss

$$L = \min_{I} \mathbb{E}_{cb}[\lambda c^2 + p^2] \tag{4.3}$$

where $c = y - p$ is the output gap and λ the weight assigned to the output gap variability. Note that the central bank has no incentive to push the output above its natural level. For the sake of simplicity, we assume that the central bank directly controls nominal aggregate demand with its monetary instrument ($y = I$). So, the pricing rule (4.2) can be rewritten as

$$p_i = \mathbb{E}_i[(1 - \xi)p + u + \xi I]. \tag{4.4}$$

Finally, the economy is affected by cost-push shocks that are normally distributed:

$$u \sim N(0, \sigma_u^2).$$

The monetary response to cost-push shocks is a particularly interesting issue since cost-push shocks cannot be neutralized by the central bank. Indeed, cost-push shocks create a trade-off between price level and output gap stabilization. In the absence of any monetary policy action, a positive cost-push shock raises the price level and generates a negative output gap. While price level stabilization calls for a contractionary policy, output gap stabilization requires an expansionary one. As we argue in this chapter, whether the central bank will be involved in price level or in output gap stabilization depends on its communication strategy since it determines the effectiveness of monetary policy to stabilize prices.

4.3 Perfect common knowledge

Standard monetary policy analysis assumes that information is common knowledge among firms. While this chapter deals with monetary policy under imperfect common knowledge, the current section derives, as a benchmark, the optimal monetary policy under perfect common knowledge.

When information is perfect and common to all firms, every firm sets the same price ($p_i = p$). The pricing rule (4.4) then simplifies to

$$p_i = p = I + \frac{1}{\xi}u.$$

The impact of cost-push shocks u on the price level increases with the degree of strategic complementarities $1 - \xi$. When ξ is small, nominal aggregate demand is given a lower weight into the pricing rule, which increases the relative weight assigned to cost-push shocks.

The central bank chooses its instrument to minimize its loss (4.3). The monetary instrument is linear in central bank's information u_{cb}: $I = \nu u_{cb}$, where ν stands for the monetary policy coefficient. When the central bank has perfect information about the shock, its monetary instrument simplifies to $I = \nu u$.

The loss under perfect information can be written as

$$L = \lambda(- \frac{1}{\xi}u)^2 + [(\frac{1}{\xi} + \nu)u]^2,$$

and minimizing it yields the following optimal monetary policy:

$$\nu \quad = \quad -\frac{1}{\xi}. \tag{4.5}$$

The corresponding unconditional expected loss is a function of the variance of cost-push shocks:

$$\mathbb{E}(L) = \frac{\lambda}{\xi^2}\sigma_u^2.$$

The optimal monetary policy coefficient (4.5) is consistent with standard optimal monetary policy analysis.[6] The optimal monetary policy coefficient

[6] See Clarida et al. (1999) for an overview on standard New Keynesian monetary policy

ν states that the central bank contracts nominal aggregate demand by $-\frac{1}{\xi}$ when the cost-push shock increases by one unit. Contracting aggregate demand whenever cost-push shocks are positive is a standard result in monetary policy and is known as the *lean against the wind* principle. As the price level increases in the case of a positive cost-push shock, the central bank contracts the nominal aggregate demand to stabilize it. The strength of the central bank's response increases with the degree of strategic complementarities.

The optimal monetary policy derived in this section illustrates that under perfect common knowledge, the central bank finds it optimal to stabilize the price level. By contrast, as we shall see in the next section, when the monetary instrument is imperfect common knowledge among firms, optimal monetary policy may call for output gap stabilization.

4.4 Imperfect common knowledge

We now turn to the more realistic case where the state of the economy is imperfect common knowledge among firms because they have differential information. We apply the methodology of Morris and Shin (2002) to our framework of optimal monetary policy. The latter emphasize the relevance of public information in an economy characterized by strategic complementarities and imperfect common knowledge. The context of their analysis fits our framework particularly well as price setting of firms exhibits strategic complementarities and as the monetary policy is imperfect common knowledge among firms when the central bank is opaque with respect to its instrument.

4.4.1 Information structure

The information structure in the economy is as follows. The central bank receives a private signal on the cost-push shock that deviates from the true fundamental value by an error term that is normally distributed:

$$u_{cb} = u + \mu, \quad \text{with} \quad \mu \sim N(0, \sigma_\mu^2).$$

analysis.

The central bank chooses its instrument to minimize (4.3). The optimal instrument rule of the central bank is a linear function of its signal and can be written as

$$I = \nu(u + \mu). \tag{4.6}$$

Each firm i receives a private signal on the cost-push shock u_i. The private signal of each firm deviates from the true cost-push shock by an error term that is normally distributed:

$$u_i = u + \rho_i, \quad \text{with} \quad \rho_i \sim N(0, \sigma_\rho^2),$$

where ρ_i are identically and independently distributed across firms.

In addition to their private signal about the cost-push shock, firms get a signal on the monetary instrument.The information conveyed by the central bank's disclosure depends upon its degree of transparency with respect to its monetary instrument. Each firm i receives a signal on the central bank's assessment of the state of the economy that is written, for the sake of generality, as

$$D_i = D + \phi_i = u + \mu + \phi_i, \quad \text{with} \quad \phi_i \sim N(0, \sigma_\phi^2),$$

where σ_ϕ^2 is the degree of transparency.[7] It captures the uncertainty surrounding the monetary instrument in the economy. Since firms are rational, they know the policy coefficient ν and can infer the instrument implemented by the central bank from their signal on its economic assessment. When the central bank is transparent, all firms perfectly observe the central bank's assessment (*i.e.* $\sigma_\phi^2 \rightarrow 0$) and the monetary instrument becomes common knowledge among them. By contrast, under opacity (*i.e.* $\sigma_\phi^2 \rightarrow \infty$), the central bank's disclosure does not contain any valuable information. This increases the uncertainty of firms about the instrument.

Historically, central banks used to be extremely opaque and have become recently more and more transparent about their instrument. For example before February 1994, the Federal Reserve did not publicly report on the federal funds rate it was targeting. In this context, the private sector had to infer the policy decisions of the Federal Open Market Committee

[7] One can alternatively imagine that the central bank direclty provides information about its instrument.

from the market operations conducted by the trading-desk of the Fed. This lack of transparency was a source of fundamental uncertainty about the rate targeted by the Fed and of strategic uncertainty about the beliefs of others about this target.

4.4.2 Equilibrium

To determine the perfect Bayesian equilibrium behaviour of firms, we recall the optimal pricing rule (4.4) for convenience and substitute successively the average price level with higher-order expectations about the cost-push shock and the monetary instrument

$$\begin{aligned} p_i &= \mathbb{E}_i[(1-\xi)p + u + \xi I] \\ &= \mathbb{E}_i\Big[u + \xi I + (1-\xi)\Big[\bar{\mathbb{E}}[u + \xi I + (1-\xi)[\bar{\mathbb{E}}[u + \xi I + \ldots]]]\Big]\Big]. \end{aligned}$$

We denote by $\mathbb{E}_i(.)$ the expectation operator of firm i conditional on its information and by $\bar{\mathbb{E}}(.)$ the average expectation operator such that $\bar{\mathbb{E}}(.) = \int_i \mathbb{E}_i(.)di$. With heterogeneous information, the law of iterated expectations fails and expectations of higher-order do not collapse to the average expectation of degree one.[8] Thus, we rewrite the pricing rule as

$$p_i = \sum_{k=0}^{\infty}(1-\xi)^k \mathbb{E}_i\Big[\bar{\mathbb{E}}^{(k)}(u + \xi I)\Big],$$

and averaging over firms yields

$$p = \sum_{k=0}^{\infty}(1-\xi)^k \Big[\bar{\mathbb{E}}^{(k+1)}(u + \xi I)\Big], \tag{4.7}$$

where $\bar{\mathbb{E}}^{(k)}$ stands for the higher-order expectation of degree k. We use the following notation of higher-order expectations: $\bar{\mathbb{E}}^{(0)}(x) = x$ is the expected variable x itself, $\bar{\mathbb{E}}^{(1)}(x) = \bar{\mathbb{E}}(x)$ is the average expectation of x, $\bar{\mathbb{E}}^{(2)}(x) = \bar{\mathbb{E}}\bar{\mathbb{E}}^{(1)}(x) = \bar{\mathbb{E}}\bar{\mathbb{E}}(x)$ is the average expectation of the average expectation of x, and so on.

[8]See Morris and Shin (2002).

In order to solve the inference problem of each firm

$$\mathbb{E}_i(u, I) = \mathbb{E}[u, I | u_i, D_i],$$

we define the corresponding covariance matrix $\mathbf{V}_{4\times4}$ and the relevant submatrices

$$\mathbf{V} \quad = \quad \begin{pmatrix} \mathbf{V_{uu}} & \mathbf{V_{uo}} \\ \mathbf{V_{ou}} & \mathbf{V_{oo}} \end{pmatrix}.$$

The expectation of both the cost-push shock and the instrument conditional on the information set of firm i is given by

$$\mathbb{E}\left(\begin{array}{c} u \\ I \end{array} \middle| \; u_i, D_i \right) = \mathbf{\Omega} \begin{pmatrix} u_i \\ D_i \end{pmatrix} = \begin{pmatrix} \Omega_{11} & \Omega_{12} \\ \Omega_{21} & \Omega_{22} \end{pmatrix} \begin{pmatrix} u_i \\ D_i \end{pmatrix} \tag{4.8}$$
$$= \begin{pmatrix} \frac{\sigma_u^2\sigma_\mu^2+\sigma_u^2\sigma_\phi^2}{\sigma_u^2\sigma_\mu^2+\sigma_u^2\sigma_\rho^2+\sigma_u^2\sigma_\phi^2+\sigma_\mu^2\sigma_\rho^2+\sigma_\rho^2\sigma_\phi^2} & \frac{\sigma_u^2\sigma_\rho^2}{\sigma_u^2\sigma_\mu^2+\sigma_u^2\sigma_\rho^2+\sigma_u^2\sigma_\phi^2+\sigma_\mu^2\sigma_\rho^2+\sigma_\rho^2\sigma_\phi^2} \\ \frac{\nu\sigma_u^2\sigma_\phi^2}{\sigma_u^2\sigma_\mu^2+\sigma_u^2\sigma_\rho^2+\sigma_u^2\sigma_\phi^2+\sigma_\mu^2\sigma_\rho^2+\sigma_\rho^2\sigma_\phi^2} & \frac{\nu(\sigma_u^2\sigma_\mu^2+\sigma_u^2\sigma_\rho^2+\sigma_\mu^2\sigma_\rho^2)}{\sigma_u^2\sigma_\mu^2+\sigma_u^2\sigma_\rho^2+\sigma_u^2\sigma_\phi^2+\sigma_\mu^2\sigma_\rho^2+\sigma_\rho^2\sigma_\phi^2} \end{pmatrix} \begin{pmatrix} u_i \\ D_i \end{pmatrix},$$

where $\mathbf{\Omega} = \mathbf{V_{uo}}\mathbf{V_{oo}^{-1}}$.

We express the price equation (4.7) as

$$p = \sum_{k=0}^{\infty}(1-\xi)^k \Big[\begin{pmatrix} 1 & \xi \end{pmatrix} \mathbf{\Omega}\mathbf{\Xi}^k \begin{pmatrix} u \\ D \end{pmatrix} \Big], \tag{4.9}$$

where the matrix Ξ is given by the first-order expectation of the cost-push shock u and the average central bank's disclosure D

$$\mathbb{E}\left(\begin{array}{c} u \\ D \end{array} \middle| \; u_i, D_i \right) = \mathbf{\Xi} \begin{pmatrix} u_i \\ D_i \end{pmatrix} = \begin{pmatrix} \Omega_{11} & \Omega_{12} \\ \frac{1}{\nu}\Omega_{21} & \frac{1}{\nu}\Omega_{22} \end{pmatrix} \begin{pmatrix} u_i \\ D_i \end{pmatrix}.$$

Appendix 4.A shows that the perfect Bayesian equilibrium yields the linear price setting of firm i

$$\begin{aligned} p_i &= \gamma_1 u_i + \gamma_2 D_i \qquad \text{with} \\ \gamma_1 &= \frac{\frac{(1-\xi)}{\nu}\gamma_2\Omega_{21} + \Omega_{11} + \xi\Omega_{21}}{1-(1-\xi)\Omega_{11}} \\ \gamma_2 &= \frac{(1-\xi)\gamma_1\Omega_{12} + \Omega_{12} + \xi\Omega_{22}}{1-\frac{(1-\xi)}{\nu}\Omega_{22}}. \end{aligned} \tag{4.10}$$

The optimal monetary policy consists of choosing the instrument (4.6) that minimizes the loss (4.3) subject to the price rule (4.9).

According to (4.3), the central bank minimizes the unconditional expected loss

$$\mathbb{E}(L) = \text{var}(p) + \lambda \cdot \text{var}(c). \tag{4.11}$$

The variance of the price level is given by

$$\text{var}(p) = (\gamma_1 + \gamma_2)^2 \sigma_u^2 + \gamma_2^2 \sigma_\mu^2,$$

and the variance of the output gap is

$$\text{var}(c) = (\nu - \gamma_1 - \gamma_2)^2 \sigma_u^2 + (\nu - \gamma_2)^2 \sigma_\mu^2.$$

The optimal monetary policy will depend on the degree of central bank's transparency. We derive the optimal monetary policy first under opacity and then under transparency.

4.4.3 Optimal montary policy under opacity

Under opacity ($\sigma_\phi^2 \to \infty$), firms do not observe the monetary instrument. They are however aware that the central bank responds to cost-push shocks according to its information and rationally use their private information u_i to infer the monetary instrument I.

In that case, the second column of $\mathbf{\Omega}$ in (4.8) consists of zeros as the central bank's disclosure does not contain any valuable information. The solution to the inference problem of each firm boils down to

$$\mathbb{E}_i(u, I) = \mathbb{E}\left(\begin{array}{c} u \\ I \end{array} \middle| \; u_i \right) = \left(\begin{array}{c} \Omega_1 \\ \Omega_2 \end{array} \right) u_i = \left(\begin{array}{c} \frac{\sigma_u^2}{\sigma_u^2 + \sigma_\rho^2} \\ \frac{\nu \sigma_u^2}{\sigma_u^2 + \sigma_\rho^2} \end{array} \right) u_i.$$

Plugging this into equation (4.7) yields

$$\begin{aligned} p &= \sum_{k=0}^{\infty} (1-\xi)^k \left[\Omega_1^{k+1} (1 + \xi\nu) u \right] \\ &= \frac{\Omega_1 (1 + \xi\nu)}{1 - (1-\xi)\Omega_1} u = \frac{\sigma_u^2}{\sigma_\rho^2 + \xi \sigma_u^2} (1 + \xi\nu) u = \gamma_1 u. \end{aligned} \tag{4.12}$$

The optimal monetary policy consists of choosing the instrument (4.6) that minimizes the unconditional expected loss (4.11) subject to the price rule (4.12). The variance of the price level is simply given by

$$\mathrm{var}(p) = \gamma_1^2 \sigma_u^2,$$

while the variance of the output gap is

$$\mathrm{var}(c) = (\nu - \gamma_1)^2 \sigma_u^2 + \nu^2 \sigma_\mu^2.$$

The fixed-point solution to this optimization problem yields the following equilibrium price setting for firm i:

$$p_i = \gamma_1 u_i = \frac{\lambda \sigma_u^2}{\xi \sigma_u^2 + \sigma_\rho^2} \cdot \frac{\sigma_u^2 \sigma_\rho^4 + \xi^2 \sigma_u^4 \sigma_\mu^2 + 2\xi \sigma_u^2 \sigma_\rho^2 \sigma_\mu^2 + \sigma_\rho^4 \sigma_\mu^2 + \xi \sigma_u^4 \sigma_\rho^2}{\xi^2 \sigma_u^6 + \lambda \sigma_u^2 \sigma_\rho^4 + \lambda \xi^2 \sigma_u^4 \sigma_\mu^2 + 2\lambda \xi \sigma_u^2 \sigma_\rho^2 \sigma_\mu^2 + \lambda \sigma_\rho^4 \sigma_\mu^2} u_i,$$

while the optimal monetary policy satisfies

$$\begin{aligned} \nu &= -\frac{(\xi \Omega_1^2 - \lambda(1-\Omega_1)\Omega_1)\sigma_u^2}{(\xi^2 \Omega_1^2 + \lambda(1-\Omega_1)^2)\sigma_u^2 + \lambda(1-(1-\xi)\Omega_1)^2 \sigma_\mu^2} \\ &= \frac{\lambda \sigma_u^4 \sigma_\rho^2 - \xi \sigma_u^6}{\xi^2 \sigma_u^6 + \lambda \sigma_u^2 \sigma_\rho^4 + \lambda \xi^2 \sigma_u^4 \sigma_\mu^2 + 2\lambda \xi \sigma_u^2 \sigma_\rho^2 \sigma_\mu^2 + \lambda \sigma_\rho^4 \sigma_\mu^2}. \end{aligned} \tag{4.13}$$

Interestingly, under opacity, the optimal monetary policy coefficient (4.13) can be positive or negative depending on the parameter configuration. As discussed above, cost-push shocks create a trade-off between price level and output gap stabilization. The central bank's disclosure influences the reaction of the price level to monetary policy and thereby the trade-off the central bank faces. Opacity reduces the effectiveness of monetary policy on the price level as it increases fundamental and strategic uncertainty of firms about the central bank's action. Under opacity, the central bank's influence on the price level is limited as firms do not observe its instrument. So, contracting the aggregate demand is relatively ineffective to reduce the price level. Hence, the central bank may find it optimal to reduce the negative output gap (instead of the price level) by increasing aggregate demand (*i.e.* $\nu > 0$).

Yet opacity is not a sufficient condition for the policy coefficient to be positive. The sign of the policy coefficient (4.13) depends on the relation between the degree of strategic complementarities $1 - \xi$, the preference of the central bank for output gap stabilization λ, and the relative precision of firm's information σ_ρ^2/σ_u^2. In particular, the following condition holds:

$$\nu > 0 \Leftrightarrow \xi < \lambda \frac{\sigma_\rho^2}{\sigma_u^2}. \tag{4.14}$$

We propose to call the case where $\nu > 0$ the *blow with the wind* principle, according to which the central bank expands nominal aggregate demand whenever cost-push shocks are positive. We now discuss the conditions for $\nu > 0$.

Degree of strategic complementarities The policy coefficient is positive when complementarities are high (ξ low). As opacity weakens the effectiveness of monetary policy on the price level, strong complementarities reduce it even further. Two related intuitions can be mentioned for this effect to arise. First, when the degree of strategic complementarities in the economy is high, higher-order expectations are given an increasing weight in the price setting. This exacerbates the strategic uncertainty about the monetary instrument that characterizes opacity and reduces the effectiveness of monetary policy to stabilize the price level. This renders price level stabilization ineffective compared to output gap stabilization and the central bank finds it optimal to set a monetary policy coefficient that accommodates the aggregate demand: $\nu > 0$. Second, when the degree of strategic complementarities is high, the monetary instrument I has a small impact on the price level. The price stabilization is less effective and more difficult to achieve as aggregate demand variations have a smaller impact on the price level. The central bank then faces a trade-off that incites it to stabilize the output gap instead of the price level.

Figure 4.1 computes the central bank's response ν as a function of strategic complementarities $1 - \xi$ with $\sigma_u^2 = 1$, $\sigma_\rho^2 = 0.5$, and $\lambda = 1$ for three values of dispersion of central bank's signals σ_μ^2. As strategic complementarities increase, strategic uncertainty reduces the effectiveness of monetary policy and the policy coefficient ν increases. Not surprisingly, the strength of the central bank's response (absolute value of ν) increases with the precision of its signal.

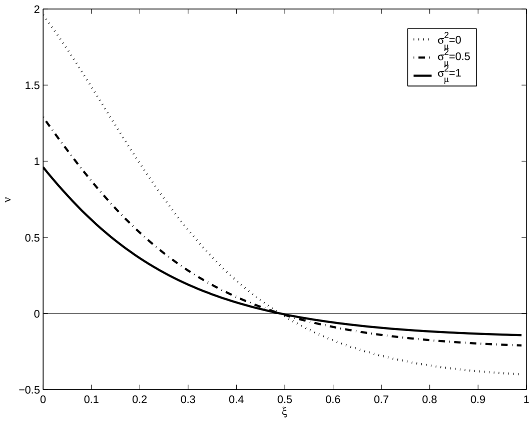

Figure 4.1: Optimal monetary policy under opacity (impact of xi)

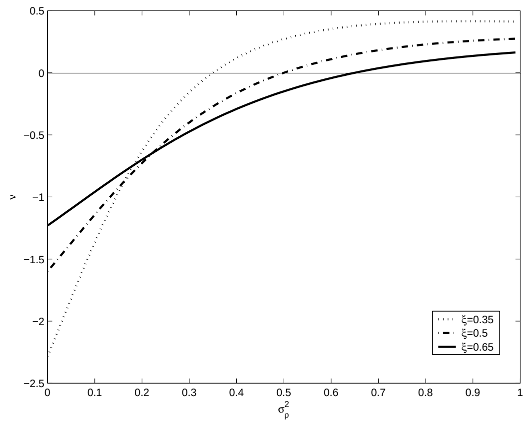

Figure 4.2: Optimal monetary policy under opacity (impact of σ_ρ^2)

Precision of private information When the relative precision of firms' private information increases (σ_ρ^2/σ_u^2 falls), the fundamental and strategic uncertainty of firms about the monetary instrument decreases. The reduction of uncertainty makes the monetary policy more effective to stabilize the price level and the trade-off favours the *lean against the wind* principle. This increases the incentive of the central bank to reduce price deviation. Firms also respond more strongly to cost-push shocks with more accurate information. This implies that the strength of the central bank's response increases: the absolute value of the policy coefficient rises.

Figure 4.2 shows the optimal monetary policy as a function of the precision of firms' private information σ_ρ^2, with $\sigma_u^2 = 1$, $\sigma_\mu^2 = 0.25$, and $\lambda = 1$ for three values of complementarities ξ. When the precision of firms' private information increases (σ_ρ^2 falls), firms' uncertainty about cost-push shocks is reduced and prices respond more strongly to cost-push shocks. This increases the variability of the price level and the incentive of the central bank to stabilize the price level.

Central bank's preference Finally, when the central bank is more inclined towards price stabilization, the incentive of the central bank to contract the nominal demand in order to reduce the price level increases in a very intuitive way. Then the *lean against the wind* principle is preferred to the *blow with the wind* principle.

4.4.4 Optimal monetary policy under transparency

This section derives the optimal monetary policy when the monetary instrument is common knowledge among firms. In the case of full transparency ($\sigma_\phi^2 = 0$), the solution to the inference problem of firm i is given by

$$\begin{aligned} \mathbb{E}\left(\begin{array}{c} u \\ I \end{array} \middle| \; u_i, D \right) &= \begin{pmatrix} \Omega_{11} & \Omega_{12} \\ \Omega_{21} & \Omega_{22} \end{pmatrix} \begin{pmatrix} u_i \\ D \end{pmatrix} \\ &= \begin{pmatrix} \frac{\sigma_u^2 \sigma_\mu^2}{\sigma_u^2\sigma_\mu^2 + \sigma_u^2\sigma_\rho^2 + \sigma_\rho^2\sigma_\mu^2} & \frac{\sigma_u^2 \sigma_\rho^2}{\sigma_u^2\sigma_\mu^2 + \sigma_u^2\sigma_\rho^2 + \sigma_\rho^2\sigma_\mu^2} \\ 0 & \nu \end{pmatrix} \begin{pmatrix} u_i \\ D \end{pmatrix}. \end{aligned}$$

The equilibrium pricing rule (4.10) is described by

$$p_i = \frac{\sigma_u^2 \sigma_\mu^2}{\xi\sigma_u^2\sigma_\mu^2 + \sigma_u^2\sigma_\rho^2 + \sigma_\mu^2\sigma_\rho^2} u_i + \Big[\frac{\sigma_u^2 \sigma_\rho^2}{\xi(\xi\sigma_u^2\sigma_\mu^2 + \sigma_u^2\sigma_\rho^2 + \sigma_\mu^2\sigma_\rho^2)} + \nu \Big] D. \quad (4.15)$$

Minimizing the unconditional expected loss (4.11) subject to firms' pricing rule (4.15) yields the following optimal monetary policy:

$$\nu = -\frac{1}{\xi} \frac{\sigma_u^2}{\sigma_u^2 + \sigma_\mu^2} < 0. \quad (4.16)$$

The optimal policy under transparency coincides with the standard monetary policy analysis and satisfies the *lean against the wind* principle. Indeed, the standard literature assumes that the instrument is common knowledge among firms (firms know the monetary instrument implemented by the

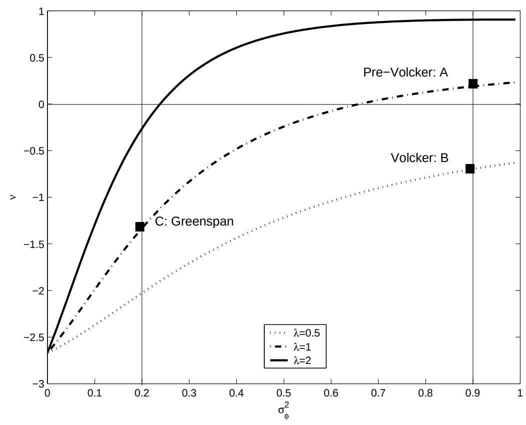

Figure 4.3: Optimal monetary policy for intermediate degree of transparency

central bank) but appears as a particular case in our framework (*i.e.* transparency case).

4.4.5 Increase in central bank's transparency

While the former analysis is restricted to extreme disclosure strategies (*i.e.* opacity *vs.* transparency), the current section discusses the case of intermediate levels of transparency ($0 < \sigma_\phi^2 < \infty$). More particularly, we examine the impact of an increase in transparency about central bank's monetary instrument on the optimal monetary policy. We show that small variations in transparency or in central bank's preferences can have large effects on the optimal conduct of monetary policy.

Figure 4.3 computes the central bank's response ν as a function of the degree of transparency σ_ϕ^2, with $\sigma_u^2 = 1$, $\sigma_\mu^2 = 0.5$, $\sigma_\rho^2 = 0.5$, and $\xi = 0.25$ for three values of λ, the weight assigned to output gap variability.

In the case of full transparency ($\sigma_\phi^2 = 0$), the policy coefficient ν is independent from the preference λ (as equation (4.16) shows) and always negative whatever the parameter configuration. For intermediate levels of transparency, the sign (and strength) of the policy coefficient depends on the preference of the central bank and on the degree of transparency.

First, for a given level of transparency (say $\sigma_\phi^2 = 0.9$), a switch in preference towards greater price level stabilization from $\lambda = 1$ to $\lambda = 0.5$ renders the optimal monetary policy coefficient negative. When the central bank is less inclined towards output gap stabilization, it tends to contract nominal aggregate demand in a larger extent in order to reduce inflation.

Second, a small increase in transparency (σ_ϕ^2 falls) may also have a large impact on the policy coefficient as it leads to a change in its sign. As more transparency reduces the cost of reducing inflation, the central bank finds it optimal to achieve a lower level of inflation by contracting nominal aggregate demand in a larger extent.

4.4.6 Discussion

Our result with respect to the optimal monetary policy in response to cost-push shocks under opacity gives an interesting insight into the conduct of monetary policy in the 70s. Over this decade, the world economy has experienced both important oil shocks and high inflation level. Yet, it seems that oil shocks alone could not account for the high level of inflation. As argued by Clarida et al. (2000) (p. 168) for the case of the US economy, "*it is hard to imagine [...] that the 1973 oil shock alone could have generated high inflation [...] in the absence of an accommodating monetary policy*." While these authors show that the conduct of monetary policy violated the so-called Taylor principle[9] in the pre-Volcker era and satisfied it during the Volcker-Greenspan era, they conclude that (p. 178) "*one important question [their] paper raises but does not answer is the following: why is it that during the pre-1979 period the Federal Reserve followed a rule that was clearly inferior?*". The optimal monetary policy derived in our model provides a rationale for this puzzle.

De Long (1997) extensively documents the evolution in the perception of the response to be adopted in case of cost shock occurrence. He underlines central bankers' concern for the impact of a restrictive monetary policy on output and more particularly on unemployment. Our model shows that the trade-off between inflation and output strongly depends on the level of transparency in the economy. In the case of opacity, the trade-off is clearly unfavourable to inflation stabilization. The central bank can only reduce inflation at the cost of a strong decrease in output; as it becomes more trans-

[9]The Taylor principle calls for an increase in nominal interest rate larger than the rise in expected inflation, so that the real interest rate rises as well. A central bank following this principle fights inflation as it contracts the economy whenever inflation expectations rise.

parent, the central bank can reduce inflation at a lower cost. De Long argues that the main reason for the inflation in the 70s lies in the "*shadow of the Great Depression*". The fear of recession and the excessive emphasis on the output gap[10] are somehow rationalized in our model as the reduction of inflation leads to a much higher contraction in output under opacity than under transparency.

Hence, we can illustrate the development in the conduct of monetary policy in the US as follows. In the pre-Volcker era, the Fed was rather opaque with respect to nominal aggregate demand and did not assign as much weight to price stabilization as it does today. Our framework shows that opacity and some considerations for output gap may explain why central banks conducted an accommodating monetary policy in response to oil shocks. This policy configuration is represented by the point A in figure 4.3.

Then, under Volcker, the Fed became much more inclined towards price stabilization.[11] This corresponds to a reduction in the value of λ and may imply according to (4.14) a switch from the *blow with wind* to the *lean against the wind* principle. In figure 4.3, the move from A to B illustrates the shift in the conduct of monetary policy as Volcker took office.

Finally, under the influence of Greenspan, the Fed becomes much more transparent. Our analysis then suggests that the *lean against the wind* principle is always optimal when the degree of common knowledge about monetary instrument (nominal aggregate demand) is high among firms whatever the parameter configuration. As point C indicates on the figure, when the central bank is very transparent, the optimal monetary policy satisfies the *lean against the wind* principle even if the preference for output gap stabilization is large ($\lambda = 2$).

4.4.7 Phillips curves and economic outcomes

This section interprets former monetary policy issues in terms of Phillips curves. The latter describe the price-output combinations the central bank can achieve with its policy. Since the degree of transparency drives the effectiveness of monetary policy to stabilize prices, it also shapes the slope of the Phillips curve.

[10]See Orphanides (2005)

[11]See Orphanides (2005).

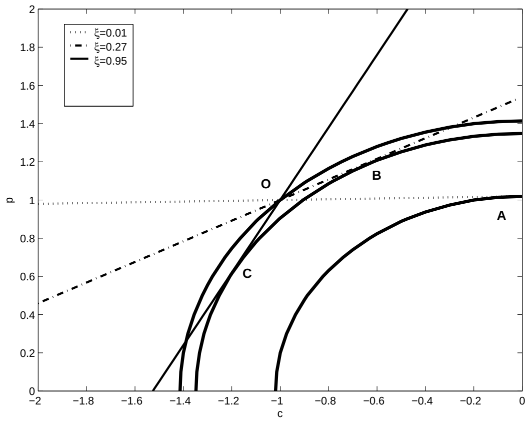

Figure 4.4: Phillips curves and economic outcomes under opacity: impact of strategic complementarities

Full opacity

The case of opacity derived in section 4.4.3 is represented by figure 4.4. It is computed with $\sigma_\mu^2 = \sigma_\rho^2 = \sigma_u^2/2$ and $\lambda = 1$ ($\sigma_\phi^2 \to \infty$ under opacity). As opacity enhances uncertainty about the monetary instrument, its effectiveness is driven by the degree of strategic complementarities $1-\xi$ and the precision of firms' information σ_ρ^2/σ_u^2. More particularly, when complementarities are extremely strong *or* precision of firms' information nearly zero ($\xi \to 0$ *or* $\sigma_\rho^2 \to \infty$), the effectiveness of monetary policy on prices is highly limited and the corresponding Phillips curve is horizontal.

Suppose that the economic outcome in the absence of central bank's intervention is written O. When the central bank is opaque, the degree of complementarities relatively strong, and firms' information not too accurate, condition (4.14) says that the optimal monetary policy is expansive. The resulting economic outcomes are written A and B in figure 4.4. Reducing complementarities or increasing precision of firms' information reduces uncertainty (or its impact) and raises the slope of the Phillips curve under opacity as figure 4.4 shows. When firms' information is very accurate ($\sigma_\rho^2 \to 0$), the curve is vertical. From the slope of the Phillips curve depends whether the monetary policy is expansive (points A and B) or contractive (point C).

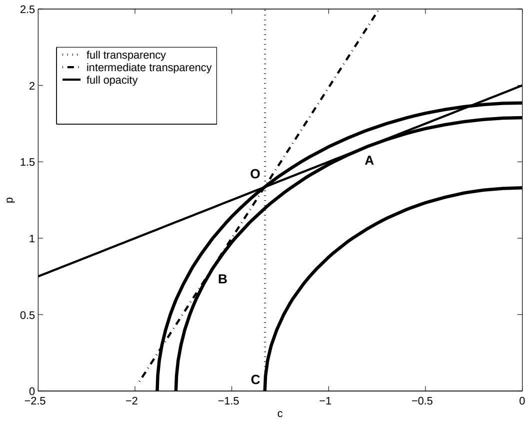

Figure 4.5: Phillips curves and economic outcomes: impact of transparency ($\lambda = 1$)

Intermediate degrees of transparency

Figures 4.5 illustrate the economic outcome for different degrees of transparency. The parameter values are $\sigma_\mu^2 = \sigma_\rho^2 = \sigma_u^2/2$, $\xi = 0.25$, and $\lambda = 1$. The dotted line represents the possible price-output combinations for a fully transparent central bank. In this case, since monetary policy is common knowledge among firms, the Phillips curve is vertical. The solid line is the Phillips curve for full opacity. The slope of the curve falls with strategic complementarities, and rises with the precision of firms' private information and with the degree of transparency. Under opacity and when the curve is relatively flat, the optimal monetary policy is expansive and leads to the economic outcome indicated by point A. By contrast, when transparency increases or when complementarities weaken or when firms' information is more accurate, the Phillips curve becomes steeper. This yields a contractive optimal monetary policy (point B). Finally, with full transparency the policy is always contractive and the outcome is given by C.

One can make the following digression with respect to the rule that the central bank would follow according to its communication strategy. Under opacity, the central bank chooses the inflation-output gap combination given by the point A in figure 4.5. When a positive cost-push shock occurs, firms' expectation of inflation rises. Interestingly, the optimal monetary policy under opacity consists of increasing inflation even more by accommodating nominal aggregate demand. This suggests that when the

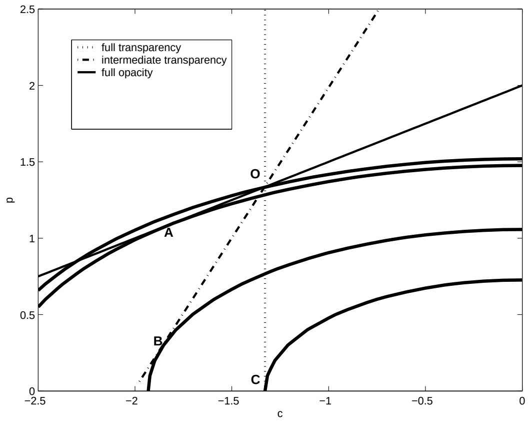

Figure 4.6: Phillips curves and economic outcomes: impact of transparency ($\lambda = 0.3$)

central bank seeks to reach the point A, the Taylor principle[12] is violated since the increase of inflation expectation is not reduced by contractive policy.[13] By contrast, for higher degree of transparency, the point B indicates that the central bank contracts nominal aggregate demand in response to the increase in inflation expectation: the Taylor principle is satisfied. The degree of transparency then rationalizes the observation made by Clarida et al. (2000) concerning the satisfaction or violation of the Taylor principle. Note that the literature in the vein of Barro and Gordon (1983) does not address this issue since it considers excess inflation as a permanent phenomenon.

Figure 4.6 illustrates the case where the central bank is more inclined towards price stabilization ($\lambda = 0.3$). The optimal monetary policy may be restrictive even for an opaque central bank. The point A shows the outcome resulting from a contractive monetary policy.

4.5 Conclusion

The accommodating monetary policy of the 70s is usually rationalized within the Barro-Gordon framework. This literature presumes that the high

[12] According to the Taylor principle, the central bank should contract the economy whenever inflation expectation rises in order to fight inflation.

[13] This result however suggests that the nature of the increase of inflation expectation is crucial to determine the optimal policy under opacity. While the violation of the Taylor principle seems to be optimal when the increase in inflation expectation is caused by a cost-push shock, this would not be optimal if the increase in expectation would be unfounded (sun spot).

inflation episode comes from the incentive of the central bank to push the output above its natural level and to cheat the private sector.

By contrast, our analysis shows that, even in the absence of inflationary bias, a credible central bank may find it optimal to accommodate monetary policy in response to cost-push shocks whenever the uncertainty surrounding its monetary instrument is high. Our model highlights the relevance of central bank's disclosure for the effectiveness of monetary policy in an economy characterized by strategic complementarities and imperfect common knowledge. In particular, central bank's opacity linked to some preference for output gap stabilization yields an optimal monetary policy that violates the *lean against the wind* principle. As the central bank faces a trade-off between price and output gap stabilization, its disclosure influences the effectiveness of its policy, and thereby whether it will be involved into price or output gap stabilization. Briefly, this chapter rationalizes why inflation is lower when the central bank is transparent with respect to its monetary instrument.

4.A Appendix: Linear pricing rule

This appendix solves the perfect Bayesian equilibrium for the pricing rule of firms given by equation (4.9).

We first postulate that the optimal price of firm i is a linear combination of its two signals

$$p_i = \gamma_1 u_i + \gamma_2 D_i. \tag{4.17}$$

The optimal weights γ_1 and γ_2 depend on firms' expectations about the pricing behaviour of other firms. The conditional estimate of the average price is therefore given by

$$\mathbb{E}_i(p) = \gamma_1 \mathbb{E}_i(u) + \gamma_2 \mathbb{E}_i(D). \tag{4.18}$$

Plugging $\mathbb{E}_i(p)$ in the pricing rule (4.4) and replacing the expectations of firm i about u, D, and I yields

$$\begin{aligned} p_i &= \mathbb{E}_i[(1-\xi)p + u + \xi I] \\ &= (1-\xi)[\gamma_1 \mathbb{E}_i(u) + \gamma_2 \mathbb{E}_i(D)] + \mathbb{E}_i(u) + \xi \mathbb{E}_i(I) \end{aligned}$$

$$
\begin{aligned}
&= (1-\xi)[\gamma_1(\Omega_{11}u_i + \Omega_{12}D_i) + \gamma_2(\frac{\Omega_{21}}{\nu}u_i + \frac{\Omega_{22}}{\nu}D_i)] \\
&\quad +\Omega_{11}u_i + \Omega_{12}D_i + \xi\Omega_{21}u_i + \xi\Omega_{22}D_i.
\end{aligned}
$$

Rearranging gives

$$
\begin{aligned}
p_i &= u_i[(1-\xi)(\gamma_1\Omega_{11} + \gamma_2\frac{\Omega_{21}}{\nu}) + \Omega_{11} + \xi\Omega_{21}] \\
&\quad +D_i[(1-\xi)(\gamma_1\Omega_{12} + \gamma_2\frac{\Omega_{22}}{\nu}) + \Omega_{12} + \xi\Omega_{22}].
\end{aligned}
$$

Identifying the coefficients, we get

$$
\begin{aligned}
\gamma_1 &= \frac{\frac{(1-\xi)}{\nu}\gamma_2\Omega_{21} + \Omega_{11} + \xi\Omega_{21}}{1-(1-\xi)\Omega_{11}} \\
\gamma_2 &= \frac{(1-\xi)\gamma_1\Omega_{12} + \Omega_{12} + \xi\Omega_{22}}{1-\frac{(1-\xi)}{\nu}\Omega_{22}}.
\end{aligned}
$$

This system of equations is equivalent to (4.10) in the text.

Chapter 5

Monetary Policy and its Informative Value[1]

5.1 Introduction

Over the last decades, there has been a switch in central banks' practice from secrecy to transparency. Generally speaking, central bank's transparency refers to the absence of asymmetric information between the central bank and the private sector. This trend in central banking has given rise to a growing literature about the pros and cons of higher transparency. Higher transparency is usually rationalized by the economic benefits and democratic accountability required from an independent central bank.[2]

The literature mainly focuses on the impact of economic and political transparency of central banks in the Barro and Gordon (1983) framework. As central banks are presumed to systematically boost the economy above its natural level, the literature examines the extent to which transparency helps to reduce the inflation bias and time-inconsistency problem and to increase the credibility and flexibility of central banks.[3]

Yet, in the current context of central bank's independence and historically – and durable – low levels of inflation, many central banks have reached a high degree of credibility. On the one hand, the benefit of independence

[1]This chapter has been developed with the collaboration of Camille Cornand.

[2]These are the two main premises of the Code of Good Practices on Transparency in Monetary and Financial Policies (paragraph 4) adopted by the Interim Committee of the Board of Governors of the International Monetary Fund (IMF (1999)).

[3]See Geraats (2002) for an overview.

from political interferences is nowadays commonly accepted.[4] On the other hand, central bankers are aware that boosting the output above its natural level would be inflationary and consider that the assumption of inflationary biased central banks does not capture the actual rationale for the conduct of monetary policy.[5] In particular, Blinder (1998), King (1997), and Vickers (1998) argue that the Barro-Gordon argument is not applicable to their respective central banks.[6]

The aim of this chapter is to analyze the benefits and costs of transparency for well-established and credible central banks. Under these circumstances, the question of transparency deals with the provision of central bank's information to the private sector about its economic assessment. There is an ongoing debate about whether a central bank should explain its decisions: many central banks discuss nowadays whether they should publish their macroeconomic forecasts or the minutes of deliberations of their policy board.

Recently, the literature has raised questions about the value of having central banks provide more and better information to the public. There is a general presumption that more information enhances efficiency as economic agents make better decisions when they are better informed. Yet, in their seminal beauty contest paper, Morris and Shin (2002) – emphasizing the relevance of strategic complementarities underlying most of macroeconomic aggregates – argue that, in an environment characterized by imperfect common knowledge and strategic complementarities, more accurate public information may be detrimental to welfare because public information is attributed too large a weight relative to its face value. Their argument has received a great deal of attention in the academic literature, the financial press[7], and central banks[8]. In a closely related work, Amato et al.

[4]For example, as politicians gave their opinion about the conduct of monetary policy by the European Central Bank, its president at that time, Wim Duisenberg, stated that it was a "*normal phenomenon*" to observe suggestions from politicians but that "*it would be very abnormal if those suggestions were to be listened to*" (The Economist (1998)).

[5]Note that we have shown in chapter 4 that the lack of credibility is not necessary for the central bank to implement an accommodating policy in response to positive cost-push shocks.

[6]For a discussion of this issue, see Cukierman (2002). Blinder (2000) also shows that there is a strong consensus among central bankers about the importance and benefit of credibility.

[7]See The Economist (2004).

[8]See for example Kohn (2005) and Issing (2005).

(2002) interpret the model by Morris and Shin (2002) as a Lucas-Phelps islands economy in which firms try to second-guess the pricing strategies of their competitors. Challenging this result, Hellwig (2005) shows in a fully micro-founded model that more accurate public information about monetary shocks is always welfare increasing because it reduces price dispersion.[9] In chapter 3, we have developed another argument in favour of transparency by showing that when the economy is hit by demand shocks that the central bank tries to offset, transparency is particularly beneficial when central bank's information is rather noisy.

The present chapter contributes to this debate on the welfare effects of economic transparency in the conduct of monetary policy. While Hellwig (2005) considers the case where money supply follows a stochastic process, we focus on the optimal monetary policy. Our analysis is based on a model of monopolistic competition with imperfect common knowledge and where two shocks affect the economy, namely demand and cost-push shocks. Both the central bank and firms are uncertain about the true state of the economy. Our approach has two main characteristics. First, we concentrate on the effect of economic transparency in the case where the central bank has no inflationary bias and where the private sector perfectly knows its preferences. Second, we consider the instrument of the central bank not only as an action that stabilizes the economy but also as a signal that partially reveals to firms its own imperfect assessment of the state of the economy. The signaling role of monetary policy has been well documented by Romer and Romer (2000). Using US data, they show that "*the Federal Reserve's actions signal its information*" and that "*commercial forecasters raise their expectations of inflation in response to contractionary Federal Reserve actions [...]*" (p. 430). So, monetary policy entails a dual role, as an action and as a vehicle for information. The central bank chooses its instrument by optimally balancing its action and information purposes.

In our set-up, an *opaque* central bank does not share its information about the state of the economy with firms. When the economy is simultaneously hit by many types of shocks, firms are unable to properly interpret the monetary instrument as they cannot disentangle the rationale behind it. For instance, the central bank may implement an expansionary instrument ei-

[9]See chapter 2 section 2.3 for a detailed discussion.

ther because of a negative demand shock or because of a negative cost-push shock. This confusion reduces the informative value of the instrument on both fundamental shocks and on the beliefs of others about these shocks. By contrast, a *transparent* central bank discloses enough information so that it reveals to firms its assessment of fundamental shocks. A transparent central bank thus discloses an additional announcement indicating its own signals on the state of the economy.

Walsh (2006) considers a similar framework. However, his work differs to ours in two respects. First, he assumes prices to be sticky. This implies transmission mechanisms to be forward-looking. Second, his central bank imperfectly controls a real variable (the output gap) while ours imperfectly controls the nominal aggregate demand.

This chapter analyzes the welfare effect of economic transparency, that is the extent to which the central bank should fully reveal to firms its own assessment of fundamental shocks (namely demand and cost-push shocks). We derive the optimal monetary policy and optimal central bank's disclosure strategy. The welfare analysis of transparency is driven by three intertwined effects.

First, transparency has a positive *incentive effect* on the optimal monetary policy. As firms are unable to properly disentangle the reasons behind the instrument under opacity, the central bank balances the action and information purposes of its monetary instrument. This distorts its policy away from what would be optimal with respect to the action purpose only. By contrast, under transparency, since its assessments are revealed to firms, the central bank implements the instrument that is optimal from the perspective of its sole action purpose.

Second, transparency has a positive *uncertainty effect* with respect to demand shocks. Reducing the fundamental and strategic uncertainties about demand shocks is welfare increasing. This arises because demand shocks can be neutralized by the policy implemented by the central bank. Even if central bank's information about demand shocks is noisy, transparency is welfare increasing since it reveals to firms how monetary policy influences the economy firms have to respond to. This mechanism is in line with the conclusion of chapter 3.

Third, transparency has a negative *uncertainty effect* with respect to cost-push shocks. Cost-push shocks cannot be neutralized by the central bank as they create a trade-off between price level and output gap stabilization. Reducing the fundamental and strategic uncertainty about cost-push shocks owing to transparency is consequently detrimental to welfare since it exacerbates the response of each firm to cost-push shocks and increases the resulting loss.

Overall, we show that transparency is welfare increasing (i) when the degree of strategic complementarities is low, (ii) when the economy is not too affected by cost-push shocks (relative to other shocks), (iii) when the central bank is more inclined towards price level rather than output gap stabilization, (iv) when firms have relatively precise private information, and (v) when the central bank has information that is relatively precise on demand shocks and relatively imprecise on cost-push shocks. Hence, our framework gives a rationale for the development of the economy over the last decades. Increasing transparency[10] seems appropriate in the current context of declining occurrence and amplitude of cost-push shocks[11] and increasing inclination of central banks towards price stabilization.

The remaining of the chapter is structured as follows. Section 5.2 outlines a monopolistic competition economy, in which firms' pricing decisions represent strategic complements. Section 5.3 considers a benchmark case under perfect common knowledge that recalls standard findings in monetary policy analysis and gives useful insights for the intuition behind our main results. Section 5.4 turns to the case of imperfect common knowledge and examines the optimal monetary policy and transparency. This section considers how announcements affect the optimal policy responses to demand and cost-push shocks and whether transparency is welfare increasing. Finally section 5.5 concludes.

5.2 The economy

The economy is populated by a *continuum* of monopolistic competitive firms, and a central bank. We abstract here from the microfounded market interactions since they are very standard and focus on the optimal be-

[10] The increase in transparency in the conduct of monetary policy in recent years is studied by Eijffinger and Geraats (2006).

[11] See Andersen and Wascher (2001) and Blanchard and Simon (2001).

haviour of firms.[12]

5.2.1 Firms

The central equation of our model is given by the optimal pricing rule of firms. This is derived from an economy where the representative household consumes a composite good *à la* Dixit and Stiglitz (1977) and where goods are imperfect substitutes. In such a context, the optimal price set by firm i is

$$p_i = \mathbb{E}_i[p + \xi c + u], \tag{5.1}$$

where $\mathbb{E}_i$ is the expectation operator of firm i conditional on its information, p the overall price level, c the output gap, and u the cost-push shock. The pricing rule (5.1) says that each firm sets its price according to both its own expectations about the real output gap and the cost-push shock, and its expectations about the overall price level. Per definition, the nominal aggregate demand deviation is the sum of deviations of the output gap and the price level: *i.e.* $y = c + p$. So, one can write the pricing rule as

$$p_i = \mathbb{E}_i[(1 - \xi)p + \xi y + u]. \tag{5.2}$$

The parameter ξ captures the impact of the real output gap on prices (through wages). A large ξ means that the representative household is highly risk averse and that output gaps imply large variations in wages and thereby in prices. ξ also describes whether prices are strategic complements or substitutes. We assume that $0 < \xi < 1$, which implies that prices are strategic complements, meaning that firms tend to raise their price whenever they expect the others to do so. This assumption seems very natural and captures the concept of beauty contest introduced by Keynes: firms base their decision not only on their own expectations of fundamentals but also on the so-called higher-order expectations, *i.e.* expectations of the average expectations of fundamentals, up to an infinite number of iterations.

[12] See appendix 1.A for the derivation of the microfoundations.

5.2.2 The central bank

Based on its information, the central bank minimizes both the variability of the output gap c and that of the price level p owing to its monetary instrument I:

$$\min_I \mathbb{E}_{cb}[\lambda c^2 + p^2], \tag{5.3}$$

where λ is the weight assigned to the output gap variability. The monetary instrument implemented by the central bank is a linear combination of its signals on shocks: $I = \nu_1 g_{cb} + \nu_2 u_{cb}$. ν_1 and ν_2 are the policy coefficients, and g_{cb} and u_{cb} stand for the central bank's signals on demand and mark-up shocks, respectively. We assume that the monetary instrument I implemented by the central bank partially determines nominal aggregate demand. Precisely, the nominal aggregate demand y is the sum of the central bank's instrument I and of the demand shock g, *i.e.* $y = I + g$. So, the pricing rule becomes

$$p_i = \mathbb{E}_i[(1-\xi)p + \xi g + u + \xi I]. \tag{5.4}$$

For the sake of simplicity, we assume that both shocks affecting the economy are normally and independently distributed:

$$\begin{aligned} g &\sim N(0, \sigma_g^2) \\ u &\sim N(0, \sigma_u^2). \end{aligned}$$

5.3 Perfect common knowledge

Standard monetary policy analysis assumes that information is common knowledge among firms. While this chapter deals with monetary policy under imperfect common knowledge, the current section derives, as a benchmark, the optimal monetary policy under perfect common knowledge.

When information is perfect and common to all firms, every firm sets the same price. The pricing rule (5.4) then simplifies to

$$p_i = p = I + g + \frac{1}{\xi}u.$$

Note that the impact of cost-push shocks u on the price level increases with the degree of strategic complementarities $1-\xi$. As discussed in appendix 1.A, when the economy is highly extensive (ξ small), firms assign a smaller weight to the nominal aggregate demand and a relatively larger one to the cost-push shock and to average price level.

When the central bank has perfect information as well, its instrument simplifies to

$$I = \nu_1 g + \nu_2 u.$$

The resulting loss under perfect information is

$$L = \lambda\Big(-\frac{1}{\xi}u\Big)^2 + \Big[(1+\nu_1)g + (\frac{1}{\xi}+\nu_2)u\Big]^2,$$

and minimizing the unconditional expected loss yields the following optimal monetary policy:

$$\begin{aligned}\nu_1 &= -1\\ \nu_2 &= -\frac{1}{\xi}.\end{aligned}$$

The corresponding unconditional expected loss is a function of the variance of cost-push shocks and yields

$$\mathbb{E}(L) = \frac{\lambda}{\xi^2}\sigma_u^2.$$

This result is consistent with standard optimal monetary policy analysis.[13] The coefficient ν_1 indicates that the central bank perfectly offsets demand shocks. Since the monetary instrument is part of the nominal aggregate demand, the central bank is able to offset demand shocks. By closing the output gap, the central bank also gets rid of price deviations. So demand shocks are perfectly neutralized.

By contrast, cost-push shocks cannot be neutralized by the central bank as they create a trade-off between price level and output gap stabilization. Indeed, in the absence of any monetary policy action, a positive cost-push shock raises the price level and generates a negative output gap. While price level stabilization calls for a contractionary policy, output gap stabilization

[13] See Clarida et al. (1999) for an overview on standard New Keynesian monetary policy.

requires an expansionary one. Under perfect common knowledge, the optimal monetary policy coefficient ν_2 states that the central bank lowers its instrument by $-\frac{1}{\xi}$ when the cost-push shock increases by one unit (*i.e.* contractionary policy). As the price level increases because of a positive cost-push shock, the central bank contracts the nominal aggregate demand so that the price level is completely stabilized (*i.e.* $p = 0$). The resulting output gap is $c = -\frac{1}{\xi}u$. The strength of the central bank's response increases with the degree of strategic complementarities. Contracting aggregate demand whenever cost-push shocks are positive is a standard result in monetary policy and is known as the *lean against the wind* principle.[14]

5.4 Imperfect common knowledge

We now turn to the more realistic case where the state of the economy is imperfect common knowledge among firms because they have differential information. We derive the optimal monetary policy as a function of the central bank's transparency and then analyze the welfare effect of transparency. As information provided by the monetary instrument influences firms' reaction, the optimal policy varies according to the communication strategy adopted by the central bank.

We assume that the monetary instrument is perfectly observed by firms. This corresponds to the current practice of most central banks.[15] By setting its instrument publicly, the central bank implicitly discloses a public signal to firms. However, without additional information, firms are unable to understand the central bank's assessment of the economy. This is the reason why many central banks, additionally to revealing the level of their instrument (*e.g.* the level of the overnight interest rate), explain their decision. A clear trend in this respect is the switch towards communication of the minutes of Monetary Policy Committee discussions. This section precisely aims at evaluating such communication strategies by considering whether the central bank should disclose additional information in the form of an

[14]As we shall see below, this standard principle does not necessarily hold under imperfect common knowledge.

[15]Note that the transparency of the monetary instrument is often rationalized by the fact that it renders monetary policy more effective as it exempts the private sector to "*waste effort inferring the stance of monetary policy from diffuse signals generated in the day-to-day implementation of policy*" (Greenspan (2001)). See chapter 1 section 1.2.2 for an overview.

explicit announcement that precisely reveals to the private sector its view about the state of the economy.

The information structure of the central bank is as follows. The central bank receives a signal on both the demand and the cost-push shocks in private. Each signal – or estimate – deviates from the true fundamental value by an error term that is normally distributed:

$$g_{cb} = g + \eta, \quad \text{with} \quad \eta \sim N(0, \sigma_\eta^2)$$
$$u_{cb} = u + \mu, \quad \text{with} \quad \mu \sim N(0, \sigma_\mu^2),$$

where η and μ are independently distributed.

The central bank chooses its instrument to minimize (5.3). Since both fundamental shocks and both error terms are independently normally distributed, the optimal instrument rule of the central bank is a linear combination of its signals and can be written as

$$I = \nu_1(g + \eta) + \nu_2(u + \mu). \tag{5.5}$$

We first present the case where the central bank does not announce the rationale behind its instrument (opacity) and second the case where it reveals its own signals with an explicit announcement (transparency). Then we compare and discuss the optimal disclosure policy.

5.4.1 No announcement (opacity)

Each firm i receives a private signal on the cost-push shock u_i that can be interpreted as a private estimate. The private signal of each firm deviates from the true cost-push shock by an error term that is normally distributed:

$$u_i = u + \rho_i, \quad \text{with} \quad \rho_i \sim N(0, \sigma_\rho^2),$$

where ρ_i are identically and independently distributed across firms.

Firms also receive a public signal in the form of the monetary policy instrument (5.5). By setting its instrument, the central bank gives an indication to firms of its own beliefs about the state of the economy. Yet, without announcement, firms are uncertain about the right interpretation of the monetary instrument and about how others may interpret it. Firms rationally use the monetary instrument to infer the fundamental shocks g and u, and the expectations of other firms about these shocks.

Equilibrium

To determine the perfect Bayesian equilibrium behaviour of firms, we recall the optimal pricing rule (5.4) for convenience and substitute successively the average price level with higher-order expectations about the demand and cost-push shocks and the monetary instrument

$$\begin{aligned} p_i &= \mathbb{E}_i[(1-\xi)p + \xi g + u + \xi I] \\ &= \mathbb{E}_i\Big[\xi g + u + \xi I + (1-\xi)\Big[\bar{\mathbb{E}}[\xi g + u + \xi I + (1-\xi)[\bar{\mathbb{E}}[\xi g + u + \xi I + \ldots]]]\Big]\Big]. \end{aligned}$$

We denote by $\mathbb{E}_i(.)$ the expectation operator of firm i conditional on its information and by $\bar{\mathbb{E}}(.)$ the average expectation operator such that $\bar{\mathbb{E}}(.) = \int_i \mathbb{E}_i(.)di$. With heterogeneous information, the law of iterated expectations fails and expectations of higher-order do not collapse to the average expectation of degree one.[16] Thus, we rewrite the pricing rule as

$$p_i = \sum_{k=0}^{\infty}(1-\xi)^k \mathbb{E}_i\Big[\bar{\mathbb{E}}^{(k)}(\xi g + u + \xi I)\Big],$$

and averaging over firms yields

$$p = \sum_{k=0}^{\infty}(1-\xi)^k \Big[\bar{\mathbb{E}}^{(k+1)}(\xi g + u + \xi I)\Big], \tag{5.6}$$

where k is the degree of higher-order iterations. We use the notation: $\bar{\mathbb{E}}^{(0)}(x) = x, \bar{\mathbb{E}}^{(1)}(x) = \bar{\mathbb{E}}(x)$, and $\bar{\mathbb{E}}^{(2)}(x) = \bar{\mathbb{E}}\bar{\mathbb{E}}^{(1)}(x) = \bar{\mathbb{E}}\bar{\mathbb{E}}(x)$. The price level p is a weighted average of higher-order expectations of the nominal aggregate demand $g + I$ and the cost-push shock u. The corresponding output gap is given by

$$c = y - p = g + I - \sum_{k=0}^{\infty}(1-\xi)^k \Big[\bar{\mathbb{E}}^{(k+1)}(\xi g + u + \xi I)\Big].$$

[16] See Morris and Shin (2002).

The output gap is the difference between the nominal aggregate demand and the weighted average of higher-order expectations of the demand shock g, the cost-push shock u, and the monetary instrument I. As fundamental and strategic uncertainties about nominal aggregate demand increase, the real effect of variations in nominal demand increases as well. In the particular case where it is common knowledge, nominal aggregate demand has only a price effect. This does not mean however that the central bank cannot stabilize (fully or partially) both demand and cost-push shocks.

In order to solve the inference problem of each firm

$$\mathbb{E}_i(g,u) = \mathbb{E}[g,u|u_i,I],$$

we define the corresponding covariance matrix $\mathbf{V}_{4\times 4}$ and the relevant submatrices

$$\mathbf{V} \;=\; \begin{pmatrix} \mathbf{V_{uu}} & \mathbf{V_{uo}} \\ \mathbf{V_{ou}} & \mathbf{V_{oo}} \end{pmatrix}.$$

The expectation of shocks conditional on the private and public signals of firm i is given by

$$\mathbb{E}\left(\begin{array}{c} g \\ u \end{array}\middle|\; u_i, I\right) = \mathbf{\Omega}\begin{pmatrix} u_i \\ I \end{pmatrix} = \begin{pmatrix} \Omega_{11} & \Omega_{12} \\ \Omega_{21} & \Omega_{22} \end{pmatrix}\begin{pmatrix} u_i \\ I \end{pmatrix},$$

where $\mathbf{\Omega} = \mathbf{V_{uo}}\mathbf{V_{oo}^{-1}}$.

Using this, equation (5.6) becomes

$$p \;=\; \sum_{k=0}^{\infty}(1-\xi)^k\Big[\begin{pmatrix} \xi & 1 \end{pmatrix}\mathbf{\Omega}\mathbf{\Xi^k}\begin{pmatrix} u \\ I \end{pmatrix} + \xi I\Big], \tag{5.7}$$

where

$$\mathbf{\Xi} = \begin{pmatrix} \Omega_{21} & \Omega_{22} \\ 0 & 1 \end{pmatrix}.$$

Appendix 5.A derives the equilibrium pricing rule. The equilibrium strategy for firm i is a linear combination of its private signal on cost-push shocks u_i and the public signal I:

$$\begin{aligned} p_i &= \gamma_1 u_i + \gamma_2 I \qquad \text{with} \\ \gamma_1 &= \frac{\xi\Omega_{11} + \Omega_{21}}{1-(1-\xi)\Omega_{21}} \\ \gamma_2 &= \frac{(1-\xi)\gamma_1\Omega_{22} + \xi(1+\Omega_{12}) + \Omega_{22}}{\xi}. \end{aligned} \tag{5.8}$$

Optimal monetary policy

This section derives the optimal monetary policy under opacity. The central bank sets its monetary instrument (5.5) to minimize the expected loss (5.3) subject to the price rule (5.8). The unconditional expected loss is given by

$$\mathbb{E}(L) = \text{var}(p) + \lambda \cdot \text{var}(c).$$

First, the variance of the price level p can be written as

$$\text{var}(p) = (\gamma_2\nu_1)^2\sigma_g^2 + (\gamma_2\nu_1)^2\sigma_\eta^2 + (\gamma_1 + \gamma_2\nu_2)^2\sigma_u^2 + (\gamma_2\nu_2)^2\sigma_\mu^2.$$

Secondly, we determine the variance of the output gap. The output gap is

$$\begin{aligned} c &= I + g - p \\ &= g - \gamma_1 u + (1-\gamma_2)I. \end{aligned}$$

Therefore, the variance of the output gap yields

$$\begin{aligned} \text{var}(c) &= (1 + (1-\gamma_2)\nu_1)^2\sigma_g^2 + ((1-\gamma_2)\nu_1)^2\sigma_\eta^2 \\ &\quad + ((1-\gamma_2)\nu_2 - \gamma_1)^2\sigma_u^2 + ((1-\gamma_2)\nu_2)^2\sigma_\mu^2. \end{aligned}$$

As the monetary policy is both an action and a vehicle for information, the central bank chooses its instrument by optimally balancing its action and information purposes.

The instrument that is optimal from the perspective of its action is given by the optimal monetary policy in the case where both the central bank and firms share the same information. Indeed, when firms already know (before observing the instrument) the central bank's assessment of the state

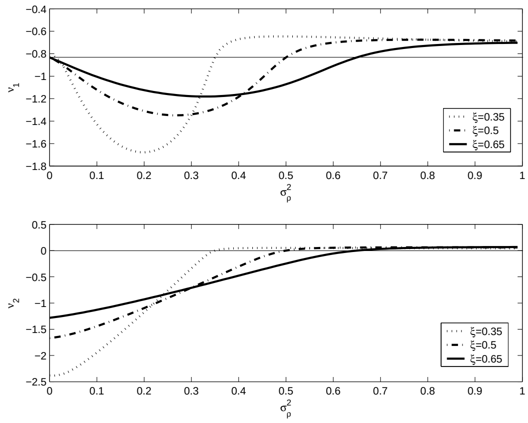

Figure 5.1: Optimal monetary policy under opacity

of the economy, the central bank has no incentive to distort its instrument in order to disguise its signals. When central bank's and firms' information is symmetric, the monetary instrument reflects its action purpose only.

However, as soon as firms have imperfect information about the central bank's assessment, the central bank can reduce its loss by considering also the informative value of its instrument. The information purpose of monetary policy calls for making the instrument as less informative as possible on cost-push shocks and as informative as possible on demand shocks.

Figure 5.1 shows the optimal monetary policy as a function of σ_ρ^2, the variance of the error terms of firms' private signal on cost-push shocks. The precision of firms' information declines moving from the left to the right part of the graph. The optimal monetary policy is computed with the following parameter values: $\sigma_g^2 = 1$, $\sigma_u^2 = 1$, $\sigma_\eta^2 = 0.2$, $\sigma_\mu^2 = 0.2$, and $\lambda = 1$. Three cases can be distinguished with respect to the precision of firms' information.

First, when firms have perfect information on the cost-push shock ($\sigma_\rho^2 = 0$), the central bank implements the policy that is optimal from the perspective of its action and ignores the informative value of its instrument. Indeed, the central bank has no incentive to disguise its signal on the cost-push shock by altering its policy because firms already know the true cost-push shock. At the same time, revealing its signal on the demand shock to firms is not welfare detrimental since demand shocks are neutralized.[17] The

[17] Chapter 3 shows that transparency reduces the distorting effect of the monetary instrument implemented by a central bank with poorly accurate information.

strength of demand shock neutralization depends on the precision of central bank's information. In the present case where the variance of the error term is one fifth of the variance of the true demand shock, the optimal neutralization becomes $\nu_1 = -\frac{\sigma_g^2}{\sigma_g^2+\sigma_\eta^2} = -0.833$. In a similar way, the response of the central bank to cost-push shocks $\nu_2 = -\frac{1}{\xi}\frac{\sigma_u^2}{\sigma_u^2+\sigma_\mu^2}$ increases (in absolute value) with the precision of its information. The response to cost-push shocks also depends on the degree of strategic complementarities. As the latter increases, cost-push shocks are given an increasing relative weight in the pricing decision of firms and the central bank responds more strongly. With higher complementarities, monetary policy is less effective because nominal aggregate demand management has a small impact on prices when the economy is "highly extensive".

Second, when firms' private information is extremely noisy, again the central bank fully neutralizes demand shocks according to the precision of its information, *i.e.* $\nu_1 \to -\frac{\sigma_g^2}{\sigma_g^2+\sigma_\eta^2}$ as $\sigma_\rho^2 \to \infty$. However, the central bank does not respond to cost-push shocks because firms do not react to them since they get very noisy private signals, *i.e.* $\nu_2 \to 0$ as $\sigma_\rho^2 \to \infty$.

Third, for intermediate values of information precision, the optimal monetary policy depends on both the precision of private information and the degree of strategic complementarities. We first describe the central bank's response to cost-push shocks and then its response to demand shocks.

The optimal policy can be divided into two policy regions. When $\lambda\frac{\sigma_\rho^2}{\sigma_u^2} < \xi$, the central bank responds to cost-push shocks according to the so-called *lean against the wind* principle by contracting the nominal aggregate demand whenever its signal on the cost-push shock is positive (*i.e.* $\nu_2 < 0$). And when $\xi < \lambda\frac{\sigma_\rho^2}{\sigma_u^2}$, it implements a slightly expansionary instrument whenever its signal on the cost-push shock is positive.[18] The sign of the policy coefficient ν_2 depends on the effectiveness of monetary policy to stabilize the price level. Under opacity, the uncertainty of firms about the policy response of the central bank to cost-push shocks is large and this reduces the impact of the policy on the price level. As discussed in section 5.3, cost-push shocks create a trade-off between price level and output gap stabilization.

[18]Interestingly, the condition for the policy coefficient ν_2 to be positive is identical to that derived in chapter 4 under opacity even if the monetary instrument is common knowledge in the current chapter (while it was uncertain in chapter 4). See equation (4.14).

The central bank is involved either in price level or output gap stabilization according to the effectiveness of its policy to stabilize the price level. This effectiveness is high when firms' fundamental and strategic uncertainty about the central bank's response to cost-push shocks is low. This arises either when firms' private information is highly accurate (*i.e.* private signals are good indicators for central bank's response) or when strategic complementarities are weak (*i.e.* strategic uncertainty plays only a minor role). Otherwise, as uncertainty surrounding the response to cost-push shocks is high, the central bank finds it optimal to stabilize the output gap by expanding nominal demand in response to positive cost-push shocks. The strength of the policy response to cost-push shocks ν_2 declines with σ_ρ^2. As the quality of firms' information decreases, prices react also less to firms' expected cost-push shocks and the central bank finds it optimal to respond less strongly to them as well. By doing so, the central bank reduces the informative value of its instrument about cost-push shocks.

The response of the central bank to demand shocks also depends on whether ξ is larger than $\lambda\frac{\sigma_\rho^2}{\sigma_u^2}$. In the region where $\lambda\frac{\sigma_\rho^2}{\sigma_u^2} < \xi$, the central bank finds it optimal to respond more aggressively to demand shocks than it would do in the perspective of its sole action purpose. As firms have relatively precise information about cost-push shocks, the central bank strengthens its response to demand shocks to make its instrument less informative about cost-push shocks. When $\lambda\frac{\sigma_\rho^2}{\sigma_u^2} = \xi$, as the central bank does not respond to cost-push shocks ($\nu_2 = 0$), the optimal response to demand shocks coincides with the policy required by a pure action motive. And finally, when $\xi < \lambda\frac{\sigma_\rho^2}{\sigma_u^2}$, the central bank weakens its response to demand shocks. Compared to the policy case where the pure action purpose matters for the setting of the instrument, this policy reduces the informative value of the instrument about its cost-push shock signal and increases its value about its demand shock signal.

5.4.2 Announcement (transparency)

Although the instrument provides information on the central bank's signals, it does not allow firms to properly understand the reason for the chosen monetary policy. As most central banks publish their instrument target, many of them are even more transparent and make the minutes of their

Monetary Policy Committee deliberations available to the public. This reveals to the public the viewpoint of the central bank about the economy and rationalizes the monetary instrument.

As in the former case without announcement (opacity), each firm receives a private signal on the cost-push shocks u_i and the monetary instrument I is publicly available. With both demand and cost-push shocks hitting the economy, the sole observation of the monetary instrument does not allow firms to disentangle the extent to which each shock is responsible for the instrument. In the current set-up, the central bank can remove uncertainty about the rationale for the instrument by explicitly announcing (one of) its signals. This renders the informative purpose of the monetary instrument redundant and induces the central bank to implement its instrument for its action purpose only. We qualify such a central bank as *transparent* since its announcement eliminates any information asymmetry between itself and firms. For the sake of simplicity, we assume that the central bank directly announces its signal on the demand shock g_{cb}.[19] In this context, firms rationally use their three signals to infer the fundamental shocks and other firms' expectations about them.

Equilibrium

This section solves the perfect Bayesian equilibrium and derives the optimal behaviour of firms and of the central bank. We proceed as in the former section to solve the inference problem each firm faces

$$\mathbb{E}[g, u, I | u_i, I, g_{cb}]$$

and define the corresponding covariance matrix $\mathbf{V}_{6\times 6}$ and the relevant submatrices

[19]One may think of different types of announcement that would reveal central bank's signals to firms. In practice, the publication of inflation forecast and/or target appears to be the main form of announcement adopted by transparent central banks. Indeed, inflation is a concept firms are familiar with and is likely to be better interpreted than other measures, like output gap for example. Nevertheless, announcement of the inflation or output gap targets are equivalent in our context of rational expectations.

$$\mathbf{V} = \begin{pmatrix} \mathbf{V_{uu}} & \mathbf{V_{uo}} \\ \mathbf{V_{ou}} & \mathbf{V_{oo}} \end{pmatrix}.$$

The expectation of the fundamental shocks conditional on the private and public signals of firm i is given by

$$\mathbb{E}\left(\begin{array}{c|c} g & \\ u & u_i, I, g_{cb} \\ I & \end{array}\right) = \mathbf{\Omega_T}\begin{pmatrix} u_i \\ I \\ g_{cb} \end{pmatrix} = \begin{pmatrix} \Omega_{11} & \Omega_{12} & \Omega_{13} \\ \Omega_{21} & \Omega_{22} & \Omega_{23} \\ 0 & 1 & 0 \end{pmatrix}\begin{pmatrix} u_i \\ I \\ g_{cb} \end{pmatrix},$$

where $\mathbf{\Omega} = \mathbf{V_{uo}}\mathbf{V_{oo}^{-1}}$.

Using this result into the price rule (5.6) yields

$$p = \sum_{k=0}^{\infty}(1-\xi)^k \begin{pmatrix} \xi & 1 & \xi \end{pmatrix} \mathbf{\Omega}\mathbf{\Xi^k} \begin{pmatrix} u \\ I \\ g_{cb} \end{pmatrix}, \tag{5.9}$$

where

$$\mathbf{\Xi} = \begin{pmatrix} \Omega_{21} & \Omega_{22} & \Omega_{23} \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}.$$

As appendix 5.A shows, the price level equation (5.9) is a linear combination of the cost-push shock u and of the public signals I and g_{cb}:

$$\begin{aligned} p &= \gamma_1 u + \gamma_2 I + \gamma_3 g_{cb} \qquad \text{with} \qquad (5.10) \\ \gamma_1 &= \frac{\xi\Omega_{11} + \Omega_{21}}{1-(1-\xi)\Omega_{21}} \\ \gamma_2 &= \frac{(1-\xi)\gamma_1\Omega_{22} + \xi(1+\Omega_{12}) + \Omega_{22}}{\xi} \\ \gamma_3 &= \frac{(1-\xi)\gamma_1\Omega_{23} + \xi\Omega_{13} + \Omega_{23}}{\xi}. \end{aligned}$$

Optimal monetary policy

The central bank sets its monetary instrument to minimize the expected loss given the precision of its information. First, the variance of the price level p can be written as

$$\mathrm{var}(p) = (\gamma_2\nu_1 + \gamma_3)^2\sigma_g^2 + (\gamma_2\nu_1 + \gamma_3)^2\sigma_\eta^2 + (\gamma_1 + \gamma_2\nu_2)^2\sigma_u^2 + (\gamma_2\nu_2)^2\sigma_\mu^2.$$

Secondly, we determine the variance of the output gap. The output gap is

$$\begin{aligned} c &= I + g - p \\ &= g - \gamma_1 u + (1-\gamma_2)I - \gamma_3 g_{cb}. \end{aligned}$$

Therefore,

$$\begin{aligned} \mathrm{var}(c) &= (1 + (1-\gamma_2)\nu_1 - \gamma_3)^2\sigma_g^2 + ((1-\gamma_2)\nu_1 - \gamma_3)^2\sigma_\eta^2 \\ &\quad + ((1-\gamma_2)\nu_2 - \gamma_1)^2\sigma_u^2 + ((1-\gamma_2)\nu_2)^2\sigma_\mu^2. \end{aligned}$$

With the additional announcement, firms are able to perfectly disentangle the signals of the central bank. Thus the central bank cannot influence firms' beliefs by altering its instrument. The central bank does not face, unlike under opacity, the problem of optimally balancing the action and information purposes of its monetary instrument anymore. On the contrary, the central bank implements the instrument that is optimal from the perspective of its action purpose only. The corresponding coefficients of monetary policy satisfy:

$$\nu_1 = -\frac{\sigma_g^2}{\sigma_g^2 + \sigma_\eta^2} \tag{5.11}$$

$$\nu_2 = -\frac{1}{\xi}\frac{\sigma_u^2}{\sigma_u^2 + \sigma_\mu^2}. \tag{5.12}$$

As stated above, equation (5.11) indicates that the central bank tries to fully neutralize demand shocks according to the precision of its signal. The central bank's response to cost-push shocks (5.12) increases with the precision of its information. However, the response also depends on the degree of strategic complementarities since monetary policy is less effective for influencing the price level.

5.4.3 Welfare effect of transparency

This section analyzes the welfare effect of transparency. The main results are the following. First, transparency is welfare increasing with respect to demand shocks but detrimental with respect to cost-push shocks. As demand shocks can be neutralized by the central bank, reducing uncertainty about how the central bank responds to them helps stabilizing the economy.[20] By contrast, reducing uncertainty about cost-push shocks is detrimental as it exacerbates firms' reaction and raises the resulting loss since the central bank cannot neutralize this type of shocks. Transparency is welfare improving either when cost-push shocks are not too relevant compared to demand shocks or when the degree of strategic complementarities is low as firms' pricing decision relies less on cost-push shocks. Second, transparency is particularly beneficial when the central bank is more inclined towards price stabilization. Indeed, transparency increases the effectiveness of monetary policy on the price level.

We first describe the three mechanisms that drive these results. Then, we compare the welfare level under opacity *versus* transparency, and emphasize the impact of the degree of strategic complementarities $(1 - \xi)$, of the precision of firms' private information σ_ρ^2, of the variance of cost-push shocks σ_u^2, and of the preference of the central bank for output gap stabilization λ.

Effects at stake

Our results are driven by three effects. First, transparency has a positive *incentive effect* on the optimal monetary policy. In the absence of transparency, firms are unable to disentangle the reasons behind the monetary instrument. Monetary policy then entails a dual role, which induces the central bank to optimally balance the action and information purposes of its instrument. Transparency eliminates the informative value of the instrument (or makes it redundant) and the central bank focuses on its action purpose. The incentive effect of transparency is welfare increasing as transparency allows the central bank to choose the instrument that optimally stabilizes the economy.

[20]This result is consistent with our conclusion of chapter 3.

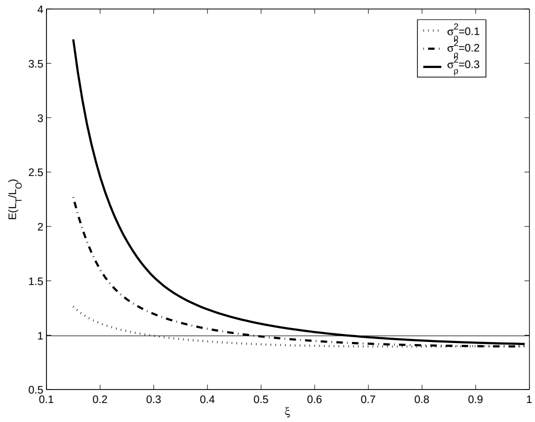

Figure 5.2: Welfare effect of transparency: impact of ξ

Second, transparency has a positive *uncertainty effect* with respect to demand shocks on the behaviour of firms. Transparency reduces both fundamental and strategic uncertainties about demand shocks. Reducing this uncertainty is welfare improving since demand shocks can be neutralized by the central bank. As discussed in chapter 3, this mainly departs from the conclusion by Morris and Shin (2002) because our framework additionally accounts for the action taken by the central bank.

Third, transparency has a negative *uncertainty effect* with respect to cost-push shocks. As cost-push shocks create a trade-off between price and output gap stabilization, they cannot be neutralized by the central bank. Reducing uncertainty about cost-push shocks is thus welfare detrimental because it exacerbates the reaction of firms to them.

Degree of strategic complementarities and precision of private information

Figure 5.2 represents the ratio of the unconditional expected loss under transparency (*i.e.* with announcement) to the unconditional expected loss under opacity (*i.e.* without announcement) $\mathbb{E}(L_T/L_O)$ as a function of strategic complementarities ξ for three values of precision of firms' information σ^2_ρ. Transparency is welfare detrimental whenever the ratio is larger than one. The model is solved numerically with the following parameter values: $\sigma^2_g = 1$, $\sigma^2_u = 1$, $\sigma^2_\eta = 0.2$, $\sigma^2_\mu = 0.2$, and $\lambda = 1$.

Transparency is welfare detrimental when the negative uncertainty effect with respect to cost-push shocks dominates both positive incentive and uncertainty effects with respect to demand shocks. Removing uncertainty about cost-push shocks is highly relevant either when higher-order expectations are given a large weight or when firms have very noisy information about them.

Figure 5.2 shows that transparency is welfare detrimental when the degree of strategic complementarities $(1 - \xi)$ is high. Price setting in an economy with a high degree of strategic complementarities is characterized by two intertwined features. First, prices are mainly determined by cost-push shocks when complementarities are high because demand shocks have a limited impact on prices as the economy is highly extensive. Second, firms are more sensitive to other firms' pricing decision. This implies that, with increasing strategic complementarities, firms put an increasing weight on higher-order expectations of cost-push shocks. In this context, the detrimental effect of transparency is driven by the negative uncertainty effect related to cost-push shocks. Indeed, when strategic complementarities are strong, transparency, by reducing higher-order uncertainty, induces firms to strongly react to cost-push shocks.

The precision of firms' private information strongly influences the effects at stake. In the case where firms' private information is very noisy, the detrimental uncertainty effect of transparency dominates its positive incentive effect. When firms already have precise private information, reducing uncertainty on fundamental shocks and higher-order expectations has a relatively small negative effect compared to the positive incentive effect. So, transparency is welfare detrimental when complementarities are high and as long as firms' private information is not too precise.

Relative importance of cost-push shocks

Figure 5.3 represents the ratio $\mathbb{E}(L_T/L_O)$ as a function of the variance of cost-push shocks for three levels of strategic complementarities. Other parameter values are $\sigma_g^2 = 1$, $\sigma_\eta^2 = 0.2$, $\sigma_\mu^2 = 0.2\sigma_u^2$, $\sigma_\rho^2 = 0.2\sigma_u^2$, and $\lambda = 1$.

The variance of cost-push shocks σ_u^2 captures the importance of cost-push shocks in the economy. When there is no cost-push shock ($\sigma_u^2 = 0$), the question of transparency is irrelevant to welfare whatever the degree of strategic complementarities. As the central bank exclusively responds

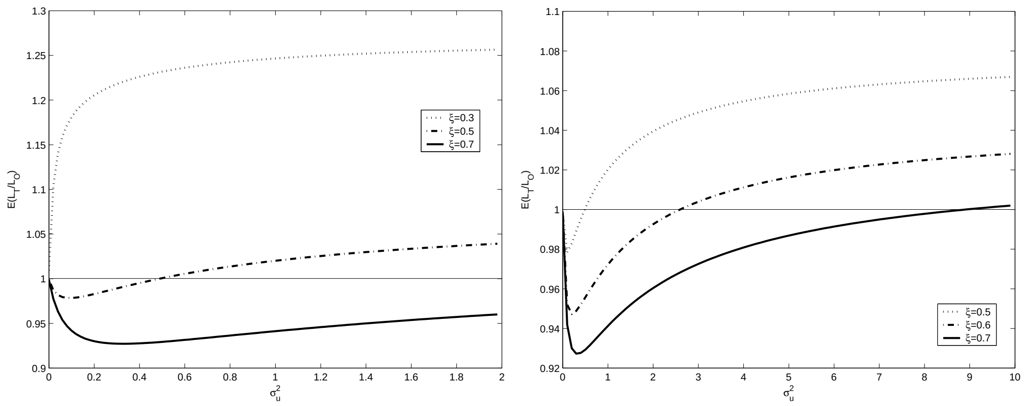

Figure 5.3: Welfare effect of transparency: impact of σ_u^2

to demand shocks, firms perfectly interpret the rationale behind the monetary instrument even under opacity. So, the optimal monetary policy and the economic outcome cannot be distinguished between opacity and transparency.

However, as soon as σ_u^2 increases, the first panel of figure 5.3 shows that the welfare effect of transparency depends on both the degree of strategic complementarities and the importance of cost-push shocks in the economy, relative to demand shocks. As discussed in the previous section, transparency tends to improve welfare when complementarities are weak. But whatever the degree of strategic complementarities, transparency turns out to be welfare detrimental as the relative importance of cost-push shocks increases. Indeed, since cost-push shocks cannot be neutralized by the central bank, the detrimental uncertainty effect of transparency dominates as cost-push shocks become more relevant. The second panel of figure 5.3 allows the variance of cost-push shocks to become very large. Transparency is welfare detrimental even in the case of low complementarities ($\xi = 0.7$) when the importance of cost-push shocks is very high relative to that of demand shocks.

Central bank's preference for output gap stabilization

Figure 5.4 illustrates the ratio $\mathbb{E}(L_T/L_O)$ as a function of σ_u^2 for three levels of λ, the weight the central bank assigns to output gap variability. The parameter values used for the simulation are $\sigma_g^2 = 1$, $\sigma_\eta^2 = 0.2$, $\sigma_\mu^2 = 0.2\sigma_u^2$,

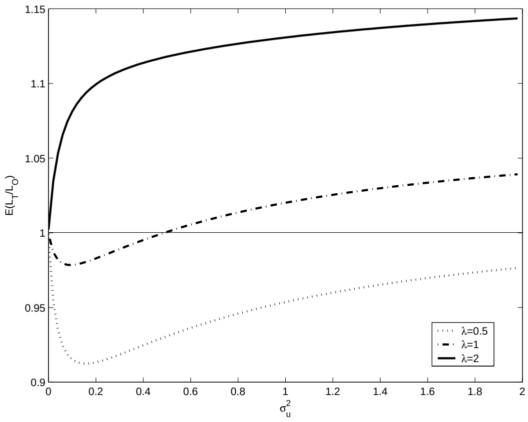

Figure 5.4: Welfare effect of transparency: impact of λ

$\sigma_\rho^2 = 0.2\sigma_u^2$, and $\xi = 0.5$.

It turns out that transparency is welfare improving when the central bank is more inclined towards price stabilization. Indeed, the central bank more effectively influences firms' behaviour and thus the price level when it is transparent. As the central bank becomes more inclined towards price level stabilization (λ falls), the optimal central bank's response to cost-push shocks under opacity becomes stronger. Indeed, as the central bank's influence on firms' behaviour is limited under opacity, it finds it optimal to respond more strongly to shocks to better control the price level. In order to reduce price variability, the central bank more strongly expands or contracts nominal aggregate demand subsequent to cost-push shocks. This makes the monetary instrument more informative about cost-push shocks and considerably reduces the negative uncertainty effect of transparency.

Precision of central bank's signal on cost-push shocks

Figure 5.5 illustrates the ratio $\mathbb{E}(L_T/L_O)$ as a function of the precision of central bank's information on cost-push shocks σ_μ^2 for three levels of ξ. The parameter values used for the simulation are $\sigma_g^2 = 1$, $\sigma_u^2 = 1$, $\sigma_\eta^2 = 0.2$, $\sigma_\rho^2 = 0.2$, and $\lambda = 1$.

This figure shows that transparency is welfare improving as the precision of central bank's signal on cost-push shocks decreases. The intuition is straightforward. Transparency is welfare detrimental when it exacerbates firms' reaction to cost-push shocks. But with poorly accurate central bank's

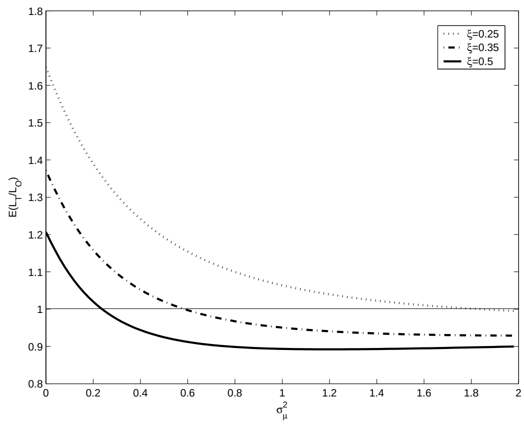

Figure 5.5: Welfare effect of transparency: impact of σ_μ^2

information about cost-push shocks, the announcement does not contain much valuable information about them. As more accurate information on cost-push shocks exacerbates firms' reaction, noisy central bank's information reduces the pertinence of the announcement with respect to cost-push shocks. But, as transparency does not provide much information about cost-push shocks when σ_μ^2 is large, it provides firms with valuable information about demand shocks and central bank's response to them.

When the economy is exclusively hit by demand shocks, transparency allows the central bank to better stabilize the economy since firms know the policy implemented by the central bank. With both demand and cost-push shocks hitting the economy and imprecise central bank's information about cost-push shocks, transparency also improves the neutralization of demand shocks without increasing too much the loss due to cost-push shocks.

Discussion

Our framework potentially rationalizes the recent trend towards transparency in the conduct of monetary policy with respect to a couple of stylized facts. First, the occurrence and amplitude of cost-push shocks have declined over the last decades.[21] Our model suggests that economic transparency turns out to be more beneficial as the economy becomes less sensitive to cost-push shocks. Second, central banks are more inclined towards price stability today than they were in the past. Indeed, the recent switch

[21] See Blanchard and Simon (2001) and Andersen and Wascher (2001).

from secrecy to transparency is often motivated by the will of central banks to publicly reveal their intention to stabilize prices.[22] In this respect, our model suggests that stronger price stabilization calls for higher economic transparency. Since the main aim of political transparency (openness about policy objective, explicit inflation target) is better price stabilization, our result highlights that economic transparency should go along with political transparency.

5.5 Conclusion

This chapter analyzes the welfare effects of economic transparency in the conduct of monetary policy with imperfect common knowledge on the state of the economy. The main characteristic of our analysis is to recognize that monetary policy entails a dual role: the instrument of the central bank is both an action that stabilizes the economy and a signal that partially reveals to firms the central bank's assessment of the state of the economy. We derive both the optimal monetary policy and the optimal central bank's disclosure.

The notion of transparency considered in this chapter is the following. The observation of the monetary instrument does not allow firms to disentangle the central bank's opinion about each shock. A transparent central bank removes this uncertainty by disclosing an additional announcement that explains to the private sector the rationale behind its instrument. Under opacity, firms are unable to perfectly disentangle the central bank's signals responsible for the instrument. So, the central bank chooses its instrument by optimally balancing its action and information purposes. By contrast, under transparency, the central bank allows firms to identify the rationale behind the instrument and implements the policy that is optimal in the perspective of its sole action purpose.

In this context, we show that transparency is welfare increasing (i) when the degree of strategic complementarities is low, (ii) when the economy is not too much affected by cost-push shocks, (iii) when the central bank is more inclined towards price stabilization, (iv) when firms have relatively precise private information, and (v) when the central bank has information that is relatively precise on demand shocks and relatively imprecise on cost-

[22]See Geraats (2002) and Rogoff (2003).

push shocks.

This result rationalizes the increase in central bank's transparency in the current context where cost-push shocks have a relatively low impact on the economic development. Since central banks that assign a large weight on price stabilization tend to be transparent with respect to their political targets, our framework suggests that economic transparency should go along with political transparency.

5.A Appendix: Linear resolutions

This appendix solves the rational expectations equilibrium for the pricing rule of firms given by equation (5.7) and (5.9) under opacity and under transparency.

Opacity case

We first postulate that the optimal price of firm i is a linear combination of its two signals

$$p_i = \gamma_1 u_i + \gamma_2 I.$$

The optimal weights γ_1 and γ_2 depend on firms' expectations about the pricing behaviour of other firms. The conditional estimate of the average price is therefore given by

$$\mathbb{E}_i(p) = \gamma_1 \mathbb{E}_i(u) + \gamma_2 I.$$

Plugging $\mathbb{E}_i(p)$ in the pricing rule (5.4) and replacing the expectations of firm i about shocks yields

$$\begin{aligned} p_i &= (1-\xi)[\gamma_1 \mathbb{E}_i(u) + \gamma_2 I] + \xi I + \xi \mathbb{E}_i(g) + \mathbb{E}_i(u) \\ &= (1-\xi)[\gamma_1(\Omega_{21} u_i + \Omega_{22} I) + \gamma_2 I] \\ &\quad + \xi I + \xi(\Omega_{11} u_i + \Omega_{12} I) + (\Omega_{21} u_i + \Omega_{22} I). \end{aligned}$$

Rearranging gives

$$
\begin{aligned}
p_i &= u_i[(1-\xi)\gamma_1\Omega_{21} + \xi\Omega_{11} + \Omega_{21}] \\
&\quad + I[(1-\xi)(\gamma_1\Omega_{22} + \gamma_2) + \xi(1+\Omega_{12}) + \Omega_{22}].
\end{aligned}
$$

Identifying the coefficients, we get

$$
\begin{aligned}
\gamma_1 &= \frac{\xi\Omega_{11} + \Omega_{21}}{1-(1-\xi)\Omega_{21}} \\
\gamma_2 &= \frac{(1-\xi)\gamma_1\Omega_{22} + \xi(1+\Omega_{12}) + \Omega_{22}}{\xi}.
\end{aligned}
$$

This solution is equivalent to equation (5.8) in the text.

Transparency case

In the case of transparency, the optimal price of firm i is assumed to be a linear combination of its three signals

$$
p_i = \gamma_1 u_i + \gamma_2 I + \gamma_3 g_{cb}.
$$

The optimal weights γ_1, γ_2, and γ_3 depend on firms' expectations about the pricing behaviour of other firms. The conditional estimate of the average price is therefore given by

$$
\mathbb{E}_i(p) = \gamma_1\mathbb{E}_i(u) + \gamma_2 I + \gamma_3 g_{cb}.
$$

Plugging $\mathbb{E}_i(p)$ in the pricing rule (5.4) and replacing the expectations of any firm i about shocks yields

$$
\begin{aligned}
p_i &= (1-\xi)[\gamma_1\mathbb{E}_i(u) + \gamma_2 I + \gamma_3 g_{cb}] + \xi I + \xi\mathbb{E}_i(g) + \mathbb{E}_i(u) \\
&= (1-\xi)[\gamma_1(\Omega_{T21}u_i + \Omega_{T22}I + \Omega_{T23}g_{cb}) + \gamma_2 I + \gamma_3 g_{cb}] \\
&\quad + \xi I + \xi(\Omega_{T11}u_i + \Omega_{T12}I + \Omega_{T13}g_{cb}) + (\Omega_{T21}u_i + \Omega_{T22}I + \Omega_{T23}g_{cb}).
\end{aligned}
$$

Rearranging gives

$$
\begin{aligned}
p_i &= u_i[(1-\xi)\gamma_1\Omega_{T21} + \xi\Omega_{T11} + \Omega_{T21}] \\
&\quad + I[(1-\xi)(\gamma_1\Omega_{T22} + \gamma_2) + \xi(1+\Omega_{T12}) + \Omega_{T22}]
\end{aligned}
$$

$$+g_{cb}[(1-\xi)(\gamma_1\Omega_{T23}+\gamma_3)+\xi\Omega_{T13}+\Omega_{T23}].$$

Identifying the coefficients, we get

$$\begin{aligned}
\gamma_1 &= \frac{\xi\Omega_{T11}+\Omega_{T21}}{1-(1-\xi)\Omega_{T21}} \\
\gamma_2 &= \frac{(1-\xi)\gamma_1\Omega_{T22}+\xi(1+\Omega_{T12})+\Omega_{T22}}{\xi} \\
\gamma_3 &= \frac{(1-\xi)\gamma_1\Omega_{T23}+\xi\Omega_{T13}+\Omega_{T23}}{\xi}.
\end{aligned}$$

This solution is equivalent to equation (5.10) in the text.

Chapter 6

Sticky Information and Monetary Policy

6.1 Introduction

Monetary policy analysis is mainly based on two equations: a Phillips curve that describes the set of feasible inflation-output combinations and an objective function that describes the target of the central bank. The optimality of monetary policy crucially depends on how money is supposed to influence the real economy. This chapter compares optimal monetary policy in economies where money nonneutrality is caused either by sticky price or sticky information.

Standard monetary policy analysis builds on the sticky-price Phillips curve in the tradition of Calvo (1983).[1] In that economy, price adjustment is time-contingent. Every period, each firm can adjust its price with some probability. When a firm has the opportunity to adjust its price, this adjustment may remain effective for future periods. Therefore, the firm sets a price equal to a weighted average of the current and expected future optimal prices. As a result, the Phillips curve is forward-looking. Yet, the sticky-price Phillips curve seems to be inconsistent with some basic empirical evidence.[2] It is especially unable to account for the gradual impact of monetary shocks on inflation. The pertinence of the policy recommendations arising

[1]See Clarida et al. (1999) for a comprehensive overview.

[2]We discuss below the critiques of the sticky-price Phillips curve made by Ball (1994), Fuhrer and Moore (1995), Mankiw (2001), and Mankiw and Reis (2002).

from a model that suffers from obvious anomalies may be thrown into question.

Mankiw and Reis (2002) propose a new Phillips curve where prices are flexible but information spreads slowly through the population. They show that the Phillips curve derived from the sticky-information economy fits the standard facts more accurately. In particular, permanent monetary shocks generate a gradual impact on inflation in the sticky-information Phillips curve in the sense that inflation rises over time and reaches its maximum with a substantial delay after the monetary innovation.

Inflation expectations play an essential role in the determination of current inflation in both models. But while the current inflation depends on current expectations about future inflation in the (forward-looking) sticky-price model, it is past expectations about current inflation and output gap that determine the current inflation in the sticky-information model. This feature accounts for different monetary policy conclusions.

Ball et al. (2005) address the question of the optimal monetary policy in an economy where information is sticky. They derive the optimal policy from a microfounded welfare function that calls for minimizing the relative price dispersion. Their welfare analysis suggests that the central bank should implement any deterministic path of price level since it minimizes price dispersion. But whether the deterministic target path is stationary, expansionary or oscillatory is irrelevant in terms of welfare. As argued by Fuhrer (2002), these conclusions are suspect since the foundations of the welfare losses are peculiar to this model.

By contrast, our analysis focuses on a flexible inflation targeting central bank. The aim of this chapter is to compare the optimal monetary policy in response to cost-push shocks with the sticky-information Phillips curve to the standard analysis based on the sticky-price Phillips curve when the central bank's concern is about inflation. We show that the optimal targeting rule under commitment in the sticky-information model (contrary to sticky price) has no *history-dependence* in the sense of Woodford (1999a) but is forward-looking. As a result, the price level is not stationary in the sticky-information economy.

Section 6.2 presents the sticky-price and sticky-information Phillips curves. We address the extent to which cost-push shocks generate a gradual impact on inflation with sticky information. It turns out that the impact on inflation is gradual when information faster spreads among firms than the shock wears off. The optimal targeting rules are derived in section 6.3 and the economic outcomes are presented in section 6.4. The optimal output gap path is strongly influenced by whether the impulse response of inflation is gradual or not. In particular, when the impact of cost-push shocks on inflation is gradual, the central bank acting under commitment finds it optimal to wait that information disseminates in the population before fighting inflation by strongly contracting the output gap. The central bank contracts the economy to fight inflation when the spread of information is high. This comes from the fact that reducing inflation is much less costly when firms are informed than when they are not. It also suggests that any communication policy that tends to increase the speed of information dissemination deteriorates welfare. Finally, section 6.5 concludes.

6.2 The model

In the following section, we discuss the sticky-price *versus* sticky-information Phillips curve, and motivate our choice to consider an inflation targeting policy objective.

In a monopolistic competitive economy, firms' prices are strategic complements. The optimal price for each firm i in period t is a function of the expected price level p_t and the expected output gap c_t. The linearized expression of the price setting rule is given by

$$p_{i,t} = \mathbb{E}_{i,t}[p_t + \xi c_t], \tag{6.1}$$

where ξ captures the sensitivity of real wage conditions and thereby prices to the output gap.[3] Per definition, the following identity equation holds: $y_t = c_t + p_t$, where y_t is the nominal aggregate demand. Plugging this into the pricing rule (6.1) yields

$$p_{i,t} = \mathbb{E}_{i,t}[(1-\xi)p_t + \xi y_t]. \tag{6.2}$$

The degree of strategic complementarities is driven by the parameter ξ.

[3]See microfoundations in section 1.A.

If ξ is small, the output gap weakly influences the real wage and each firm more strongly weights the average price level into its pricing rule. Note that in the absence of frictions and under perfect common knowledge, the pricing decision (6.2) becomes $p_t = y_t$. In this case, variations of the nominal aggregate demand would have a strong impact on the price level but no impact at all on the output gap. For monetary policy to have a real impact on the economy, some imperfections or rigidities must be added into the model. We first present the standard New Keynesian Phillips curve that is built on the assumption that prices are sticky. Then we turn to the Phillips curve derived by Mankiw and Reis (2002) that assumes sticky information.

6.2.1 Sticky-price Phillips curve

The sticky-price Phillips curve describes how inflation is related to the economic activity and to the private sector's expectations in an economy where price adjustment is time-contingent. Under monopolistic competition, the optimal price a firm would set in each period t is given by (6.2). Yet, prices are assumed to be sticky in this economy. In the tradition of Calvo (1983), each agent is given the opportunity to adjust his price with some probability α every period.[4] When an agent has the opportunity to adjust his price, he recognizes that the price he chooses may remain effective for a while and sets a price $p^*_{i,t}$ equal to a weighted average of current and expected future optimal prices $p_{i,t+j}$ determined by

$$\begin{aligned} p^*_{i,t} &= (1-(1-\alpha)\beta)\sum_{j=0}^{\infty}(1-\alpha)^j\beta^j\mathbb{E}_{i,t}[p_{i,t+j}] && (6.3) \\ &= (1-(1-\alpha)\beta)\sum_{j=0}^{\infty}(1-\alpha)^j\beta^j\mathbb{E}_{i,t}[(1-\xi)p_{t+j}+\xi y_{t+j}] && (6.4) \end{aligned}$$

where $\beta \in (0,1)$ stands for the discount factor of an agent adjusting his price. The private agent assigns less weight to prices that are further in the future since it may get another price adjustment opportunity in the subsequent periods. The next date for price adjustment is geometrically distributed. Since firms are homogeneous with respect to their price setting

[4] Alternatively, Cochrane (1995) shows that this model can be derived from an economy with convex costs of changing prices.

rule and information they have, every firm adjusting its price in period t sets the same price $p^*_{i,t}$. To derive the sticky-price Phillips curve, we express the current price level as

$$p_t = \alpha p^*_{i,t} + (1-\alpha)p_{t-1}. \tag{6.5}$$

Combining (6.3) and (6.5), we get

$$\begin{aligned}
\frac{1-\alpha}{\alpha}(p_t - p_{t-1}) &= (1-(1-\alpha)\beta)\Big[\xi(y_t - p_t) + p_t \\
&\quad + (1-\alpha)\beta\sum_{j=0}^{\infty}(1-\alpha)^j\beta^j\mathbb{E}_{i,t}[(1-\xi)p_{t+1+j} + \xi y_{t+1+j}]\Big] - p_t \\
&= (1-(1-\alpha)\beta)[\xi(y_t - p_t)] + \frac{(1-\alpha)\beta}{\alpha}\mathbb{E}_t(p_{t+1} - p_t),
\end{aligned}$$

which is equivalent to the standard New Keynesian Phillips curve

$$\pi_t = \kappa c_t + \beta\mathbb{E}_t\pi_{t+1} + u_t, \tag{6.6}$$

where $\pi_t = p_t - p_{t-1}$ and $\kappa = \frac{\alpha\xi(1-(1-\alpha)\beta)}{1-\alpha}$. The relation between inflation and output gap is perturbed by the cost-push shock u_t. In the absence of cost-push shocks, the output gap could be filled by stabilizing inflation to zero. The introduction of this shock gives rise to a trade-off between inflation stabilization and output gap stabilization: it changes the equilibrium level of output under flexible prices without changing the efficient level of output. Cost-push shocks are assumed to follow an AR(1)-process in the form $u_t = \rho u_{t-1} + \epsilon_t$, where ϵ_t is white noise.[5]

Many economists have recently emphasized that the sticky-price Phillips curve (6.6) makes some implausible predictions about the effects of monetary policy on the economic activity.[6]

First, Ball (1994) shows that the sticky-price Phillips curve predicts credibly announced disinflation to create a boom rather than a recession. The former statement contradicts the standard observation that slowdowns in money growth caused recessions in the last decades.[7] This counterfactual

[5]Note that adding the cost-push shock u in the Phillips curve (6.6) is equivalent to introducing it into (6.1) since the cost-push shock u is exogeneous.

[6]See Estrella and Fuhrer (2002) and Christiano et al. (2005) for empirical evidence.

[7]One may argue that the announced disinflations were contractionary because of a lack of credibility. However, the prediction of the sticky-price Phillips curve also contradicts the

feature arises because of the forward-looking behaviour of firms. When the central bank announces a future slowdown in money growth, the price development will experience a slowdown as well. But firms that get a price adjusting opportunity between the announcement and the implementation of disinflation recognize that their price will remain effective for a while and act in advance by reducing their price increase before the policy is implemented even if money growth is still unchanged. This implies that the slowdown in price increase will precede the reduction in money growth, which increases real money balances and yields a boom.

Second, Mankiw (2001) documents the fact that monetary shocks have their maximal impact on inflation instantaneously in the sticky-price Phillips curve. Yet, empirical observation shows a substantial delay between monetary shocks and their maximal impact on inflation (*i.e.* the impact on inflation is gradual in the sense that inflation rises after the shock occurs over some quarters).[8]

Third, as underlined by Mankiw and Reis (2002), the sticky-price Phillips curve shows a slightly negative correlation between the change in inflation and the level of economic activity. This contradicts the acceleration phenomenon observed in real data. These empirical anomalies seem to be caused by the lack of inflation inertia. Although the price level is sticky in the sticky-price Phillips curve, the inflation rate itself can change quickly.[9]

The sticky-price Phillips curve also violates the strict natural rate hypothesis according to which no announced monetary policy can keep output permanently high. McCallum (1994) argues that satisfaction of the natural rate hypothesis is a criterion that models used for monetary policy should meet. This hypothesis states that output should be equal to potential output on average, regardless of monetary policy regime, that is

$$\mathbb{E}c_t = 0.$$

The sticky-price Phillips curve violates this hypothesis since permanently falling inflation keeps output permanently high.[10] This is shown by apply-

intuition about the effect of a slowdown in money growth on the real economy.

[8]See Friedman (1968) and Christiano et al. (1996) for empirical evidence.

[9]See Fuhrer and Moore (1995).

[10]Yun (1996) shows that indexing all prices to the steady-state inflation rate makes the sticky-price model conform to the natural rate hypothesis.

ing the unconditional expectation operator $\mathbb{E}(\cdot)$ to (6.6), which can then be written as

$$\mathbb{E}(\pi_t - \beta\pi_{t+1}) = \kappa\xi\mathbb{E}c_t.$$

We recognize from the previous expression that a permanent decline in inflation keeps the output gap permanently positive.

In spite of its poor dynamic properties briefly mentioned above, the sticky-price Phillips curve has become the workhorse for monetary policy analysis. We now turn to the newly competing Phillips curve.

6.2.2 Sticky-information Phillips curve

Mankiw and Reis (2002) propose an alternative Phillips curve derived from an economy where prices are fully flexible but where information spreads slowly through the population.[11] Money non-neutrality arises in the economy because of the limited ability of individuals to process information. The behavioural foundation of their model returns to Friedman's idea that private agents often fail to incorporate all available macroeconomic information into their decision-making. Again, the optimal price an agent would set in each period, if information were perfect, is given by equation (6.2). While an agent can adjust his price every period, he only updates his information set on current and future states of the economy with the probability α every period. This means that every period t a fraction α of firms sets its price based on available information in period t while the remaining fraction $1-\alpha$ of firms sets its price in period t on past information about current period t. More precisely, the fraction of firms that sets its price based on information available in period $t-j$ is given by $\alpha(1-\alpha)^j$ for $\forall j \geq 0$. Information includes all variables that are relevant to the development of economic outcomes.[12] On receiving an information update, a rational agent computes his optimal prices path for the current and all future periods (based on that

[11] Lucas (1972) first underlines that real effects of purely nominal disturbances result from imperfect information. However, his model predicts only highly transitory effects on real activity because common knowledge is achieved immediately in the subsequent period after a shock. By contrast, information in the model of Mankiw and Reis (2002) literally never becomes common knowledge.

[12] Note that models considered in the previous chapters formalize imperfect common knowledge by assuming that all firms get imperfect and differential information about the economy. By contrast, the model of Mankiw and Reis assumes that some firms get perfect information while others no information at all.

information). Therefore, the price an agent sets in any period t is the optimal price for the period t expected at the date of the last information update, *i.e.* $\mathbb{E}_{t-j}p_{i,t}$ if his last information update occurred j periods ago.

The price level is a weighted average of current and past expectations of the current optimal price (6.1)

$$\begin{aligned} p_t &= \alpha \sum_{j=0}^{\infty} (1-\alpha)^j \mathbb{E}_{t-j} p_{i,t} \\ &= \alpha \sum_{j=0}^{\infty} (1-\alpha)^j \mathbb{E}_{t-j} (p_t + \xi c_t). \end{aligned} \tag{6.7}$$

To derive the sticky-information Phillips curve, we rewrite (6.7) as

$$p_t = \frac{\alpha\xi}{1-\alpha} c_t + \alpha \sum_{j=0}^{\infty} (1-\alpha)^j \mathbb{E}_{t-1-j} (p_t + \xi c_t). \tag{6.8}$$

Expressing (6.7) as in the previous period yields

$$p_{t-1} = \alpha \sum_{j=0}^{\infty} (1-\alpha)^j \mathbb{E}_{t-1-j} (p_{t-1} + \xi c_{t-1}). \tag{6.9}$$

Subtracting (6.9) from (6.8), we get the sticky-information Phillips curve

$$\pi_t = \frac{\alpha\xi}{1-\alpha} c_t + \alpha \sum_{j=0}^{\infty} (1-\alpha)^j \mathbb{E}_{t-1-j} (\pi_t + \xi \Delta c_t) + u_t, \tag{6.10}$$

where $\pi_t = p_t - p_{t-1}$ and $\Delta c_t = c_t - c_{t-1}$. Again, we assume that the inflation-output gap relation is disturbed by the introduction of the cost-push shock u_t in the absence of which monetary policy would be trivial (as it would simultaneously stabilize inflation by closing the output gap). Cost-push shocks are assumed to follow an AR(1)-process in the form $u_t = \rho u_{t-1} + \epsilon_t$, where ϵ_t is white noise.

Mankiw and Reis (2002) show that the sticky-information Phillips curve fits the standard facts more accurately. First, disinflation always causes a contraction, even if pre-announced. Monetary policy is neutral in the extent that it is common knowledge among all firms. The degree of common knowledge in the sticky-information Phillips curve increases with the fraction of informed firms, that is with the length of the pre-announcement. Monetary policy is common knowledge only in the limit when it is announced an infinite number of periods before its implementation such that all firms are informed. When the announcement occurs some periods before implementation, the degree of common knowledge increases compared to the case without pre-announcement. This reduces the detrimental effect of disinflation but does not remove it totally.

Second, monetary policy shocks have their maximum impact on inflation with a substantial delay. The intuition behind the hump-shaped response of inflation is as follows. Suppose a sudden permanent increase in money supply. Since prices are flexible, a firm updating its information in period t decides its future price path following two reasonings. On the one hand, abstracting from strategic complementarities ($\xi = 1$), fundamentals call for a unique price increase in the updating period. This would imply a maximal impact of the monetary shock on inflation at the date of the shock since the fraction of firms updating subsequently their information for the first time $\alpha(1-\alpha)^j$ decreases over time. However, on the other hand, strategic motives incite firms to raise their price only when others raise it as well. As a consequence, firms updating their information at the date of the shock t plan to increase their rise in price over time because the coordination motive incites them to "wait" that others raise their price as well. As a result of both effects, the impact of new information on first updating firms is limited as the coordination motive prevents them to fully react immediately.

And third, the sticky-information model can explain the acceleration phenomenon: inflation is positively correlated with output gap.

The sticky-information Phillips curve does also satisfy the strict natural rate hypothesis since no announced monetary policy can permanently increase the output. By applying the unconditional expectation to the Phillips curve (6.10) and under the assumption of perfect foresight (*i.e.* all agents know the true state of the economy because the last innovation occurred at $t = -\infty$), we obtain

$$\mathbb{E}(c_t) = (1-\alpha)\mathbb{E}(c_{t-1}).$$

The latter expression implies that the output gap converges toward zero, *i.e.* that the sticky-information Phillips curve (6.10) conforms to the natural rate hypothesis.

Delayed and gradual effect on inflation

While the main merit of the sticky-information Phillips curve (6.10) is its power to reproduce the gradual and inertial property of inflation observed in real data, this feature is not inherent to the model but principally depends on the relation between the persistence of shocks hitting the economy and the speed of information dissemination in the population.

Mankiw and Reis (2002) illustrate the gradual impact of *permanent* monetary shocks on inflation when strategic complementarities are relatively strong. As we show below, highly persistent shocks (relative to the speed of information dissemination) and strong complementarities are essential for the sticky-information Phillips curve to create gradual inflation. The contribution of this section is to discuss the parameters configuration for this Phillips curve to yield a delayed and gradual effect of shocks on inflation.[13]

We restrict our analysis to the simple following case. Suppose that the economy is in equilibrium and that the private sector expects it to remain so forever. This initial equilibrium assumption implies that the expectations built before period zero $\mathbb{E}_{-1}(\cdot), \mathbb{E}_{-2}(\cdot), \ldots, \mathbb{E}_{-\infty}(\cdot)$ are all equal to zero. Then, the economy is hit in the initial period 0 by a unique innovation in cost-push shock $\epsilon_0 = u_0$ with known correlation ρ. Since the innovation ϵ_0 is the only innovation in the economy (*i.e.* $\epsilon_t = 0$, $\forall t > 0$), expectations about future economic conditions are all homogeneous regardless of the period of information update. And finally, the rational private sector slowly learns about the initial cost-push innovation and adjusts its expectations.

Under these two assumptions and by restricting our attention to the rational expectation equilibrium, one can rewrite the Phillips curve (6.10) in a more convenient way as

$$\pi_t = a_t c_t - a_{t-1} c_{t-1} + b_t u_0 \qquad \forall t \geq 0, \tag{6.11}$$

[13]Collard and Dellas (2003) address the extent to which an alternative information dissemination scheme yields a gradual inflation response by replacing the random scheme suggested by Calvo by that suggested by Taylor (*i.e.* information update at fixed intervals). They show that sticky information with the Taylor scheme does not lead to gradual inflation. This arises because a long lasting lack of common knowledge is necessary for inflation to be gradual (what is difficult to achieve with Taylor scheme unless updating intervals are rather long).

where

$$a_t = \xi\Big(\Big(\frac{1}{1-\alpha}\Big)^{t+1} - 1\Big) \qquad \text{and}$$

$$b_t = \Big(\frac{\rho}{1-\alpha}\Big)^t.$$

Note that the Phillips curve (6.11) describes the development of the Phillips curve according to a unique innovation at period $t = 0$. This relation becomes steeper and steeper with the information dissemination, moving from a short-run to a long-run Phillips curve.[14] If an additional innovation would occur in an unfolding period, then a *new* short-run Phillips curve would describe the inflation-output combination with respect to this unexpected innovation.

To illustrate the intrinsic gradual inflation of the Phillips curve, we close the model with a rule that links inflation to the output gap. For the sake of simplicity, we assume that inflation and output gap evolve in a symmetric way and set

$$c_t = -\iota\pi_t$$

with $\iota > 0$. Using this we rewrite (6.11) as

$$\begin{aligned}\pi_t &= -\iota a_t \pi_t + \iota a_{t-1}\pi_{t-1} + b_t u_0 \\ &= \frac{b_t}{1+\iota a_t} u_0 + \frac{\iota a_{t-1}}{1+\iota a_t}\pi_{t-1}.\end{aligned}$$

Substituting successively for lagged inflation, one can express current inflation as a function of the initial shock u_0,

$$\pi_t = \Big\{\Psi_t b_t + \sum_{i=1}^{t}\prod_{j=0}^{i-1}(\iota\Psi_{t-j}a_{t-1-j})\Psi_{t-i}b_{t-i}\Big\}u_0 \qquad \forall t \geq 0, \tag{6.12}$$

where

$$\Psi_t = \frac{1}{1+\iota a_t}.$$

We now determine the parameters configuration that leads to a gradual impact of cost-push shocks on inflation, *i.e.* to an increasing inflation over time. We first examine the conditions for inflation to increase from the initial

[14] Note some similarities with our result in chapter 4 section 4.4.7. We show in a different informational context that the slope of the Phillips curve increases with the degree of central bank's transparency.

period of the innovation $t = 0$ to the following period $t = 1$. Inflation in the initial and subsequent periods is given by

$$\begin{aligned} \pi_0 &= \Psi_0 b_0 u_0 \\ \pi_1 &= [\Psi_1 b_1 + \iota \Psi_1 a_0 \Psi_0 b_0] u_0. \end{aligned}$$

Figure 6.1 illustrates the gradual inflation increase from period 0 to period 1: $\Delta = \pi_1 - \pi_0$ as function of the information stickiness α and of the cost-push shocks persistence ρ, the degree of strategic complementarities $1 - \xi$, and the coefficient of the implemented rule ι. The light surface in the figure represents the combination of parameters for which inflation rises from period 0 to period 1 ($\Delta > 0$). Even if the analytical condition for gradual inflation is not tractable, we are able to approximately describe the main trend. The upper plot shows the influence of the information stickiness α and of the cost-push shocks persistence ρ for inflation increase and is computed with $\xi = 0.1$ and $\iota = 0.05$. When the information spreads faster than the shock vanishes, *i.e.* α is greater than $1 - \rho$, the impact of the shock on inflation is increasing between the initial period 0 and period 1. The lower plot shows the influence of the degree of strategic complementarities $1 - \xi$ and the coefficient ι. We observe that inflation rises when complementarities are rather strong. Indeed, as discussed above, it is the slow information dissemination combined with the coordination motive of the pricing equation that gives rise to the increasing inflation. As a result, when complementarities are weak, inflation tends to fall over time. A large coefficient ι also reduces the increase in inflation Δ. When ι is large, the output gap in period 0 is large as well, which implies, according to equation (6.11), a lower inflation in period 1. Consequently, a rule that keeps the output gap large relative to inflation reduces the increasing effect of cost-push shocks on inflation.

Figure 6.2 displays the inflation increase over the first 20 periods following the innovation. The difference $\Delta = \pi_{t+1} - \pi_t$ is computed with a degree of strategic complementarities $\xi = 0.1$, a shock persistence $\rho = 0.8$, and a rule coefficient $\iota = 0.05$. Again the light area illustrates cases for which inflation increases over time. The duration of the inflation increase is determined by the speed of information dissemination. Unless information spreads slower than the shock vanishes (in which case inflation never rises except in the initial period), the duration of inflation increase is higher the

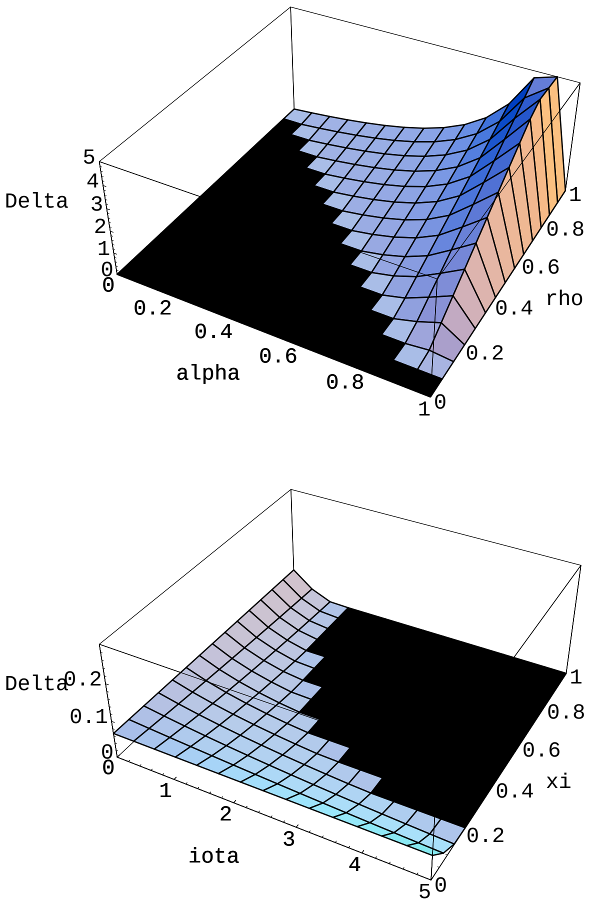

Figure 6.1: Gradual impact on inflation in period one

slower the speed of dissemination. As underlined by Woodford (2003a), the gradual characteristic of inflation dynamics relies on the lack of common knowledge among firms about shocks affecting the economy. Lowering the speed of information dissemination accounts for reducing the degree of common knowledge in every period what extends the duration of increasing inflation.

6.2.3 Central bank's policy objective

The policy objective describes the goals the central bank pursues by conducting monetary policy. Following most of the literature on monetary policy analysis, we assume that the policy objective consists in minimizing the weighted sum of the deviation of inflation π and output gap c from their

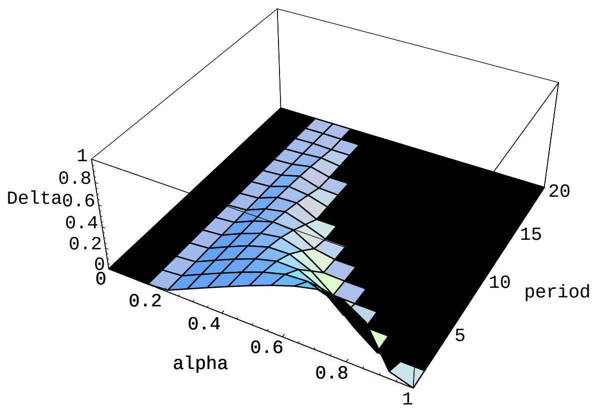

Figure 6.2: Gradual impact on inflation over time

respective target values.[15] Once the target values are normalized to zero, the welfare loss of the central bank in any period t has the quadratic form $\pi_t^2 + \lambda c_t^2$, where λ is a positive relative weight on output deviation. In any period zero, the goal of the central bank is to minimize the discounted sum of welfare losses

$$\min_{I} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_b^t (\pi_t^2 + \lambda c_t^2), \tag{6.13}$$

owing to its instrument I, where β_b is the central bank's discount factor. The policy objective guides the policy maker through the choice of the optimal policy. One may think of two ways of rationalizing the central bank's objective (6.13). Indeed, this objective can be motivated either by a pragmatic or by a microfounded welfare theoretical perspective.[16]

The pragmatic approach rationalizes objective (6.13) by stressing two well-known features. First, monetary policy is recognized to play a crucial role in the determination of inflation. Central bankers are also aware that inflation involves real costs for the economy as a whole. While Fischer and Modigliani (1978) classify potential costs of inflation according to the indexation of the economy,[17] De Long (1997) argues that the experience of

[15]See Walsh (2003a).

[16]See Clarida et al. (1999) section 2.2.

[17]For instance, Fischer and Modigliani (1978) propose an overview of the potential costs of inflation. They classify the costs of inflation according to the extent to which the economy is indexed to inflation. In a fully indexed economy, the real effects of inflation are limited to seigniorage, diversion of resources to transactions, and menu costs. Yet, when inflation is

the 1970s awakened central bankers to the costs of high inflation.[18] Hence, the central bank should keep inflation under control. Second, as described by Phillips curves, monetary policy may influence the real economy in the short run. Models incorporate a combination of long-run monetary neutrality and short-run nominal inertia, such that monetary policy has a potentially significant role in stabilizing the economy. Resting on these two common ideas, the policy objective has been motivated in the literature in a very intuitive way that clearly captures both central bank's tasks: the control of inflation and the stabilization of output gap.

It is worth noting that the policy objective (6.13) has been recently rationalized into fully microfounded models motivating the policy objective from the utility of a representative household. Indeed, by deriving microeconomic foundations of monetary policy analysis, one can show that the welfare maximization of a representative agent calls for stabilization of both the output gap (because of the concavity of household's utility function and Jensen's inequality) and the relative price distortion across goods (because price dispersion leads to inefficient substitution between goods).[19] While this result is robust, the determinants of the variance of relative price distortion depend on the price setting scheme.

In the Calvo sticky-price model, Woodford (2003b) shows that the relative price distortion is related to the inflation squared. Since firms set their price at different periods, price dispersion will be low when the optimal price path remains constant over time, *i.e.* when inflation is minimal. It turns out that the optimal approximated welfare of the representative household yields a policy objective in the form of (6.13).

Ball et al. (2005) derive the microfounded policy objective a central bank should adopt in the case of sticky information. Since prices are flexible in this economy, relative prices are distorted if agents do not share the same information. In this context, the central bank should commit to a deterministic path for the price level in order to insure common information among private agents. Whether the deterministic path is stationary, explosive, or

unanticipated or not fully indexed, the list of potential costs is much longer and includes – to mention but a few – redistributive effects, forecast imprecision, and distortion of relative prices.

[18]See also Shiller (1996).

[19]See Woodford (2003b), chapter 6.2.

oscillatory is irrelevant in terms of welfare.[20]

However, the microfounded approach of central bank policy objective has at least two limitations. First, these models do not seem to capture the real costs of inflation as perceived by real world experiment. For instance, in the sticky-price model, apart from its impact on relative price distortion, inflation *per se* is costless. Second, the use of a representative household may be misleading in deriving the welfare analysis related to monetary policy issues as it ignores the disparate effect of monetary policy across society members. For instance, redistributive effects or forecast imprecisions are absent from microfounded models. The microeconomic derivation of the objective function is on a knife-edge: economists like their models to have microeconomic foundations but microfounded objectives miss the real effects and costs of inflation as described by Fischer and Modigliani (1978), Shiller (1996), and De Long (1997).

Therefore, in this chapter, we adopt the pragmatic approach as in most of the literature. The central bank is assumed to care about inflation instead of relative price distortion. We focus on the inflation targeting objective (6.13) whatever the economy we refer to, even if it could be regarded as microeconomically inconsistent in the case of sticky information. This approach is nevertheless consistent with concerns of central banks in the conduct of monetary policy in reality.[21]

6.3 Optimal stabilization policy

The central bank's optimal policy consists of choosing the time path of inflation-output combinations that minimize its objective function (6.13), which is subject to the constraints characterized either by the sticky-price Phillips curve (6.6) or by the sticky-information Phillips curve (6.10). We define the optimal monetary policy as a "*specific targeting rule*" in the sense of Svensson (2003). Such rules are expressed as an operational condition for the target variables (π and c) or for forecasts of the target variables. This

[20]Note that alternative information diffusion schemes may lead to different welfare function. For instance, Adam (2006) analyzes monetary policy when firms have limited capacity to process information (following Sims (2003)) and shows that stationary price level targeting minimizes the price dispersion across firms.

[21]See King and Wolman (1996) for example.

allows us to define the optimal path of economic outcomes without specifying the monetary instrument path that the central bank would implement. We abstract from the interest rate or money supply required for implementation. One can however obtain the implied optimal interest rate rule by substituting the inflation-output gap combination resulting from the specific targeting rule in an IS (or aggregate-spending) equation. Or, the implied money supply can be obtained by substituting the inflation-output gap combination in a quantity-theory equation. Since there is currently no consensus about the right specification of the demand side model (in particular of the right IS curve) we leave the demand side unspecified.

We first present the canonical optimal specific targeting rule derived from the sticky-price economy and then turn to the rule in the case of sticky information. While our analysis focuses on the unconstrained optimal monetary policy under commitment, we also present alternative monetary policy designs, namely discretion, myopia, and re-optimized commitment. Contrary to standard literature which distinguishes only discretion from commitment, we introduce myopia which gives useful insights for the sticky-information economy.

6.3.1 Sticky-price economy

The private sector of a sticky-price economy is forward-looking. In a forward-looking system, the present outcome depends not only on the current policy but also on current expectations of future events that will be driven by future policy. The way how the private sector builds its expectations about future events plays an essential role in this environment. In particular, the extent to which the central bank can influence private sector's expectations about its future monetary policy determines the current economic outcome.[22]

Commitment We first derive the optimal monetary policy under the assumption that the central bank can commit to implement in the future the policy it announces at the date of policy optimization. Under commitment, the central bank accounts for its ability to influence private sector's expecta-

[22]Currie and Levine (1993) propose a methodology to derive the optimal policy in forward-looking models.

tions because a precommitment technology is assumed to exist. At the time of optimization, the central bank chooses once and for all the optimal path of inflation-output combinations that minimize its expected loss given by (6.13) subject to the current and future Phillips curves in the form of (6.6). The optimization problem is given by the following Lagrangian:

$$\mathcal{L}_0 = E_0 \sum_{t=0}^{\infty} \beta_b^t \Big\{ (\pi_t^2 + \lambda c_t^2) + \mu_t \Big[\pi_t - \kappa c_t - \beta E_t \pi_{t+1} - u_t \Big] \Big\}, \tag{6.14}$$

where μ_t is the Lagrange multiplier associated with the Phillips curve. Differentiating with respect to π_t and c_t for any $t \geq 0$ yields the first-order conditions

$$\begin{aligned} \frac{\partial \mathcal{L}_0}{\partial \pi_t} &= 2\pi_t + \mu_t - \mu_{t-1} = 0 \\ \frac{\partial \mathcal{L}_0}{\partial c_t} &= 2\lambda c_t + \mu_t \kappa = 0, \end{aligned}$$

for all $t \geq 0$, with the initial condition $\mu_0 = 0$. Combining both first-order conditions together, the commitment solution for a central bank optimizing (6.14) at date $t = 0$ is given by

$$c_t = -\frac{\kappa}{\lambda}\pi_t \qquad t = 0 \quad \text{and} \tag{6.15}$$

$$c_t - c_{t-1} = -\frac{\kappa}{\lambda}\pi_t \qquad t = 1, 2, \ldots \quad . \tag{6.16}$$

The commitment solution is determined by two different conditions. At the date of optimization, the monetary policy is given by condition (6.15) according to which the central bank contracts the output gap in response to inflationary pressure. This rule is independent from past endogeneous variables. By contrast, the optimal monetary policy for periods subsequent to the date of optimization is given by condition (6.16) according to which the central bank implements a positive inflation whenever the output gap growth is negative. This policy rule minimizes the expected loss (6.13) caused by a positive cost-push shock because it reduces current firms' expectations about future inflation. Indeed, by announcing the targeting rule (6.16) the central bank commits to create a deflation when the output gap growth will be positive (*i.e.* when the negative output gap will converge to zero) what lowers the current expectation about future inflation and thereby the optimal price setting of firms in the initial period. As a result, the targeting rule under commitment is *history-dependent* in the sense of Woodford (1999a): the optimal monetary policy is a function of the previous output gap in a way "*that is unrelated to any constraints that past events impose upon what is technically achievable in the present*" (p. 282).[23] History-dependence leads the central bank to implement a deflation after inflation episodes. Firms' expectations about future deflation reduce the current inflation, which improves welfare.

However, once it has reaped the benefit of firms' expectations about deflation, the central bank faces the temptation to deceive the private sector by renouncing to implement deflation. The optimal monetary policy under commitment suffers from time inconsistency since it yields a special condition for the initial period with respect to the condition for the subsequent periods. Time inconsistency arises because the initial action can be chosen independently of the policy the central bank commits to (it fails to be history-dependent). The policy implemented by the central bank at the date of optimization must not satisfy any consistency with respect to the announcement it makes. Therefore, even in the present environment of perfect information, private agents cannot control whether the announcement made by the central bank about future economic conditions is consistent with the policy the central bank really plans to implement in the future. If the central bank re-optimizes its Lagrangian later on, it would find it optimal to implement condition (6.15) in that period, even if it had committed itself to implementing (6.16) at the previous optimization date. That is what McCallum (2003) calls "strategic incoherence": at the date of optimization, "*the optimizing central bank can see that, if it were to apply the same optimizing procedure again in the future, it would choose to depart from the plan that it is now choosing*" (p. 4). As a result, a re-optimizing central bank would implement in all periods the condition (6.15) which fails to drive firms' expectations in an optimal way.

To cope with strategic incoherence, Woodford (1999a) proposes to conduct monetary policy under a *timeless perspective* according to which the central bank should implement in the optimizing period the policy that would have been optimal to commit to far away in the past. This comes to im-

[23]See also Woodford (1999b).

plement condition (6.16) in the initial period as well. However, since the optimal commitment policy is given by the rules (6.15) in the initial period *and* (6.16) in the subsequent periods, Sauer (2006) shows that, under some conditions, implementing (6.16) in the initial and subsequent periods (timeless perspective) may yield a worst economic outcome than implementing (6.15) in all periods (discretion).

Discretion Discretionary monetary policy is related to the case where no precommitment technology exists. In the absence of any precommitment technology, a central bank cannot credibly influence beliefs and consequently takes private sector expectations as given. The strategic interactions between the central bank and the private sector do not have to be specified.[24] The central bank optimizes its Lagrangian by ignoring its influence on the expectation term $E_t\pi_{t+1}$. In other words, the Phillips curve, under discretion, can be written as $\pi_t = \kappa c_t + q_t$, where q_t stands for the values the central bank takes as given, *i.e.* $\beta E_t\pi_{t+1} + u_t$. The discretionary Lagrangian becomes

$$E_0 \sum_{t=0}^{\infty} \beta_b^t \Big\{ (\pi_t^2 + \lambda c_t^2) + \mu_t \Big[\pi_t - \kappa c_t - q_t \Big] \Big\}, \tag{6.17}$$

and the optimization yields the following inflation-output combination:

$$c_t = -\frac{\kappa}{\lambda}\pi_t \qquad \forall t. \tag{6.18}$$

The discretionary central bank contracts the output whenever inflation is positive and expands it whenever inflation is too low. The discretionary solution is time consistent. Whether the central bank optimizes its Lagrangian (6.17) once and for all at date $t = 0$ or re-optimizes it later on does not alter the optimality of the condition. The optimal discretionary condition (6.18) coincides with condition (6.15) that is optimal in the initial period under commitment. The discretionary policy is equivalent to the policy resulting from a central bank under commitment re-optimizing at each successive date.

[24] Another way to understand discretion, is to say that the central bank moves after the private sector has built its expectation. See Stokey (1989).

Myopia Apart from the usual *discretion* and *commitment* solutions, it is worthwhile, at this point, to introduce a third type of policy: the *myopic* solution. We define as myopic a central bank that chooses it monetary policy in order to minimize the current welfare loss exclusively and ignores the welfare losses in the future periods. Whether a precommitment technology exists or not, has no relevance in this type of policy. The myopic solution is often assimilated, by simplicity, to discretion. The myopic policy design is associated with the case where the discount factor of the central bank β_b approaches zero. The optimal myopic solution is the inflation-output combination that minimizes the current loss $\pi_t^2 + \lambda c_t^2$ under the current restriction (6.6) and is given by

$$c_t = -\frac{\kappa}{\lambda}\pi_t \qquad \forall t.$$

We recognize that the myopic condition coincides with both the discretionary and the initial commitment condition. This statement may help explain why the *absence of a precommitment technology*, the *policy re-optimization*, and *myopia of the central bank* are often interchangeably used.[25] However, we show in the next section that each scenario leads to distinct first-order conditions in the sticky-information economy.

6.3.2 Sticky-information economy

We derive in this section the optimal monetary policy for the sticky-information economy. As in the sticky-price economy, the current economic outcome depends on firms' expectations. This gives rise to potentially different outcomes according to the extent the central bank manages to influence firms' belief. The current economic outcome is driven by firms' past expectations about the current state of the economy. This sharply contrasts with the sticky-price model where the current outcome is determined by current expectations about future inflation. We focus on the optimal monetary policy under commitment and under myopia.[26] The central bank of the

[25] For example, McCallum (1995) says that the discretionary solution concerns the case where "*there is no precommitment technology available to the unconstrained central bank*" and, in the same paper, that a discretionary central bank "*minimizes (its loss) on a period-by-period basis (...).*"

[26] Note that an analytical solution for discretionary policy is not available because the previous output gap is a state variable in the sticky-information Phillips curve and because

sticky-information economy chooses the path of inflation-output combinations that minimizes its welfare loss (6.13) subject to the sticky-information Phillips curves in the form of (6.10). As in the former section, the optimization problem at date $t = 0$ can be determined by the following Lagrangian:

$$E_0 \sum_{t=0}^{\infty} \beta_b^t \Big\{ (\pi_t^2 + \lambda c_t^2) + \mu_t \Big[\pi_t - \frac{\alpha\xi}{1-\alpha} c_t - \alpha \sum_{j=0}^{\infty} (1-\alpha)^j E_{t-1-j}(\pi_t + \xi \Delta c_t) - u_t \Big] \Big\}, \tag{6.19}$$

where μ_t is the Lagrange parameter.

Myopia A myopic central bank minimizes its current loss exclusively and ignores its future losses (*i.e.* the discount factor of the central bank β_b approaches zero). In this case, the central bank minimizes the current loss $\pi_t^2 + \lambda c_t^2$ under the current restriction $\pi_t = \frac{\alpha\xi}{1-\alpha} c_t + q_t$, where $q_t = \alpha \sum_{j=0}^{\infty} (1 - \alpha)^j E_{t-1-j}(\pi_t + \xi \Delta c_t) + u_t$ and stands for the variables that the central bank cannot influence. The myopic central bank ignores the impact of its current policy on future economic outcomes. The optimization process yields the following myopic condition:

$$c_t = -\frac{\alpha\xi}{\lambda(1-\alpha)} \pi_t \qquad \forall t. \tag{6.20}$$

According to this policy, the central bank implements a positive output gap whenever inflation is below its target (and a negative output gap whenever inflation is above its target). This condition is similar to the standard discretionary policy under sticky price. But as we see below, the myopic solution does not coincide with the optimal condition for the initial period of commitment under sticky information.

Commitment Under commitment, the central bank commits itself once and for all to implement a path of inflation-output combinations. The commitment solution describes the unconstrained optimal policy path that minimizes (6.19) when a precommitment technology is assumed to exist. Differentiating (6.19) with respect to π_t and c_t for any $t \geq 0$ yields the first-order

the corresponding value function is time-varying (information spreads over time). Jensen (2005) keeps out of this problem by ignoring the state variable in the sticky-information Phillips curve in an *ad hoc* way.

conditions

$$\frac{\partial \mathcal{L}_0}{\partial \pi_t} = 2\pi_t + \Big(1 - \alpha \sum_{j=0}^{t-1} (1-\alpha)^j\Big)\mu_t = 0$$

$$\frac{\partial \mathcal{L}_0}{\partial c_t} = 2\lambda c_t - \alpha\xi \sum_{j=0}^{t} (1-\alpha)^{j-1}\mu_t + \alpha\beta\xi \sum_{j=0}^{t} (1-\alpha)^j \mu_{t+1} = 0,$$

for all $t \geq 0$. Combining these conditions together, we get the following consolidated first-order conditions:

$$c_t = \frac{\alpha\xi}{\lambda(1-\alpha)}(\beta_b E_t \pi_{t+1} - \pi_t) \qquad \text{for } t = 0,$$

$$c_t = \frac{\alpha\xi}{\lambda(1-\alpha)}\Big(1 + \frac{1}{1-\alpha}\Big)(\beta_b E_t \pi_{t+1} - \pi_t) \qquad \text{for } t = 1,$$

$$c_t = \frac{\alpha\xi}{\lambda(1-\alpha)}\Big(1 + \frac{1}{1-\alpha} + \frac{1}{(1-\alpha)^2}\Big)(\beta_b E_t \pi_{t+1} - \pi_t) \qquad \text{for } t = 2,$$

and so on. Let these optimal conditions be re-written more compactly as

$$c_t = \frac{\xi}{\lambda}\Big(\frac{1}{(1-\alpha)^{t+1}} - 1\Big)(\beta_b E_t \pi_{t+1} - \pi_t) \qquad \forall t. \tag{6.21}$$

We note that the commitment condition for every period is *special*. The impact of an announcement on private sector's expectations increases over time as announcements refer to dates further in the future. An announcement made in period x about period $x+2$ benefits from a higher dissemination through the population than an announcement made in period $x+1$ about period $x+2$. As a result, the policy the central bank commits to accounts for its impact on firms' expectations.

As in the sticky-price model, the commitment solution suffers from time inconsistency. This arises because of the progressive information dissemination: since firms' expectations about current outcome have been mainly formed in the past, the central bank has an incentive to deceive firms by re-optimizing its policy considering past expectations as given. This arises because the plan the central bank committed to in previous periods about the current policy accounted for its impact on past expectations, while in the current period the current policy has no impact on expectations since they have been determined in the past. If the central bank re-optimizes its

Lagrangian (6.19) in a subsequent period, it will find it optimal to adjust its plans accordingly. However, in contrast to the sticky-price model, there is no immediate benefit of commitment in the stick-information economy. Since information progressively spreads through the population, the benefit of commitment depends on the share of the population whose expectations have been influenced by the policy the central bank committed to. This has strong implications for the implementation and credibility of commitment because the central bank cannot reap the benefit of commitment in the initial period as in the sticky-price model but must wait that information spreads. As discussed below, the central bank implements in the first periods under commitment a policy that is inferior to the myopic policy and benefits from commitment only in subsequent periods. This should make it easier to achieve a credible commitment policy in the sticky-information model than in the sticky-price one.

6.4 Economic outcomes

After having derived the optimal targeting rules for central banks under different types of policy design for both the sticky-price and sticky-information economies, we discuss the resulting economic outcomes. In particular, we describe the inflation and output gap responses to cost-push shocks under alternative policy designs and address issues about price level stationarity and credibility of commitment. Impulse responses are simulated with the Matlab-codes for solving rational expectation models developed by Jensen and McCallum.

6.4.1 Sticky-price economy

Figures 6.3 and 6.4 illustrate the economic development over 40 periods in response to a cost-push innovation $u_1 = \epsilon_1 = 1$ in period $t = 1$ under discretion (according to the targeting rule (6.18)) and commitment (according to the targeting rule (6.16)), respectively. The coefficient of correlation of cost-push shocks is assumed to be $\rho = 0.8$. We think of a period as a quarter. The probability of a price adjustment in every period is set to $\alpha = 0.5$ and the degree of strategic complementarity to $1 - \xi = 0.9$. This implies that

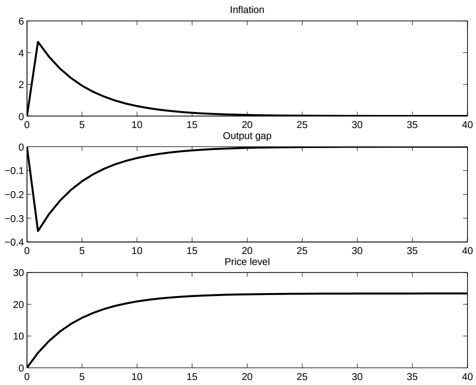

Figure 6.3: Sticky-price: Response to cost-push shocks under discretionary policy

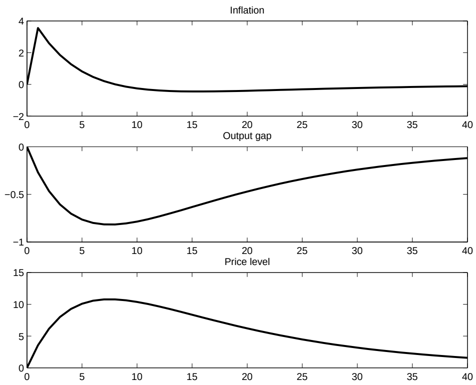

Figure 6.4: Sticky-price: Response to cost-push shocks under commitment

private agents update their information twice a year on average. We choose a central bank's and firms' discount factor $\beta_b = \beta = 0.99$ that corresponds to a real interest rate of 4% a year. The central bank equally weights inflation and output gap deviations in its objective, so $\lambda = 1/16$ since a period is a quarter.

The central bank is supposed to optimize its Lagrangian (6.14) at the date of the innovation.

The cumulative loss (6.13) over 40 periods is lower under commitment than under discretion and amounts to 36.83 and 60.09, respectively. The loss is lower under commitment because the central bank reduces the private sector's expectation about future inflation by credibly committing to implement a deflation when the output gap will converge to its steady state.

Under both discretion and commitment the cost-push innovation has no gradual impact on inflation: inflation is maximal at the date the innovation occurs. However, we note three intertwined differences between economic outcomes under discretion and under commitment. First, while inflation is always nonnegative under discretion, the central bank acting under commitment implements a deflation after some periods. Second, the output gap is U-shaped under commitment (while it is symmetric to inflation under discretion). Third, the price level is stationary under commitment but not under discretion. Appendix 6.A formally shows that the price level converges to zero under commitment but not under discretion. Under discretion, both inflation and the output gap converge to their steady state value after having reached their maximal deviation at the date of the innovation. By contrast, under commitment, inflation is rapidly brought back to zero and then turns to be negative. As a result, the output gap contraction is much more severe and inflation lower under commitment. Discretionary policy yields an excess inflation that results from the so-called stabilization bias.[27] Vestin (2003) demonstrates that the optimal monetary policy of an inflation targeting central bank acting under commitment can be replicated by the discretionary policy of a central bank targeting the price level. This arises because price targeting ensures price level stationarity even under discretion.[28]

The upper panel of figure 6.5 compares the loss under commitment to the loss under discretion over 40 periods. It turns out that commitment yields lower losses in the first nine periods but at the cost of higher losses in subsequent periods. This feature questions the credibility of commitment since the central bank has no incentive to contract the output gap for the price level to return to its initial level once it has reaped the benefit of commitment.

6.4.2 Sticky-information economy

We compute the impulse responses of the sticky-information economy to a cost-push innovation $u_1 = \epsilon_1 = 1$ in period $t = 1$. Again, the central bank optimizes its Lagrangian (6.19) at the date of the innovation. The sticky-information Phillips curve (6.10) must be computed with a finite number

[27]See Clarida et al. (1999).

[28]In a similar exercise, Walsh (2003b) argues that speed limit targeting policies (variation of output gap) are superior to inflation or price level targeting when the Phillips curve is not purely forward looking but contains some backward-looking variables.

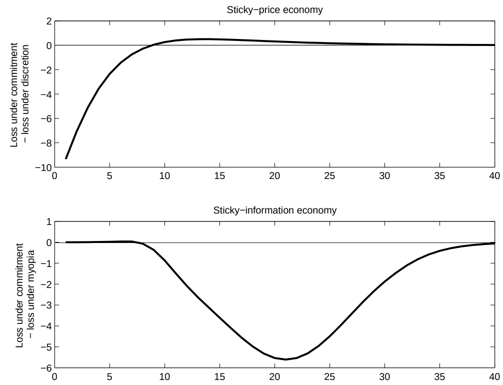

Figure 6.5: Loss under commitment minus loss under discretion

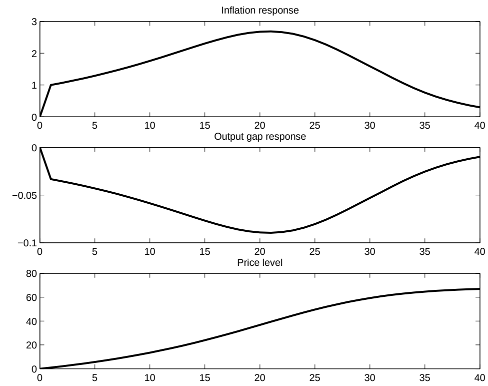

Figure 6.6: Sticky-information: Response to cost-push shocks ($\rho = 0.8$) under myopia

of lagged expectations. We insert 30 lagged expectations in the Phillips curve. This means that the first 30 simulated periods are exact computation of the sticky-information model and that the subsequent periods remain calculated with 30 lags only. Since the probability of information update is set to $\alpha = 0.25$, this approximation is robust as more than 99.98% of the population gets informed about the initial innovation with 30 lagged expectations.

Following Mankiw and Reis (2002), we set the probability of information update α to 0.25 and the degree of strategic complementarity $1 - \xi$ to 0.9. This implies that private agents update their information once a year on average. We choose a central bank's discount factor $\beta_b = 0.99$ that corresponds to a real interest rate of 4% a year. The central bank is assumed to equally weight inflation and output gap deviations in its objective, so $\lambda = 1/16$. We consider two degrees of shock persistence, $\rho = 0.6$ and $\rho = 0.8$.

As discussed in section 6.2.2, since the speed of information dissemina-

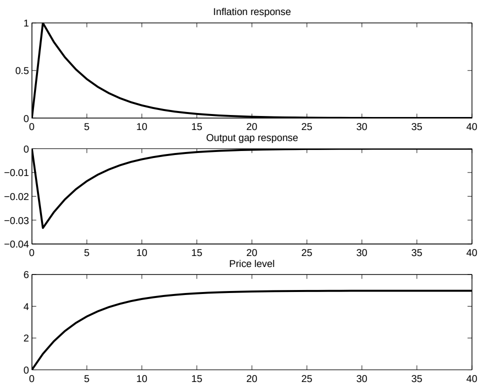

Figure 6.7: Sticky-information: Response to cost-push shocks ($\rho = 0.6$) under myopia

tion is $\alpha = 0.25$, the correlation of cost-push shocks $\rho = 0.6$ illustrates the case where the shock declines faster than information spreads: cost-push shocks are not expected to yield a gradual impact on inflation. By contrast, the impact of shocks on inflation is expected to be gradual with the correlation of $\rho = 0.8$ (information spreads faster than the shock vanishes).

Myopia Figures 6.6 and 6.7 illustrate the impulse responses for a myopic central bank (targeting rule (6.20)) with the coefficients of correlation of cost-push shocks $\rho = 0.8$ and $\rho = 0.6$, respectively.

Under myopia, the central bank contracts the output gap whenever inflation is above target and proportionally to inflation deviation. The degree of shocks persistence ρ determines whether inflation (and the output gap) rises over time or whether it reaches its maximum at the date of the innovation. Apart from the possible gradual increase in deviation over time when shocks persistence is high relative to the speed of information dissemination, the economic outcome under myopia in the sticky-information model is qualitatively similar to discretion in the sticky-price model. Inflation and output gap evolve symmetrically, and the price level is not stationary but attains a higher level after the occurrence of a positive cost-push innovation.

The persistence of shocks has a large implication in terms of welfare. While the cumulative loss (6.13) over 40 periods amounts to 2.72 when the persistence is set to $\rho = 0.6$, it amounts to 111.42 with $\rho = 0.8$. Alternatively, for a given degree of shocks persistence, reducing the speed of information dissemination weakens the hump-shape path of inflation (or even

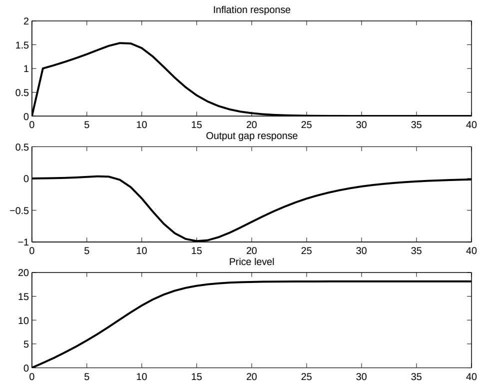

Figure 6.8: Sticky-information: Response to cost-push shocks ($\rho = 0.8$) under commitment

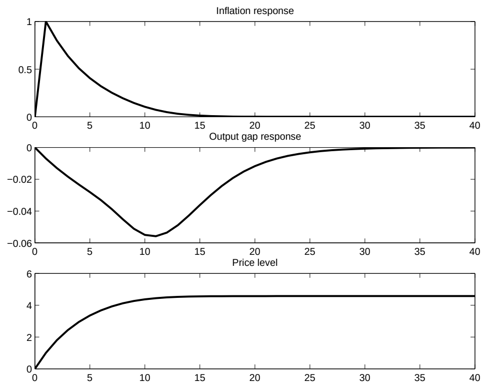

Figure 6.9: Sticky-information: Response to cost-push shocks ($\rho = 0.6$) under commitment

eliminates it totally) and reduces thereby the cumulative loss. As a result, a communication policy that tends to reduce the speed of information dissemination improves welfare.

Commitment Figures 6.8 and 6.9 show the impulse responses for a central bank acting under commitment (targeting rule (6.21)) with the coefficients of correlation of the cost-push shocks $\rho = 0.8$ and $\rho = 0.6$, respectively.

Again, the degree of persistence of shocks determines whether inflation rises over time and has a large impact on welfare. The cumulative loss amounts to 2.69 when the persistence is $\rho = 0.6$ and to 27.32 when $\rho = 0.8$. Comparing these losses with that under myopia, it turns out that commitment is particularly beneficial when cost-push shocks are highly persistent and have a gradual impact on inflation (or when information spreads slowly). Indeed, the cumulative loss under commitment represents 98.89% and 24.52% of that under myopia when $\rho = 0.6$ and $\rho = 0.8$, respectively.

When cost-push shocks are highly persistent, figure 6.8 shows that the central bank finds it optimal not to contract the output gap in the first periods following the cost-push innovation. The central bank even slightly expands the output gap as long as inflation increases. This arises because, as equation (6.10) indicates, inflation is a function of the expected output gap growth. Hence, expanding the output gap in the first periods allows the central bank to strongly fight inflation later on by then contracting the output gap in a larger extent than it would be able to do if the output gap would not be slightly positive. Interestingly, this result suggests that the central bank waits that information largely spreads among the population to fight inflation by contracting the output gap. That is to say that the central bank does not find it optimal to implement a contractive policy as long as information dissemination is low.[29]

When cost-push shocks are slightly persistent, figure 6.9 shows that the central bank never expands the output gap in response to the cost-push innovation. However, the strength of the output gap contraction increases in the first periods suggesting that information dissemination reinforces the desire of the central bank to fight inflation by creating a stronger recession.

One can easily show that the cumulative loss increases with the speed of information dissemination.[30] Faster dissemination increases the degree of common knowledge of cost-push shocks and exacerbates firms' reaction to them. While there is no role for central bank's communication in the present model, this analysis suggests however that increasing transparency about cost-push shocks is welfare detrimental. This conclusion is in line with chapter 5 that explicitly addresses the question of central bank's communication.

The price level is not stationary in the sticky-information even under commitment. As the first and third panels of figures 6.8 and 6.9 show, the

[29]This result seems to support our analysis of chatper 4. In that chapter, we argue that opacity of the central bank with respect to its instrument can rationalize an accommodating monetary policy in response to a positive cost-push shock.

[30]For example, the cumulative loss under commitment when the cost-push shock persistence is $\rho = 0.8$ accounts to 40.47 with an information dissemination speed of $\alpha = 0.3$ and to 19.65 with $\alpha = 0.22$.

central bank never implements a deflation and the price level does not return to its initial value. This result sharply contrasts with the sticky-price economy where the central bank commits to implement a deflation later on to reduce the current expectation of firms about future inflation. Since the sticky-information economy is not forward-looking, committing to implement a deflation in the future has no beneficial impact on welfare. This has some implication for the credibility of commitment with sticky information. While the central bank in the sticky-price economy faces the temptation to reap the benefit of commitment in the first periods without implementing the promised deflation in subsequent periods, the central bank in the sticky-information economy benefits from commitment in subsequent periods only at the cost of lower welfare in the first periods following the cost-push innovation. As the second panel of figure 6.5 illustrates, the loss under commitment is larger than that under myopia in the first nine periods and smaller afterwards. This does not remove the strategic incoherence and the temptation of the central bank to depart from the announced commitment by re-optimizing its policy later on (and considering past expectations as given), but the central bank can benefit from commitment at some initial costs.

6.5 Conclusion

Most of monetary policy analysis in the past has focused on an economy with monetary nonneutrality arising because of time-contingent price setting. Yet, the sticky-price model makes counterfactual predictions about the effects of monetary policy on inflation. One may therefore question the pertinence of monetary policy recommendations drawn from a model that clearly contradicts empirical evidence. As Mankiw and Reis (2002) show, substituting stickiness in price setting by stickiness in information updating yields a model that performs better at fitting the stylized facts about the output-inflation trade-off.

This chapter presents some implications for the optimal monetary policy in the case of inflation targeting when monetary nonneutrality arises because of information stickiness. The main distinction between both sticky-price and sticky-information model relies on how expectations influence inflation. While current expectations about future inflation influence current inflation in the sticky-price economy, it is past expectations about current inflation (and output gap) that matter for current inflation in the sticky-information economy.

The absence of forward-looking variables in the sticky-information Phillips curve has strong implications for the stationarity of the price level. While the central bank of the sticky-price economy acting under commitment implements a deflation after inflation episodes in order to ensure price level stationarity, the central bank of the sticky-information economy does not commit to balance inflation with subsequent deflation. As a result, the price level is not stationary in the sticky-information economy. The history-dependence of the optimal targeting rule under commitment accounts for the price level stationarity in the sticky-price economy. The central bank commits to return to the initial price level for reducing current expectations about future inflation. But since the sticky-information Phillips curve is not forward-looking, committing to price level stationarity does not improve the trade-off the central bank faces. As a result, the optimal targeting rule under commitment in the sticky-information model is not history-dependent but forward-looking.

Our analysis emphasizes the relevance of the persistence of cost-push shocks relative to the speed of information dissemination through the population for the impulse response of inflation and for the conduct of monetary policy. We show that cost-push shocks have a gradual impact on inflation only in the extent that information spreads faster among firms than shocks vanish. The response of the central bank also depends on the information dissemination in the population. The strength of output gap contraction in response to a positive cost-push innovation increases with information dissemination. In the particular case where cost-push shocks have a gradual impact on inflation, the central bank finds it optimal to wait some periods that information spreads before fighting inflation with strong output gap contractions. Hence, the central bank expands the economy as long as the private sector has poor information. This suggests that central banks should take the persistence of shocks and the speed of information dissemination into serious consideration for conducting their policy.

6.A Appendix: Price level stationarity under commitment in the sticky-price economy

This section shows that the optimal monetary policy under commitment in response to cost-push shocks leads to price level stationarity.

In order to show this property of the sticky-price Phillips curve, it is useful to rewrite (6.6) as an expectational difference equation

$$\beta \mathbb{E}_t p_{t+1} - (1+\beta)p_t + p_{t-1} = -(\kappa c_t + u_t) \tag{6.22}$$

and solve it by the method explained in Sargent (1987). First, we express with an asterisk all variables expected at date t. Second, we use the lag operator l defined by $l\mathbb{E}_t p_t = \mathbb{E}_t p_{t-1}$ and its inverse, the forward operator $f = l^{-1}$. (6.22) can then be rewritten as

$$\Big(\beta f^2 - (1+\beta)f + 1\Big) l p_t^* = -(\kappa c_t^* + u_t^*). \tag{6.23}$$

The quadratic expression $(\beta x^2 - (1+\beta)x + 1)$ has two positive roots, namely 1 and $\frac{1}{\beta}$. Then (6.23) becomes

$$\begin{aligned}
\beta(f-1)(f-\frac{1}{\beta}) l p_t^* &= -(\kappa c_t^* + u_t) \\
\beta(f-1)(f\beta-1) l p_t^* &= -\beta(\kappa c_t^* + u_t) \\
(1-l)p_t^* &= (1-f\beta)^{-1}(\kappa c_t^* + u_t) \\
p_t &= p_{t-1} + \sum_{j=0}^{\infty} \beta^j \mathbb{E}_t(\kappa c_{t+j} + u_{t+j}).
\end{aligned} \tag{6.24}$$

We seek to determine the price level at some period T sufficiently far away after the realisation of a cost-push shock u_0. More particularly, we show that inflation has an additive permanent effect on the price level under discretionary monetary policy while the price level returns to its initial position under commitment.

Substituting the discretionary first-order condition (6.18) into (6.24) yields

$$p_T = p_{T-1} + \kappa\Big(-\frac{\kappa}{\lambda}(p_T - p_{T-1})\Big) + u_T + \sum_{j=1}^{\infty} \beta^j \mathbb{E}_T(\kappa c_{T+j} + u_{T+j})$$

$$\Big(1+\frac{\kappa^2}{\lambda}\Big)p_T \;=\; \Big(1+\frac{\kappa^2}{\lambda}\Big)p_{T-1} + \underbrace{u_T + \sum_{j=1}^{\infty}\beta^j \mathbb{E}_T(\kappa c_{T+j} + u_{T+j})}_{\delta}. \qquad (6.25)$$

Setting T sufficiently large, equation (6.25) expresses the price level in a period where the real economy is not affected by the cost-push shock u_0 any more. Future output gaps and cost-push shocks can be approximated to be zero: $\lim_{T\to\infty}\delta = 0$. The price level development does not converge to its initial value of zero since $p_T = p_{T-1}$. Inflation is however stabilized at zero.

We now substitute successively the first-order condition under commitment (6.16) into (6.24). This yields

$$\begin{aligned}
p_T &= p_{T-1} - \kappa\Big(\frac{\kappa}{\lambda}(p_T - p_{T-1}) - c_{T-1}\Big) + u_T + \sum_{j=1}^{\infty}\beta^j \mathbb{E}_T(\kappa c_{T+j} + u_{T+j}) \\
\Big(1+\frac{\kappa^2}{\lambda}\Big)p_T &= \Big(1+\frac{\kappa^2}{\lambda}\Big)p_{T-1} - \kappa\Big(\frac{\kappa}{\lambda}(p_{T-1} - p_{T-2}) - c_{T-2}\Big) + \delta \\
&= p_{T-1} + \kappa\Big(\frac{\kappa}{\lambda}p_{T-2} - \frac{\kappa}{\lambda}(p_{T-2} - p_{T-3}) + c_{T-3}\Big) + \delta \\
\Big(1+\frac{\kappa^2}{\lambda}\Big)p_T &= p_{T-1} + \delta. \qquad (6.26)
\end{aligned}$$

Expression (6.26) indicates that the price level converges toward its initial level of zero with speed $\frac{\lambda}{\lambda+\kappa^2}$: the price level is stationary when the monetary policy is conducted under commitment.

As equation (6.25) indicates and figure 6.3 illustrates, the discretionary monetary policy stabilizes inflation but not the price level: its remains higher than its initial level after the shock has occured. By contrast, equation (6.26) and figure 6.4 show that the price level returns to its initial level under commitment.

Chapter 7

Conclusion

This thesis addresses issues of monetary policy in the context of strategic complementarities under imperfect common knowledge and underlines the relevance of central bank's communication.

In particular, our main contributions are to show that

- central bank's transparency deteriorates the precision of its information and disclosure when the central bank assesses economic conditions by observing the economy,
- central bank's transparency stabilizes the economy when the central bank implements a monetary instrument based on poorly accurate information,
- the optimal monetary instrument is a function of central bank's communication strategy,
- central bank's opacity increases the cost of stabilizing inflation (in terms of output gap) and rationalizes an accommodating response to cost-push shocks,
- central bank's transparency exacerbates firms' reaction to cost-push shocks, which is welfare detrimental.

As argued by Geraats (2002), "*the desirability of central bank's transparency depends crucially on the specific context*" (p. 536). Our analysis focuses on different mechanisms and draws different, sometimes opposite, conclusions.

Our results seem however to be robust to the way imperfect common knowledge is formalized. For instance, we show that many conclusions of chapters 4 and 5 where all firms have imperfect differential information are robust to the model of chapter 6 where some firms have perfect information while others have no information.

An interesting direction for future research would be to develop a model that simultaneously accounts for various aspects discussed in this thesis. In particular, we foresee a model where the central bank observes the economy to glean information about economic conditions (endogeneous information), and chooses its optimal monetary instrument and disclosure to stabilize the economy.

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