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Bank capital regulation and monetary policy transmission: an heterogeneous agents approach

Angelo Baglioni

Abstract. *This work deals with the transmission of monetary policy through the bank loan market, in presence of a capital requirement regulation. Unlike standard models, based on the "representative bank" shortcut, we adopt the heterogeneous agents approach: this allows us to explicitly model the strategic interaction between well-capitalized and under-capitalized banks. The main results are the following. (I) Well-capitalized banks are more important, in shaping the adjustment following a monetary policy shock, than what is implied by their relative number over total; this fact strengthens the monetary policy effectiveness. This result holds under two different market structures: monopolistic competition and Cournot oligopoly. (II) The propagation of a monetary policy impulse through the loan market differs considerably, depending on the market structure: under monopolistic competition, strategic complementarity among well-capitalized banks leads to a "multiplier effect"; in the oligopoly framework, an effect of the opposite sign is at work, due to strategic substitutability.*

Keywords: *monetary policy transmission, bank capital regulation, strategic interaction, heterogeneity, market structure.*

JEL: G21, E51-52, E43

1 Introduction and main results[1]

Why heterogeneity?

The transmission of monetary policy through the banking channel has been extensively analyzed, both on theoretical and on empirical grounds. Within this area of research, a relevant issue is the role played by regulation, as the banking sector is heavily regulated by the supervisory authorities. In particular, banks are imposed capital requirements, which set an upper bound to the volume of their loans as a ratio of own equity: how does this regulation modify the reaction of banks to a monetary policy impulse? To what extent the capital constraint, by limiting the scope for expanding the supply of loans, reduces the impact of a monetary policy expansionary intervention?[2]

The present paper provides a contribution in answering the above questions. The innovation we introduce, relative to the existing literature, relies on the heterogeneity approach, which we adopt for the following reason.

Models of bank behavior traditionally rely on the "representative bank" shortcut: the analysis is focussed on the behavior of a single bank; the conclusions are then extended to the whole banking system. This is equivalent to assuming that all banks behave in the same way: in particular, they show the same reaction to monetary policy.

When it is used for analyzing the impact of a capital regulation, this approach reveals all his limits. The representative bank may be either well-capitalized or under-capitalized: in the first case, it is able to expand its supply of loans, following an expansionary monetary policy, as the capital constraint is not actually binding; in the second case, it is not able to do so, as its volume of loans is limited by the lack of own equity. By extending this reasoning to the whole banking system, we may reach two alternative and extreme conclusions: i) if the banking system is well-capitalized, monetary policy is effective through the banking channel; ii) the opposite holds, if the banking system is poorly capitalized. So the representative bank approach points to the existence of two very different equilibria in the loan market, leading to opposite conclusions regarding the transmission of monetary policy through the banking channel.

Now, consider the following issue: what is the impact of monetary policy on the loan market, when both types of banks, well-capitalized and under-capitalized, are present and compete in such a market? The only way the representative bank approach has to tackle such an issue is by taking a crude average of the two extreme equilibria described above, concluding that the impact of monetary policy is proportional to the share of well-capitalized banks over total.

This answer is not correct, as the approach based on heterogeneity is able to show. In particular, the representative agent approach is unable to capture the strategic interaction between well-capitalized and under-capitalized banks:

[1] I wish to thank Andrea Boitani and Domenico Delli Gatti for very useful comments and suggestions. The usual disclaimer applies.

[2] Actually - as we will see below - the capital constraint may reduce the effectiveness of a contractionary monetary policy as well.

when both such types of banks compete in the loan market, their behavior is different from the one they show in the two above-mentioned extreme equilibria. Therefore, the impact of monetary policy on the loan market equilibrium is actually more complex than the one described by the representative bank approach.

In this work, we analyze the transmission of a monetary policy shock, namely a change of the policy interest rate, through the market for bank loans, allowing for the presence of both well-capitalized and under-capitalized banks in such a market. The strategic interaction between those two groups of banks is studied under two quite different specifications of the market structure: (i) monopolistic competition, where banks compete in prices and none of them is able to significantly alter the aggregate outcome; (ii) Cournot oligopoly, where banks compete in quantities and the action of a single agent affects the aggregate outcome. The first environment exhibits strategic complementarity, while the second one is characterized by strategic substitutability.

Main results

1. Well-capitalized banks are more important, in shaping the equilibrium prevailing after a monetary policy shock, than what is implied by their relative number over total; in other words, the equilibrium with heterogeneous banks is "distorted" towards the one where only well-capitalized banks are present. Therefore, the impact of monetary policy through the banking channel is stronger than the one obtained by simply "averaging" the two extreme equilibria (where all banks are either well-capitalized or under-capitalized). This result is "robust", as it holds under both the two different market structures we analyze.

   Under monopolistic competition, the reason behind such a result is that under-capitalized banks exhibit a high degree of real rigidity: the interest rate applied on their loans follows closely the changes of the aggregate loan rate; this (relative) price rigidity, in turn, is due to the fact that under-capitalized banks have to keep a constant volume of loans, because the capital constraint is binding on them. This is not true for well-capitalized banks, which have more room to change their relative price. As a consequence, low capital banks show a higher degree of strategic complementarity than high capital banks do: their pricing behavior is more strongly conditioned by the "imitation effect".

   In the oligopoly framework, under-capitalized banks play the role of "non-responders", as their quantity is fixed. To the contrary, well-capitalized banks exhibit strategic substitutability: then, the presence of "non-responders" induce them to react more strongly to a monetary policy impulse.

2. The propagation of a monetary policy impulse through the loan market differs considerably, depending on the market structure: this is due to the nature of the strategic interaction among well-capitalized banks. Under monopolistic competition, it is characterized by a "multiplier effect"

(which is typical of contexts where the interaction among agents exhibits strategic complementarity): the response of each bank to a central bank intervention is increased by the fact that other banks react as well, leading to an amplification of the aggregate outcome. In the oligopoly framework, an effect of the opposite sign is at work, due to strategic substitutability: the incentive of each bank to pass through the monetary policy impulse to their loan supply is decreased by the reaction of the other banks, weakening the impact of central bank action. These different patterns of aggregate response to a monetary policy shock emerge very clearly when we examine the equilibria with homogeneous high capital banks.

Related literature

The present work is related to two streams of literature, dealing respectively with: i) the transmission of monetary policy through the banking sector; ii) strategic complementarity and heterogeneity.

The first area of research was initiated by the seminal work by Bernanke - Blinder (1988), where the existence of a bank lending channel, complementary to the traditional interest rate channel, was introduced in the macroeconomic framework of the IS-LM model. Following that contribution, several theoretical and empirical studies have stressed the role of the banking system in transmitting monetary policy impulses to the real sector of the economy.[3] Among them, we wish to mention here only a few articles, dealing in particular with the role of bank capital in conditioning the way the banking channel works: Thakor (1996), Holmstrom - Tirole (1997), Repullo - Suarez (2000), Van den Heuvel (2001), Tanaka (2001), Chami - Cosimano (2001). From these models, it is possible to draw the following conclusions: i) the presence of a capital requirement may reduce the effectiveness of monetary policy; ii) a reduction of the level of equity of the banking system lowers the volume of bank credit available to the economy (so-called "credit crunch"). All these studies rely on the assumption that the banking system may be adequately described by a "representative bank": under this regard, they share the drawbacks outlined above.

The second area of research, related to this paper, points to the analysis of strategic interaction among heterogeneous agents. The article by Cooper - John (1988) opened up the way to the study of strategic complementarity and of its consequences for the properties of Nash equilibria. The article by Haltiwanger - Waldman (1991) analyzes the properties of the aggregate behavior of the economy, where heterogeneous agents interact: basically, there are two groups of agents, differing for their degree of strategic complementarity (or substitutability). It comes out that one group of agents may have a disproportionate importance - relative to its own share over the total number of agents - in shaping the aggregate equilibrium. This result may be applied, for instance, to the explanation of the real effects of monetary disturbances: the presence

[3] See the reviews of the literature in the articles by Kashyap - Stein (1994, 1997), Bernanke - Gertler - Gilchrist (1996), Mojon - Smets - Vermeulen (2000), Altunbas - Fazylov - Molyneux (2000).

of even a small number of firms, which do not adjust their price following a nominal shock (because of menu costs and/or near rationality), may cause a significant rigidity of the aggregate level of prices. This creates a fundamental link between the literature on heterogeneity (with strategic complementarity) and the one dealing with money non-neutrality, due to the joint effects of nominal and real rigidities:[4] see Akerlof - Yellen (1985) on near rational behavior and Mankiw (1985) on menu costs.

Plan of the paper

The paper is organized as follows. In the next section, we present a model of monopolistic competition in the market for bank loans, where banks are subject to a capital requirement and they may differ among each other with regard to their equity level. The model is used to analyze the impact of monetary policy on the loan market, under three alternative environments: i) all banks are well-capitalized (so they are not constrained by the capital requirement); ii) all banks are under-capitalized (constrained); iii) both types of banks are present and compete in the market for loans. In Section 3, the same type of analysis is done in the context of Cournot oligopoly. In Section 4 we draw the main conclusions from our analysis.

2 Well-capitalized and under-capitalized banks: a model of monopolistic competition with heterogeneous banks

2.1 Introduction

The market for bank loans is modelled here following the monopolistic competition framework. As the literature[5] in the banking field has shown, banks are able to segment the loan market by keeping private the information on borrowers and by building up customer relationships with them; therefore, borrowers face significant costs if they wish to switch from an existing lending relationship to a new one. As a consequence, bank loans are not perfect substitutes for borrowers. Then it is reasonable to assume that each bank has some market power in the market for loans: in particular, it faces a downward-sloped demand for loans with finite elasticity.

The same assumption that loans are "information intensive" assets implies that firms (at least part of them) cannot easily substitute bank loans with alternative sources of funding, like issuing securities in the open market. This makes firms "bank dependent" to some extent, enabling banks to apply on their loans an interest rate possibly higher than the one prevailing in the securities market.

[4] The links among these bodies of literature are shown by Boitani - Damiani (2000).

[5] See, among others, Sharpe (1990) and Rajan (1992).

Moreover, in this section we assume that banks consider the interest rate applied on loans as their strategic variable; in other words, they engage in *price* competition. More specifically, each of them sets its own interest rate, taking as given the average interest rate prevailing in the loan market at a given date; its choice will be a function of the average loan rate, but not of the interest rate applied by any other single bank, as the number of competing banks is large enough and none of them has such a size as to significantly affect the aggregate outcome. (In other words, each bank is "negligible". In the following section we will address an alternative market structure, namely the Cournot oligopoly, where the strategic variable is the *quantity* of loans and where a bank takes into account the strategies of each other bank).

The purpose of the model is to analyze how monetary policy is transmitted through the banking system. More precisely, we will consider whether a modification of the interest rate prevailing in the bond market (due to an intervention of the central bank) has any impact on the market for loans, modifying the interest rate and the volumes transacted in this market. A crucial feature of the model is that banks are subject to a capital requirement by regulators: we are interested in determining how this regulation affects the transmission of monetary policy through the banking channel.

2.2 Assumptions

Loan market

There are N identical (except for their equity capital) banks competing in the market for bank loans, indexed by $j = 1, ..., N$. Each of them faces the following individual demand schedule: $l_j = \alpha - \beta s_j - \gamma r_A$, where s_j is the spread applied by each bank j, relative to the average interest rate ($s_j \equiv r_j - r_A$, with r_j being the loan interest rate applied by each bank and $r_A = \frac{1}{N}\sum_{j=1}^{N} r_j$); α,β,γ are positive parameters. Thus, the volume of loans granted by each bank is a function of both the relative price (s_j) applied by that bank and the aggregate price (r_A) prevailing in market for loans at a given date.[6] The linear specification may be justified on the following grounds. We want to analyze the impact of a small shock in the monetary policy rate (typically: 25 or 50 basis points) on the equilibrium prevailing in the loan market: therefore, a linear approximation of the loan demand function around the initial equilibrium seems plausible. Needless to say, such specification greatly simplifies our analysis.[7]

Let us make the following assumption here: $\beta > \gamma$. Suppose bank j lowers its own rate r_j, say by Δr_j, and consider two opposite scenarios: (i) bank j is not followed by the other banks, all of them keeping their rate unchanged; (ii)

[6] Of course, the loan demand function adopted here is equivalent to: $l_j = \alpha - \beta r_j + \theta r_A$, where $\theta = \beta - \gamma$. The one chosen in the text enables us to stress the role of the relative price s_j.

[7] In particular, as we are going to see below, the linear specification implies that the coefficients of flexibility and complementarity are constant, enabling us to compare the impact of monetary policy under the three alternative equilibria that will be considered.

all the other banks lower their rate by the same amount Δr_j. It is reasonable to assume that the expansion of loan demand for bank j is greater in the former case - where such bank is presumably able to increase its market share - than in the latter. This is equivalent to assuming that l_j is more affected by a change of the relative price s_j (that's what is going on in case (i)) than by a change of the aggregate price r_A (case (ii)).[8]

The aggregate demand for loans is obtained by summing up the individual ones: $L = \sum_{j=1}^{N} l_j = A - \Gamma \cdot r_A$, where $A = N\alpha$ and $\Gamma = N\gamma$. Of course, through aggregation the individual spreads vanish, so that L is a function only of the aggregate price, i.e. the average interest rate applied by the banking system on loans.

Figure 1 provides a graphical illustration of the loan demand, both at the single bank level (upper picture) and at the aggregate level (lower picture). In order to stress the role of the relative price, the individual loan demand function is drawn in the $l_j - s_j$ space, so for a given level of r_A. Therefore a change, say a decline, of the average interest rate in the loan market makes the individual loan demand schedule shift rightward: for a given level of the spread applied, each bank is able to make a larger volume of loans; notice that this corresponds to a downward movement *along* the aggregate loan demand schedule (see also Figure 2, where a decline of the average rate from r_0^* to r_1^* moves the equilibrium from point A to point B).

Bonds

In addition to loans, banks hold a marketable financial asset (Government bonds). They decide their asset allocation between loans and bonds, taking as given the interest rate (i) earned on bonds: this is the opportunity cost of making a loan.

Capital requirement regulation

The banking sector is subject to a capital requirement, modelled upon the 1988 Basle Accord. As it is well known, under this regulation the loans to the (non-bank) private sector are all subject to the same requirement (8%),[9] while Government bonds are exempted (as they receive a zero-weight in the weighting scheme for calculating the risk weighted assets, used as denominator in the capital-to-assets ratio). Thus, we may write the capital requirement as follows:

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[8] Remember the assumption that a change of an individual loan rate r_j has only a negligible impact on the aggregate rate r_A: therefore, in case (i) r_A remains unchanged, and only the relative price s_j moves. To the contrary, in case (ii) only r_A moves (by an amount equal to Δr_j), with s_j constant.

[9] With the exception of mortgages on residential property, receiving a 50% risk weight.

The calculation of the risk-weighted assets is presently undergoing a major revision: a "New Basle Accord" should presumably be implemented in 2007. An extension of the analysis carried out in this work, based on the heterogeneity approach, to the new regulatory environment is considered as an interesting matter for future research (for an extension of the monopolist bank model - based on the representative agent approach - to "Basle-II", see Baglioni 2002). Both the proposal of the Basel Committee for a new regulatory standard and the regulation currently enforced may be found on the web site of the Bank for International Settlements (www.bis.org).

$E \geq kl$, meaning that a bank cannot have an equity level (E) lower than k times the volume of its loans.[10] While this is a quite stylized description of the Basle Accord, it captures two essential features of it: 1) all loans are treated the same way; 2) there is a zero-weight asset (Government bonds), which is "costless" as far as the capital requirement is concerned.

Equity level

We assume that the level of equity capital is exogenously determined: at some point in time, this level is inherited from the past, and it cannot be modified. This assumption is justified by the fact that we consider the reaction of banks to a modification of the monetary policy rate: this is typically a short run decision problem, where the time horizon of the decision makers (bank managers) is not longer than a few months. It is realistic to assume that in such a short time horizon bank managers find it difficult to modify the equity level of the bank: raising new capital is costly and it may take some time.

More importantly, we introduce heterogeneity here, by assuming that two different groups of banks compete in the same market for loans, differing *only* in their equity level: well-capitalized and under-capitalized banks. The first group of banks is endowed with a higher equity level than the second one: $E_H > E_L$. In particular, we make the following assumptions.

- For well-capitalized banks, the optimal level of loans is not larger than the one allowed by their equity level: $\frac{E_H}{k} \geq l^*$, where $l^* = \alpha - \beta s_j^* - \gamma r_A$ is the volume of loans determined by the profit-maximization problem of the individual bank (see below).

- For under-capitalized banks, the opposite holds true: $l^* > \frac{E_L}{k}$.

So we have two types of banks: high capital banks and low capital ones ($T = H, L$). The first group is able to set its volume of loans at a level such that their marginal revenue equals their opportunity cost; to the contrary, the second one is constrained to set its volume of loans at a level determined by the capital requirement. Let us denote by n the (exogenously given) number of under-capitalized banks and by $u = \frac{n}{N}$ their proportion over the total number of banks.

Deposits

Banks' funding is made through deposits and equity. Actually, as we want to focus on the loan market, we are not interested in determining the amount of deposits collected by banks: that's why we will not explicitly introduce such a variable into our model. We are allowed to do so, thanks to the well-known dichotomy result of the Klein - Monti model of monopolistic bank:[11] the equilibrium in the loan market is independent from the equilibrium in the deposit market, with bonds playing the role of a "buffer asset". The latter enables

[10] Of course, under the present regulation $k = 0.08$.

[11] See Klein (1971) and Monti (1972) for the original monopolistic model, and Freixas - Rochet for an extension to the oligopolistic framework.

a bank to insulate the amount of loans granted from the amount of deposits taken.[12]

Monetary policy

We model monetary policy interventions as modifications of the interest rate (i) prevailing in the market for bonds. While traditionally monetary policy has been modelled as modifying the quantity of money, modern macroeconomic theory recognizes the fact that central banks nowadays target directly the level of interest rates.[13] Of course, the picture is much more complex than it is in our stylized model: central banks set the level of short term (overnight) interest rates, so an interesting problem is how this impulse is then transmitted through the whole yield curve. We do not tackle this problem here, as we have only one interest rate on bonds, without making any distinction as far as the maturity of assets is concerned.

2.3 Individual bank behavior: flexibility and complementarity

Bank profit maximization

The profit-maximization problem is common to the two types of banks: each bank j maximizes its profit from loans with respect to its own interest rate (r_j), taking as given the average rate prevailing in the loan market (r_A). The profit from loans must be netted from their opportunity cost, i.e. the return on the alternative asset (bonds). Moreover, banks have to take into account the constraint given by the capital requirement. So for each type of banks ($T = H, L$), we have the following optimization problem:

$$\max_{r_j} \Pi = (r_j - i) \cdot (\alpha - \beta s_j - \gamma r_A)$$
$$\text{subject to: } E_T \geq k\,(\alpha - \beta s_j - \gamma r_A)$$

The FOC for this problem is:[14]

$$\alpha - \beta s_j - \gamma r_A - (r_j - i)\beta + \lambda k \beta = 0 \tag{1}$$

where λ is the Lagrangian multiplier for the capital constraint. We may now determine the individual behavioral parameters of banks, distinguishing between well-capitalized and under-capitalized ones.

[12] A possible objection is that, in presence of a capital regulation, the dichotomy mentioned in the text might fail to hold. However, the extension of the Klein - Monti model to the case where banks are constrained by a capital requirement shows that the dichotomy result is still valid, provided banks may invest in an asset (like Government bonds) which is exempted from the requirement, as we are going to assume below. See Baglioni - Cherubini (1990).

[13] See Romer (2000).

[14] The SOC is satisfied, as the objective function is concave in r_j and the constraint is linear.

High capital banks

The above FOC, with $\lambda = 0$, defines an optimal interest rate r^* as follows:

$$r^* = \frac{1}{2}\left[\frac{\alpha}{\beta} + \left(1 - \frac{\gamma}{\beta}\right) r_A + i\right] \quad (2)$$

or equivalently:[15]

$$r^* \cdot (1 - \tfrac{1}{\eta}) = i \quad \text{(2 bis)}$$

The corresponding volume of loans is $l^* = \alpha - \beta s^* - \gamma r_A$. The above assumptions ($\frac{E_H}{k} \geq l^* > \frac{E_L}{k}$) imply that only the well-capitalized (unconstrained) banks may apply the rate r^* (equivalently, the spread $s^* \equiv r^* - r_A$), such that the marginal revenue on loans (LHS) is equal to their opportunity cost (RHS).

From eq.2, we get the partial derivative of the optimal rate applied by each well-capitalized bank with respect to the policy rate i, given the average rate prevailing in the loan market:

$$f_H = \frac{\partial r^*}{\partial i} = \frac{1}{2} \quad (3)$$

which measures the degree of "individual flexibility" of banks with a high equity endowment: f_H tells us how each well-capitalized bank reacts to a change in the policy rate, taking as given the average rate r_A.

Again from eq.2, we get a measure of the individual reaction to a change in the average rate prevailing in the loan market, given the policy rate i :

$$c_H = \frac{\partial r^*}{\partial r_A} = \frac{1}{2}\left(1 - \frac{\gamma}{\beta}\right) \quad (4)$$

which is the degree of "strategic complementarity" of well-capitalized banks (of course $c_H > 0$, given that $\beta > \gamma$): this measures how much a change in the average loan rate leads an individual unconstrained bank to move - in the same direction - its own rate.

Now, we are in a position to compute the overall impact of a monetary policy intervention on the individual behavior of a well-capitalized bank. Eq.2 may be written in a compact way as follows: $r^* = g(i, r_A) = g[i, r_A(i)]$, which is a function linking the individual optimal rate r^* to the policy rate i. The total derivative of r^* with respect to i is then equal to:

$$\frac{dr^*}{di} = g_1 + g_2 \frac{dr_A}{di} = f_H + c_H \frac{dr_A}{di} \quad (5)$$

where we see that the total effect of monetary policy on the optimal loan rate is the sum of two effects: i) a "direct effect", given by the degree of individual flexibility, ii) an "indirect effect", given by the degree of strategic complementarity. The first one measures how each bank is willing to change its own relative

[15] Here η is defined as the (partial) elasticity of the loan demand function faced by each bank, relative to its own interest rate: $\eta = \beta \frac{r_j}{l_j}$.

price (s_j), in response to a change in the policy rate. The second one measures the "imitation effect" due to strategic complementarity: each bank j moves its own rate in response to a change in the average loan rate; therefore, the reaction of all the other banks to a monetary policy intervention makes bank j to react as well: the extent of this imitation effect is precisely what is measured by c_H.

Low capital banks

For under-capitalized (constrained) banks, the volume of loans is determined by the capital constraint: $\bar{l} = \frac{E_L}{k}$. The rate applied by this type of banks ($\bar{r}$) is then determined by the loan demand curve as follows:

$$\bar{r} = \frac{\alpha}{\beta} + (1 - \frac{\gamma}{\beta})r_A - \frac{E_L}{k\beta} \tag{6}$$

It is immediate to see that $\bar{r}$ does not depend on i, as the latter does not appear in eq.6. So we may say that the degree of individual flexibility of under-capitalized banks is nil:

$$f_L = \frac{\partial \bar{r}}{\partial i} = 0 \tag{7}$$

The intuition behind this result is easy to get. Consider that an under-capitalized bank, even in presence of a change in the policy rate i, has to keep its volume of loans constant (at the level $\bar{l}$): given the behavior of other banks - so for a given level of the average rate r_A - this prevents that bank from changing its own rate, so that the spread $\bar{s}$ ($\equiv \bar{r} - r_A$) applied by it remains the same. In other words, the pricing behavior of a low capital bank is characterized by a high degree of "real rigidity": its relative price does not respond to a monetary policy shock (as long as other banks do not react either).

On the other hand, from eq.6 we get:

$$c_L = \frac{\partial \bar{r}}{\partial r_A} = 1 - \frac{\gamma}{\beta} \tag{8}$$

which is the degree of strategic complementarity of low capital banks. Why do these banks show a positive degree of strategic complementarity? To understand this result, imagine first a situation where the individual loan demand depends only on the relative price ($\gamma = 0$). In such a case, a change of r_A should be met by an equal change of $\bar{r}$, because a constrained bank would have to keep its relative price $\bar{s}$ unchanged, in order to keep its loan volume constant (indeed, from eq.8 we would get: $c_L = 1$). Actually, since $\gamma > 0$ a constrained bank has to change its relative price, just to compensate for a change of r_A. To illustrate this point, let's start from an initial situation, where a constrained bank applies an interest rate on its loans higher than the average rate prevailing in the loan market: $\bar{s} > 0$. Now, suppose that the average rate declines: $\Delta r_A < 0$. Then, a constrained bank will have to adjust its own spread $\bar{s}$, in order to keep its volume of loans at the level $\bar{l}$. In particular, it has to increase such a spread, to compensate the effect of the decrease in r_A on its own loan demand. But, given that the individual loan demand responds more to the relative price than to the aggregate one ($\beta > \gamma$), a $\Delta\overline{s} < -\Delta r_A$ is sufficient to keep its loan volume constant, implying that the bank will lower its own rate: so $c_L > 0$. (In other words, if such a bank decided to keep its own rate fixed, so that $\Delta\overline{s} = -\Delta r_A$, it would suffer from an undesired reduction of quantity).

Now, we may easily determine the impact of a change in the policy rate i on the interest rate applied by the individual under-capitalized bank:

$$\frac{d\overline{r}}{di} = c_L \frac{dr_A}{di} \tag{9}$$

2.4 Aggregate equilibrium: monetary policy effectiveness

Now, we are in a position to determine the aggregate impact of monetary policy. In particular, we are able to analyze the effects of the strategic interaction between high capital and low capital banks: the advantage of the heterogeneity approach over the representative agent one is precisely that it allows us to correctly address such an issue. However, before actually doing that, we have to analyze what happens in the two extreme opposite situations, where the whole banking system is either well-capitalized ($u = 0$) or under-capitalized ($u = 1$). This analysis will provide the benchmark, with which to compare the "mixed equilibrium" ($1 > u > 0$).

2.4.1 Equilibrium 1: all banks are well-capitalized ($u = 0$)

Our first result comes from considering the equilibrium where all banks are well-capitalized, so that none of them is constrained by the capital requirement. We may easily prove the following:

Proposition 1 *In the monopolistic competition framework, when $u = 0$ the aggregate impact of monetary policy on the loan market is stronger than what is shown by the individual flexibility parameter (a "multiplier effect" is present):* $\frac{dr_A}{di} > f_H$.

Proof. We look here for a symmetric equilibrium, where all banks are identical. This implies that all banks apply the same interest rate on loans (r^*), which in turn implies: $r^* = r_A$. By applying this equilibrium condition to equation (5), we get:

$\frac{dr_A}{di} = f_H + c_H \frac{dr_A}{di}$

from which:

$$\frac{dr_A}{di} = \frac{f_H}{1 - c_H} \tag{10}$$

which is larger than f_H, given that $c_H > 0$.[16] ■

So, equilibrium 1 has the two following features.

1) *Monetary policy is effective through the banking channel*, as it is able to alter the equilibrium in the loan market; a measure of its *aggregate* impact is provided by eq.10.

For example, an expansionary intervention of the central bank, by lowering the bond rate i, leads to an increase of the loan supply, as each bank is willing to lower the interest rate applied on its loans and to expand their volume. Looking at Figure 2, we start with a symmetric equilibrium (denoted by A), where all banks apply the same interest rate r_0^*, so that $r_A = r_0^*$ and $s_j = 0$ for all banks. After the monetary policy intervention, each bank is willing to decrease its own relative price, applying a spread $s_j < 0$; moreover, there is an imitative effect, due to strategic complementarity. Given our assumption that all banks are identical, this process leads to a new symmetric equilibrium (B), where all banks have decreased their rate on loans by the same amount: again, $s_j = 0$ for all banks, but now all banks apply a lower rate $r_1^* < r_0^*$. Therefore, the individual loan demand schedule shifts from l_0 to l_1: each bank makes a higher volume of loans. This shift of the individual loan demand might generate some confusion: actually, the whole process is driven by an *increase of the loan supply* by banks: the aggregate effect is a downward movement of the equilibrium from point A to point B *along the aggregate loan demand curve.*

2) The effectiveness of monetary policy is larger than what is measured by the individual flexibility parameter f_H: this is due to the above mentioned imitation effect, which introduces a *multiplier* in the adjustment process following a monetary policy intervention. In stating the proposition, we stressed that this result crucially depends on the monopolistic competition framework: this type of competition is characterized by *strategic complementarity in prices.* As we shall see in the following section, this result does not carry over to the Cournot oligopoly market structure, where *strategic substitutability in quantities* is at work.

Figure 3 provides a graphical illustration of the result stated in Proposition 1, by showing the multiplier effect. The picture shows that the equilibrium interest rate in the loan market is determined by two conditions: (i) it must lie on the reaction curve of the individual bank, where the rate r^* applied by each bank is a function of the aggregate rate r_A (see equation 2): the positive slope of this line shows the degree of strategic complementarity c_H; (ii) the symmetric equilibrium condition: $r^* = r_A$. Now, following a reduction of the policy rate from i_0 to i_1, the individual reaction function shifts down. The change of the equilibrium rate from point A to point C is the sum of two components. From A to B, it is due to the individual flexibility: each bank is willing to lower its

[16] An alternative way to reach the same result is the following. Substitute r_A for r^* in the LHS of eq.2, solve for r_A and take the derivative of r_A with respect to i: you will get $\frac{dr_A}{di} = \frac{1}{1+\frac{\gamma}{\beta}}$, which is equivalent to what is shown in eq.10. The method adopted in the text has the advantage of stressing the role of the individual behaviorial parameters f_H and c_H.

own rate, for a given level of the average rate. From B to C, it is due to the multiplier effect (shown by the dotted line): each bank reacts to the decrease of the average rate by lowering further its own rate, and so forth until the new aggregate equilibrium C is reached.

2.4.2 Equilibrium 2: all banks are under-capitalized ($u = 1$)

In the alternative symmetric equilibrium, where all banks are under-capitalized, all of them apply the same rate $\overline{r}$, so that $\overline{r} = r_A$. Taking into account this equilibrium condition, eq.9 becomes:

$$\frac{dr_A}{di} = c_L \frac{dr_A}{di}$$

which obviously implies:[17] $\frac{dr_A}{di} = 0$.

We may explain this result as follows. Following a change in the policy rate i, each low capital bank does not change its own interest rate, given that all the other ones do not change their rates (remember that $f_L = 0$). As all banks follow this strategy, the equilibrium in the loan market is completely unaffected.[18] Thus, *monetary policy does not operate through this channel*, under the extreme assumption that the whole banking system is constrained by the capital requirement regulation.

2.4.3 Equilibrium 3: heterogeneous banks ($1 > u > 0$)

Let us now turn to the case where $1 > u > 0$: both types of banks - well-capitalized and under-capitalized ones - are present in the banking system and compete in the market for loans. What is the impact of a monetary policy intervention, changing the level of the bond interest rate i?

The "average effect" of monetary policy

Let us consider first the answer we get from the representative agent approach. Actually, by definition this approach is unable to tackle this issue in a context with heterogeneity, as it rests on the assumption that all banks are identical. Therefore, it is able to deal only with those contexts where all banks are either well-capitalized or under-capitalized: in such circumstances, it leads to the conclusions we have illustrated in the two preceding subsections, devoted to the analysis of markets with homogeneous agents.

[17] You may reach the same result by noting that eq.6, after substituting r_A for $\overline{r}$, defines r_A as a function of the equity level E_L, while r_A does not depend on the policy rate i.

[18] A possible objection is: what if banks have alternative beliefs? Suppose that each bank believes that all the other ones will lower their rate, in response to a decrease in the policy rate i. Due to strategic complementarity, this would make each bank willing to lower its own rate. In the new symmetric equilibrium all banks would lower their rate by the same amount, producing a decrease of the average rate. But this implies an increase in the (aggregate and individual) volume of loans, leading to a violation of the capital constraint. Therefore, following a reduction of the policy rate i, there cannot be an increase of the loan supply.

If one wishes to "force" such an approach and get an answer to the above question, he might think of "averaging" the effects of monetary policy obtained in equilibria 1 and 2 above, given that u is the proportion of under-capitalized banks over total, so that $r_A = u\overline{r} + (1-u)r^*$. This procedure relies on the implicit assumption that well-capitalized and under-capitalized banks behave as they do in equilibria 1 and 2 respectively. It leads to the following measure of monetary policy effectiveness:

$$\frac{dr_A}{di} = (1-u)\frac{f_H}{1-c_H} \tag{11}$$

where we made use of eq.10 and of the result that $\frac{dr_A}{di} = 0$ when $u = 1$. Let us call this the "average effect" of monetary policy.

With the representative agent approach we cannot go any further from here: the impact of monetary policy on the average loan rate is proportional to the number of high capital banks, as it is a weighted average of the reactions of each type of banks, calculated separately from each other.

This way of measuring the effectiveness of monetary policy is clearly not correct. Why? Because it fails to consider the strategic interaction between the two different types of banks ($T = H, L$); in particular, it does not capture the following fact: the reaction of each bank to a monetary policy shock, given the presence of *both* types, will be different from the one it has when only its own type is present in the market.

The "mixed equilibrium"

In order to get a correct answer to our initial question, we have to analyze the reaction of the average interest rate in the loan market to a monetary policy intervention, starting from an equilibrium where both high capital and low capital banks are present in such a market (we call this the "mixed equilibrium") and by properly taking into account the strategic interaction between those two groups of banks.

We start the analysis of the mixed equilibrium, by noting that under-capitalized banks have to apply an interest rate on their loans higher than the one applied by well-capitalized banks. This follows trivially from our initial assumption: $l^* > \frac{E_L}{k} = \overline{l}$. Let us expand this inequality, by making use of the loan demand function: $\alpha - \beta r^* + (\beta - \gamma)r_A > \alpha - \beta\overline{r} + (\beta - \gamma)r_A$, from which $\overline{r} > r^*$ (equivalently, it must be: $\overline{s} > 0 > s^*$).

Now, by applying the results obtained so far with regard to the individual bank behavior, we are able to prove that the impact of monetary policy on the average loan rate is different from the "average effect" described by eq.11.

Proposition 2 *When $1 > u > 0$, the aggregate impact of monetary policy on the loan market is larger than the one obtained by "averaging" the two extreme equilibria (where $u = 0$ and $u = 1$ respectively).*

Proof. From $r_A = u\overline{r} + (1-u)r^*$, we have:
$\frac{dr_A}{di} = u\frac{d\overline{r}}{di} + (1-u)\frac{dr^*}{di} = u \cdot c_L\frac{dr_A}{di} + (1-u)\cdot\left(f_H + c_H\frac{dr_A}{di}\right)$

where we made use of equations 5 and 9. By solving this equation for $\frac{dr_A}{di}$, taking into account that $c_L = 2c_H$, we get the following:

$$\frac{dr_A}{di} = (1-u)\frac{f_H}{1-(1+u)c_H} \tag{12}$$

It is easy to see that the value of $\frac{dr_A}{di}$ indicated in eq.12 is larger than the one indicated in eq.11.[19] ■

Eq.12 provides a correct measure of the impact of monetary policy on the loan market. This measure is a generalization of the results obtained so far, as it is valid in the "mixed" equilibrium as well as in the two extreme equilibria. Notice that eq.12 reduces to eq.10 when $u = 0$, while it gives monetary policy a nil effect when $u = 1$. Otherwise (for $1 > u > 0$) it points to an intermediate effect.

More importantly, Proposition 2 tells us that in the mixed equilibrium the effect of monetary policy will be distorted towards the result obtained in equilibrium 1 ($u = 0$): in other words, the overall equilibrium is more driven by well-capitalized banks than by under-capitalized ones. This makes the impact of monetary policy stronger, given that the unconstrained banks are more reactive to the monetary policy shock than the constrained ones. The reason is that the "imitation effect", due to strategic complementarity, is stronger for low capital banks than for high capital ones ($c_L > c_H$): as a consequence, the latter group becomes more important, in shaping the equilibrium prevailing after a monetary policy shock, than what is implied by their relative number in the population of banks. This result is an application of the principle stated in Haltiwanger - Waldman (1991) (Proposition 6). The implication is that simply averaging the two extreme equilibria 1 and 2 leads to an underestimation of monetary policy effectiveness.

Figure 4-A provides a (qualitative) illustration of the basic difference between the two measures of the aggregate impact of monetary policy. The dotted line shows the "average effect" (eq.11): this decreases linearly with u. The solid line shows the aggregate effect calculated in the "mixed equilibrium" (eq.12): this declines *less* then proportionally as u increases; therefore it lies always above the dotted line (except in the two extreme cases where $u = 0$ and $u = 1$, in which there is not heterogeneity).[20]

Individual flexibility, real rigidity and strategic complementarity

The result obtained in Proposition 2 is quite reasonable. We noticed above that under-capitalized banks are characterized by a degree of flexibility equal

[19] As for equilibria 1 and 2, the result shown here may be obtained in another way. Substitute equations 2 and 6 into the definition of r_A, solve for r_A and take the derivative with respect to i: you will get $\frac{dr_A}{di} = (1-u)\frac{1}{1-u+\frac{\gamma}{\beta}(1+u)}$: this is equivalent to what is shown in eq.12 and it is larger than $(1-u)\frac{1}{1+\frac{\gamma}{\beta}}$, which is the "average effect" of monetary policy.

[20] The shapes of the curves shown in Figure 4-A may be directly derived from equations 11-12, through derivation with respect to u.

to zero. This is equivalent to say that those banks show a high degree of real rigidity: actually, they change their relative price only to compensate a change in the average loan rate, in order to keep their volume of loans constant. This implies a high degree of strategic complementarity: as their relative price is sticky, the interest rate applied by constrained banks tends to follow closely the movements of the aggregate price (average loan rate). To the contrary, well-capitalized banks show a positive degree of flexibility, implying a lower degree of real rigidity: they have more room to change their relative price, as they are not constrained by the capital requirement. Therefore, it makes sense to say that the latter group of banks show a lower degree of strategic complementarity than the former one: this implies that the reaction of the banking system to a monetary policy intervention is more driven by the unconstrained banks.

We may formalize the above reasoning as follows. For each type of bank $T = H, L$, let us define the degree of real rigidity as $1 - f_T$. Then, it is easy to see that the following relation holds true, linking the strategic complementarity parameter to the degree of real rigidity/flexibility:

$$c_T = (1 - f_T)(1 - \frac{\gamma}{\beta}), \text{ for } T = H, L \tag{13}$$

where we see that strategic complementarity is proportional to real rigidity, which in turn is inversely related to the individual flexibility parameter. From $f_H = \frac{1}{2}$ and $f_L = 0$, it follows that $c_L = 2c_H$.

The imitation effect

It is worth stressing the role of the imitation effect mentioned above. In the mixed equilibrium, both types of banks behave differently than in the two extreme equilibria. Let us examine each of them in turn, by looking at their reaction to an expansionary monetary policy (lowering the bond rate i).

If only under-capitalized banks were present in the market for loans, they would not move their interest rates (see equilibrium 2). However, if both types of banks are present (equilibrium 3), the average rate on loans declines, driven by well-capitalized banks. Then, also under-capitalized banks will lower their rates: if they did not do so, their volume of loans would decline, as they would suffer from an increase of their relative price ($\overline{s}$) that would more than offset the decline in the average price of loans (r_A). To the contrary, they want to keep their loan volume at the level $\overline{l} = \frac{E_L}{k}$.

On the other hand, if only well-capitalized banks were present, they would move their rates by an amount given by eq.10. They will lower their rates by a smaller amount[21] if both types of banks are present, because the decline of the average loan rate is smaller.[22]

Thus, there is a sort of reciprocal influence among the two groups of banks, which we called "imitation effect": if both of them are present in the market for loans, under-capitalized banks are lead to respond to a monetary policy shock, while well-capitalized banks are lead to respond less than they would do

[21] You may check this by inserting eq.12 into eq.5 and comparing the result with eq.10.

[22] You may check this by comparing equations (12) and (10).

otherwise. As the first imitation effect is greater than the second one ($c_L > c_H$), the aggregate reaction of the banking system is more driven by well-capitalized banks.

The adjustment following a monetary policy intervention

Figure 5 shows the adjustment taking place in the loan market, following an expansionary monetary policy intervention. Suppose the central bank cuts the policy rate i, leading to a decrease of the average loan rate (say from r_A^0 to r_A^1): this makes the individual loan demand curve shift from l_0 to l_1. The spreads applied by both groups of banks - relative to the average loan rate - become larger: under-capitalized banks increase their relative price (from $\overline{s}_0$ to $\overline{s}_1$), while the opposite holds for well-capitalized ones. As a consequence, the latter group experiences an increase of volumes (from l_0^* to l_1^*) and market share: the whole increase in the aggregate volume of loans demanded, due to the decrease of the average loan rate, must be met by the unconstrained banks, given that the other ones cannot increase their loans.

The same figure may be used to visualize the adjustment following an increase of the policy rate i, which is symmetric to the one just described: starting with an initial average loan rate equal to r_A^1, the monetary restriction leads to a higher average rate (r_A^0), together with a leftward shift of the individual loan demand schedule. In this case, the spreads applied by both groups of banks shrink, implying a shift of market shares in favor of the under-capitalized banks: while these keep their loans constant, the well-capitalized banks suffer a decrease of their volumes.

The patterns illustrated in Figure 5 are a consequence of the price stickiness shown by under-capitalized banks: following a shock in the policy rate i, the interest rate on their loans changes by less than the average loan rate does.[23] On the other hand, the rate applied by well-capitalized banks on their loans varies by more than the average loan rate does.[24]

3 An oligopoly model of the loan market with capital regulation

3.1 Introduction

We turn in this section to an alternative market structure: oligopoly. Here the strategic variable is quantity instead of price: each bank decides its optimal volume of loans, taking as given the volumes supplied by the other banks ("Cournot conjectures"); the equilibrium price is the one equating the aggregate supply and demand for loans. Moreover, the action of each player significantly affects the aggregate outcome.

[23] This is immediate from eq.9 (where $c_L < 1$).

[24] You may check that $\frac{dr^*}{di} > \frac{dr_A}{di}$, by inserting equations (5) and (12) into this inequality.

The motivation leading us to carry out this supplementary analysis is twofold. On theoretical grounds, it is interesting to assess whether the main result of the preceding section, namely the disproportionate importance of well-capitalized banks in transmitting a monetary policy impulse, carries over to a market structure - oligopoly - characterized by strategic substitutability in quantities (instead of strategic complementarity in prices). As we shall see, the answer is positive, reinforcing the main message of this work: the impact of monetary policy on the loan market is stronger than what is implied by the proportion of well-capitalized to under-capitalized banks. The latter play here the role of "non-responders" in the Haltiwanger - Waldman (1991) framework: under strategic substitutability, the interaction among heterogeneous agents ("responders / non-responders") leads to an equilibrium which "more closely resembles what occurs when all agents are responders than would be suggested by their relative number in the population".

At the empirical level, the process of concentration, taking place in the banking sector, has sometimes lead to situations where a few large players account for the bulk of the market. In such circumstances, the competitive game is perhaps more adequately described by the oligopoly paradigm than by the monopolistic competition framework introduced in the preceding section.

In the following, we proceed as we did in the previous section: after introducing some modifications to the basic assumptions of the model, we first derive the parameters describing the individual bank behavior; then we compute three alternative equilibria, where none / all / some banks are constrained by the capital requirement regulation, and we investigate the impact of a monetary policy shock in each of them.

3.2 Assumptions

All the assumptions of the previous section continue to hold, except that competition is now framed as a Cournot oligopoly game. Therefore, it is convenient to directly specify an aggregate inverse demand function for loans: $r = R - \delta L$, where $L = \sum_{j=1}^{N} l_j$ is the total quantity of loans supplied by the N banks competing in the loan market (l_j is the volume supplied by each of them), r is the market-clearing interest rate, R and δ are positive parameters.

We still have two groups of banks: under-capitalized and well-capitalized ones, differing only for their equity capital: E_L and E_H respectively, with $\frac{E_L}{k} < l_c < \frac{E_H}{k}$, where l_c is the individual volume of loans emerging in the Cournot-Nash equilibrium (the "Cournot quantity" that will be found shortly). Again, the number of under-capitalized banks is exogenous (n); without loss of generality, we index such banks as $j = 1, ..., n$, while well-capitalized banks are indexed as $j = n + 1, ..., N$.

3.3 Individual bank behavior: flexibility and substitutability

Each bank decides to supply the quantity that maximizes profit from loans (net of the opportunity cost: i), taking into account the capital requirement constraint. For both types of banks ($T = H, L$), the individual profit maximization problem is the following:

$$\max_{l_j} \Pi_j = (r - i) \cdot l_j = [R - \delta (l_j + L_{-j}) - i] \cdot l_j$$
$$\text{subject to: } E_T \geq k l_j$$

where bank j takes as given the quantity ($L_{-j} \equiv \sum_{z \neq j} l_z$) supplied by all the other banks.

The FOC for this problem is:[25]

$$R - 2\delta l_j - \delta L_{-j} - i - \lambda k = 0 \tag{14}$$

where λ is the Lagrangian multiplier for the capital constraint. We may now determine the individual behavioral parameters of banks, distinguishing between well-capitalized and under-capitalized ones.

High capital banks

The above FOC, with $\lambda = 0$, defines the reaction function of each well-capitalized bank:

$$l_j^* = \frac{1}{2} \left[\frac{(R - i)}{\delta} - L_{-j} \right] \tag{15}$$

from which we get the individual flexibility parameter:

$$f_H = \frac{\partial l_j^*}{\partial i} = -\frac{1}{2\delta} \tag{16}$$

measuring the response of each high capital bank to a change in the policy rate, taking the volume of loans supplied by all the other banks as fixed. We also derive:

$$s_H = \frac{\partial l_j^*}{\partial L_{-j}} = -\frac{1}{2} \tag{17}$$

measuring the degree of strategic substitutability: a bank reacts to an increase of the total quantity supplied by the other banks by lowering its own quantity.

Now, the overall impact of a monetary policy intervention on the individual behavior may be computed. If we write eq.15 as $l_j^* = h\left[i, L_{-j}(i)\right]$, the total derivative of l_j^* with respect to i is then:

[25] The SOC is satisfied, as the objective function is concave in l_j and the constraint is linear.

$$\frac{dl_j^*}{di} = h_1 + h_2 \frac{dL_{-j}}{di} = f_H + s_H \frac{dL_{-j}}{di} \tag{18}$$

Following Haltiwanger - Waldman (1991), we may call these well-capitalized banks "responders": not only they react to a monetary policy shock, but their reaction is conditioned by the reaction of all the other banks, due to strategic substitutability. Suppose, for example, that the central bank lowers i: a single bank j has an incentive to increase its supply of loans (as their opportunity cost has been lowered); however, the reaction of other banks - increasing their quantities as well - reduces the incentive of bank j to increase its own supply.

Low capital banks

For those banks for which the capital requirement constraint is binding, the volume of loans is simply determined by the regulation: $\bar{l} = \frac{E_L}{k}$. Then, for low capital banks we have: $f_L = s_L = \frac{d\bar{l}}{di} = 0$. In other words, they are "non-responders": they do not react to a monetary policy shock, neither they show any degree of strategic interaction with other banks, as long as the quantity of loans they can supply is curbed by their lack of regulatory capital.

3.4 Aggregate equilibrium: monetary policy effectiveness

3.4.1 Equilibrium 1: all banks are well-capitalized ($n = 0$)

We look here for the usual Cournot-Nash symmetric equilibrium. The reaction function (15) may be written as:

$$l_j^* = \frac{1}{2}\left[\frac{(R-i)}{\delta} - (N-1)l_j^*\right] \tag{19}$$

from which:

$$l_j^* = \frac{1}{(N+1)} \frac{(R-i)}{\delta} \equiv l_c, \text{ for } j = 1, ..., N \tag{20}$$

where l_c denotes the Cournot quantity. Here all banks are able to supply this quantity, as all of them are supposed to have an equity capital equal to $E_H > kl_c$. Therefore, the aggregate quantity is $L_c = Nl_c$.

From eq.20:

$$\frac{dl_c}{di} = -\frac{1}{(N+1)\delta} \tag{21}$$

Given that $N \geq 2$, this implies that $\left|\frac{dl_c}{di}\right| < |f_H|$. As a consequence, $\left|\frac{dL_c}{di}\right| < |N \cdot f_H|$. Then we may state the following:

Proposition 3 *In the oligopoly framework, when* $n = 0$ *the aggregate impact of monetary policy on the loan market is weaker than what is shown by the individual flexibility parameter:* $\left|\frac{dL_c}{di}\right| < |N \cdot f_H|$.

Notice that the same result may be reached by imposing the symmetry condition in eq.18, which then becomes:

$$\frac{dl_j^*}{di} = f_H + s_H(N-1)\frac{dl_j^*}{di}$$

from which:

$$\frac{dl_j^*}{di} = \frac{f_H}{1 - s_H(N-1)} \left(= \frac{dl_c}{di}\right) \tag{22}$$

which - in absolute value - is lower than f_H, because $s_H < 0$.

Eq.22 highlights the intuition behind Proposition 3. If the strategic interaction among banks is correctly described by a Cournot game, the loan volumes they supply to the market are strategic substitutes: then, the individual incentive to react to a monetary policy shock is *lowered* by the fact that other banks react as well. This result sharply contrasts the one stated in Proposition 1, where we obtained a multiplier effect: in the monopolistic competition framework, the individual incentive to react to a monetary policy shock is *strengthened* by the fact that other banks react as well, because strategic complementarity is at work there.

Figure 6 provides a graphical illustration of Proposition 3 for the duopoly case ($N = 2$). The Cournot-Nash equilibrium (point A) lies at the intersection between the two reaction curves: $l_1^* = \frac{1}{2}\left[\frac{(R-i)}{\delta} - l_2\right]$ and $l_2^* = \frac{1}{2}\left[\frac{(R-i)}{\delta} - l_1\right]$. The Cournot quantity is $l_c = \frac{(R-i)}{3\delta}$. Now, suppose the central bank lowers i by Δi. Each reaction function shifts by an amount equal to $f_H \Delta i$. Consider bank 1: if the other bank decided to stick to the quantity l_c, the monetary policy shock would lead it to increase its loan supply from A to B_1: this is the effect of individual flexibility. However, since bank 2 reaction function has shifted as well, bank 1 increases its quantity only to l_c'. Of course, a symmetric reasoning holds for bank 2. The aggregate outcome is a new Cournot equilibrium (point C), showing that each bank increases its loan supply by less than what indicated by points B_j ($j = 1, 2$): the distance between these points and C is the consequence of strategic substitutability.

3.4.2 Equilibrium 2: all banks are under-capitalized ($n = N$)

Let us now consider what happens when all banks have an equity capital equal to $E_L < kl_c$. We may easily prove that the (unique) Nash equilibrium is the following: all banks supply a loan volume $\bar{l} = \frac{E_L}{k}$.

To prove that, let us consider a bank j: she knows that each of the other banks may supply a (constrained) quantity $\overline{l}_{-j} \leq \frac{E_L}{k} < l_c$; then the total volume of loans supplied by the other banks satisfies: $\overline{L}_{-j} \leq (N-1)\frac{E_L}{k} < (N-1)l_c$. The Cournot quantity l_c is the optimal response to $L_{-j} = (N-1)l_c$; due to strategic substitutability, the optimal response to $\overline{L}_{-j}$ is a quantity $\widetilde{l}_j > l_c$: thus the capital requirement constraint is binding on bank j and she has to stick to a loan volume $\overline{l}_j = \frac{E_L}{k}$. Of course, this reasoning applies to all banks, so that all of them are forced by the regulation to supply the quantity $\overline{l} = \frac{E_L}{k}$. ■

Therefore, to all the low capital banks we may apply what we found before: $f_L = s_L = \frac{d\overline{l}}{di} = 0$. Clearly, a monetary policy shock has no impact on the loan market equilibrium, when the whole banking system suffers from low capitalization.

Figure 7 describes this equilibrium for the duopoly case. The constrained reaction functions are the (bold) kinked lines: the quantity supplied by bank 1 is $\overline{l}_1 = \min\left[\frac{E_L}{k}, l_1^*\right]$, where l_1^* is the unconstrained reaction function; symmetrically: $\overline{l}_2 = \min\left[\frac{E_L}{k}, l_2^*\right]$. They intersect at point A, which is the constrained equilibrium. This is clearly unaffected by a change of the policy interest rate i (although the latter makes the unconstrained reaction curves shift).

3.4.3 Equilibrium 3: heterogeneous banks $(0 < n < N)$

At last, we turn to what we are more interested in: the analysis of the monetary policy impact on the loan market, when both under-capitalized and well-capitalized banks compete among each other. Remember our assumption that low capital banks are numbered from 1 to n and high capital banks from $n+1$ to N (where n is exogenous).

The "average effect" of monetary policy

As we did in Section 2, we start by considering the answer we can get from the representative agent approach. We have n constrained banks, whose behavior was found in the equilibrium 2 above, and $(N-n)$ unconstrained banks, whose behavior was determined in equilibrium 1. The aggregate supply of loans is $L = n\overline{l} + (N-n)l_c$. Then, the aggregate impact of a monetary policy shock is simply given by:

$$\frac{dL}{di} = (N-n)\frac{dl_c}{di} = -\frac{(N-n)}{(N+1)\delta} \tag{23}$$

which is linear combination between $\frac{d\overline{l}}{di}(=0)$ and $\frac{dl_c}{di}$. We call this the "average effect" of monetary policy.

As we noticed in Section 2, such an approach is misleading in this context, as it fails to consider the strategic interaction between high capital banks and low capital ones. The fundamental drawback of the above procedure is that it relies on a "representative well-capitalized bank" and on a "representative under-capitalized bank", whose behavior is determined independently from each other.

The "mixed equilibrium"

In order to correctly address the issue of monetary policy effectiveness with heterogeneous banks, we have to determine their behavior in what we call the "mixed equilibrium", where both well-capitalized and under-capitalized banks are present and interact among each other. First of all, we have to describe the initial equilibrium; then we may calculate the impact of a monetary policy shock. The first point is taken up in the following lemma.

Lemma. *If $0 < n < N$, the (unique) Nash equilibrium is the following: under-capitalized banks supply a loan volume equal to $\overline{l} = \frac{E_L}{k}$; well-capitalized banks supply a loan volume $\widehat{l}$* (defined in eq.24) such that $\widehat{l} > l_c$ *(provided $E_H \geq k\widehat{l}$).*

Proof. We have to strengthen our assumption about the equity base of well-capitalized banks, by assuming that they have enough regulatory capital (E_H) to be able to supply the equilibrium quantity of loans $\widehat{l}$, which will be defined shortly. On the other hand, under-capitalized banks are still supposed to have a capital $E_L < kl_c$ (where l_c is the Cournot quantity defined in eq. 20).

The reaction functions of the two groups of banks, under-capitalized and well-capitalized ones, are given respectively by:

$\overline{l}_j = \min\left[\frac{E_L}{k}, l_j^*\right]$ for $j = 1, ..., n$

$l_j^* = \frac{1}{2}\left[\frac{(R-i)}{\delta} - L_{-j}\right]$ for $j = n+1, ..., N$

The unique Nash equilibrium lies at the intersection among such N linear reaction functions.

Now, consider a well-capitalized bank, making the following conjectures: she takes as given the quantities of all the other banks, where in particular all the under-capitalized ones supply a quantity $\frac{E_L}{k}$. Then her optimal response is:

$l_j^* = \frac{1}{2}\left[\frac{(R-i)}{\delta} - n\frac{E_L}{k} - \sum_{\substack{z=n+1 \\ z\neq j}}^{N} l_z\right]$

Since this is the optimal response of all the well-capitalized banks, their equilibrium supply must be the solution to:

$l_j^* = \frac{1}{2}\left[\frac{(R-i)}{\delta} - n\frac{E_L}{k} - (N-n-1)l_j^*\right]$

which is:

$$l_j^* = \frac{1}{(N-n+1)}\left[\frac{(R-i)}{\delta} - n\frac{E_L}{k}\right] \equiv \widehat{l} \qquad (24)$$

Easy calculation shows that the inequality $\widehat{l} > l_c$ simplifies into $l_c > \frac{E_L}{k}$, which is true by assumption.

Now, we have to check that all the low capital banks are indeed constrained by the capital requirement, so that they supply $\overline{l} = \frac{E_L}{k}$ in equilibrium. In order to do that, consider that the optimal response of an under-capitalized bank, if it were not constrained by the capital requirement, would be:

$l_j^* = \frac{1}{2}\left[\frac{(R-i)}{\delta} - (n-1)\frac{E_L}{k} - (N-n)\widehat{l}\right] =$

$= \frac{1}{2(N-n+1)}\left[\frac{(R-i)}{\delta} + (N-2n+1)\frac{E_L}{k}\right] \equiv \widetilde{l}$

Again, easy calculation shows that the inequality $\widetilde{l} > \frac{E_L}{k}$ boils down to $l_c > \frac{E_L}{k}$, which is true by assumption. Therefore: $\min\left[\frac{E_L}{k}, l_j^*\right] = \frac{E_L}{k}$. ■

This lemma tells us that, in the mixed equilibrium, the aggregate supply of loans is $L = n\overline{l} + (N-n)\widehat{l}$. Then, the aggregate impact of a monetary policy shock is given by:

$$\frac{dL}{di} = (N-n)\frac{d\widehat{l}}{di} = -\frac{(N-n)}{(N-n+1)\delta} \tag{25}$$

It is immediate to see that this expression, in absolute value, is larger than the "average effect" indicated in eq.23; the reason behind this result is that $\left|\frac{d\widehat{l}}{di}\right| > \left|\frac{dl_c}{di}\right|$. Then we may state the following proposition:

Proposition 4 *When $0 < n < N$, the aggregate impact of monetary policy on the loan market is larger than the "average effect".*

An alternative way to reach the same result is the following. The above lemma enables us to say that, in the mixed equilibrium, we have: n constrained banks, which do not react to the monetary policy impulse; and $(N-n)$ unconstrained banks, whose reaction is described by eq.18. The latter, by imposing the symmetry condition among such unconstrained banks, becomes:

$$\frac{dl_j^*}{di} = f_H + s_H\frac{dL_{-j}}{di} = f_H + s_H(N-n-1)\frac{dl_j^*}{di}$$

from which:

$$\frac{dl_j^*}{di} = \frac{f_H}{1 - s_H(N-n-1)}\left(= \frac{d\widehat{l}}{di}\right) \tag{26}$$

which is increasing in n and it is larger (in absolute value) than the value shown in eq.22.

As we did in the monopolistic competition context, we can draw a (qualitative) illustration of the difference between the two measures of monetary policy effectiveness (see Figure 4-B). The dotted line shows the "average effect" (eq.23):

this decreases linearly with n. The solid line shows the aggregate impact calculated in the "mixed equilibrium" (eq.25): this declines *less* then proportionally as n increases, and it lies above the dotted line for all values of n for which there is heterogeneity ($0 < n < N$).[26]

The intuition behind Proposition 4 should be clear. We know that the behavior of well-capitalized banks is characterized by strategic substitutability: their individual reaction to a monetary policy shock is lowered by the fact that other banks react as well. Now, in the mixed equilibrium a number (n) of constrained banks do *not* react to such a shock: this increases the incentive of the unconstrained banks to react.[27] That's why the quantity supplied by well-capitalized banks in the mixed equilibrium ($\widehat{l}$) shows a larger response to a change of the policy rate i than the one shown by the Cournot quantity (l_c) in equilibrium 1 (where $n = 0$). This strengthens the impact of monetary policy.

Here we find an application of the principle stated in Haltiwanger - Waldman (1991) (Proposition 1): under strategic substitutability, the "responders" (in our context: well-capitalized banks) are "disproportionately important" over "non-responders" (under-capitalized banks) in shaping the aggregate outcome; as a consequence, the equilibrium is distorted towards the one where only responders are present. The implication is that the "average effect" (which simply weights the reaction of the Cournot quantity with the number of unconstrained banks) understates the impact of monetary policy.

Figure 8 visualizes what is going on here, for the duopoly case. Bank 1 is supposed to be well-capitalized (its equity level is E_H): its reaction function is $l_1^* = \frac{1}{2}\left[\frac{(R-i)}{\delta} - l_2\right]$. Bank 2 is under-capitalized (its equity level is E_L): its reaction function (the bold kinked line) is $\overline{l}_2 = \min\left[\frac{E_L}{k}, l_2^*\right]$. The initial Nash equilibrium lies at the intersection between those two curves (point A): in this "mixed equilibrium", bank 2 has to stick to the quantity $\frac{E_L}{k}$; bank 1 best response is $\widehat{l} > l_c$. Now suppose the central bank lowers i by Δi (< 0): this shock makes both l_1^* and l_2^* shift. However, it affects very differently the two banks, as it can be seen by looking at the new Nash equilibrium (point B). Bank 2 cannot increase its loan supply. As a consequence, bank 1 increases its quantity by the full amount $f_H \Delta i$ (which is the size of the rightward shift of its reaction function l_1^*). Notice here the implication of strategic substitutability: if bank 2 were allowed to increase its quantity, bank 1 would increase its supply by the less then $f_H \Delta i$ (as it happened in Figure 6); but because bank 2 cannot do that, bank 1 incentive to increase its own quantity is strengthened, leading it to cover the whole distance from A to B.[28]

[26] The shapes of the curves shown in Figure 4-B may be directly derived from equations (23) and (25), through derivation with respect to n.

[27] Formally: the parameter of strategic substitutability s_H is multiplied by $(N - n - 1)$ in eq.26, instead of $(N - 1)$ as in eq.22.

[28] We have to be careful here. The extreme result that bank 1 increases its quantity by the full amount given by its individual flexibility (formally: $\Delta\widehat{l} = f_H \Delta i$) is clearly due to the fact that Figure 8 deals with a duopoly case, where bank 2 accounts for the whole remaining part of the banking system. In the more general case ($N > 2$), where each bank faces a mixed of constrained and unconstrained competitors, we get the weaker result: $f_H \Delta i > \Delta\widehat{l} > \Delta l_c$.

4 Concluding remarks

The main findings (Propositions 2 and 4) of this work, based on the heterogeneous agents approach, point to the following result: the adjustment taking place in the loan market, after a central bank intervention, is more driven by well-capitalized than by under-capitalized banks, giving monetary policy a stronger effectiveness than what is implied by the proportion of the former to the latter in the population of banks. In other words, the aggregate impact of monetary policy on the loan market does not decrease linearly as the number of constrained banks grows large (as it is implied by the representative agent approach): it declines less than proportionally with that number.

What is remarkable is that this result was obtained under two quite different specifications of the competitive game among banks: (i) monopolistic competition, where banks compete in prices and none of them is able to significantly alter the aggregate outcome; (ii) Cournot oligopoly, where banks compete in quantities and the action of a single agent affects the aggregate outcome. The first environment exhibits strategic complementarity, while the second one is characterized by strategic substitutability. Moreover, in the homogeneous case (all banks are well-capitalized), in the first context we found a multiplier effect in the transmission of monetary policy, while in the second one we found an effect of the opposite sign (see Propositions 1 and 3).

Thus, we may say that the result stated in Propositions 2 and 4 is quite "robust". The reason behind this "robustness" has to be found in the features of the strategic interaction among heterogeneous agents, taking place under the two different market structures we have examined. Under strategic complementarity, the aggregate outcome is more driven by those agents showing the *lower* degree of strategic interaction: their behavior is conditioned by an "imitation effect" weaker than the other ones. That is the case of well-capitalized banks in the monopolistic competition framework, where the capital constraint forces the other (low capital) banks to have a higher degree of relative price rigidity ("real rigidity") and consequently a higher level of strategic complementarity. On the other hand, under strategic substitutability those agents having the *higher* degree of strategic interaction drive the equilibrium: their incentive to choose an action is increased by the fact that some other agents do not choose the same action; this gives them a higher weigh in shaping the aggregate outcome. Again, this is the case of well-capitalized banks in the oligopoly context: the presence of some (constrained) banks, not reacting to a monetary policy shock, increases their response to the same shock.

The ultimate reason for our findings relies in the way the capital requirement works. A bank experiencing a lack of equity is constrained to supply a volume of loans determined by its regulatory capital. Such a bank is forced by the regulation to be a "non-responder" (not reacting to the behavior of its competitors), if the strategic variable in the competitive game is quantity. On the other hand, its relative price is forced to be quite sticky (since a change of the relative price affects its volume of loans): then such a bank will show a high degree of strategic interaction, if the strategic variable is price.

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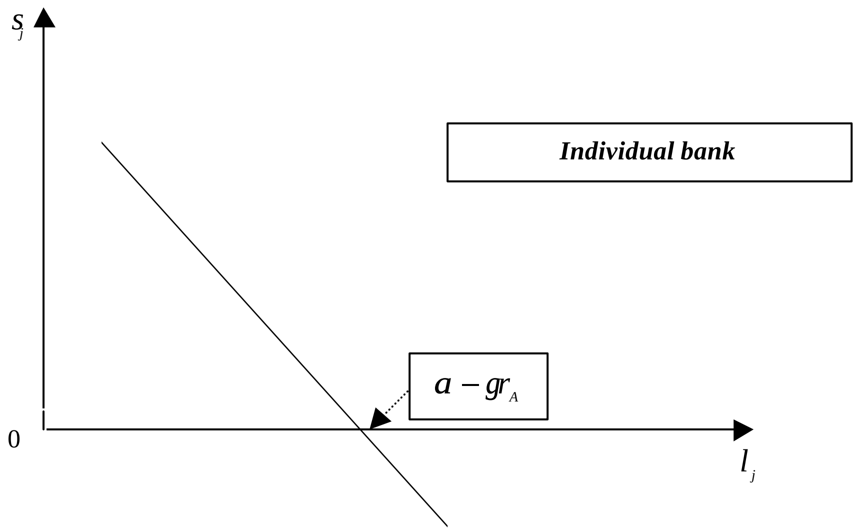
FIGURE 1 – MONOPOLISTIC COMPETITION:
INDIVIDUAL AND AGGREGATE LOAN DEMAND



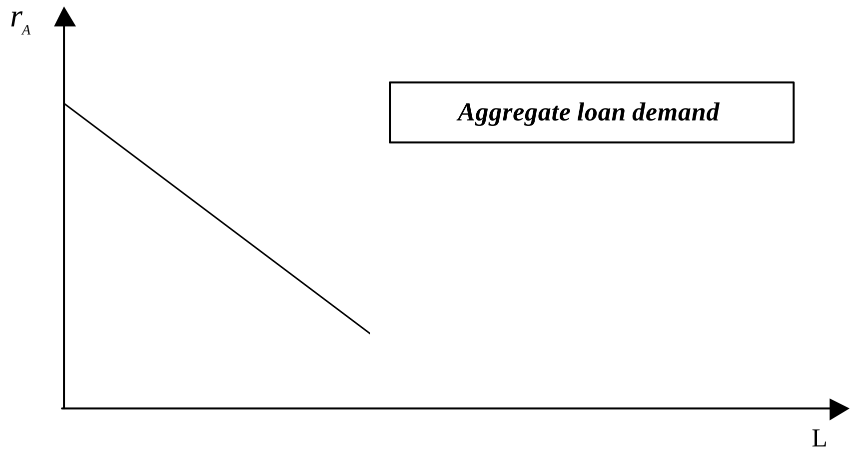
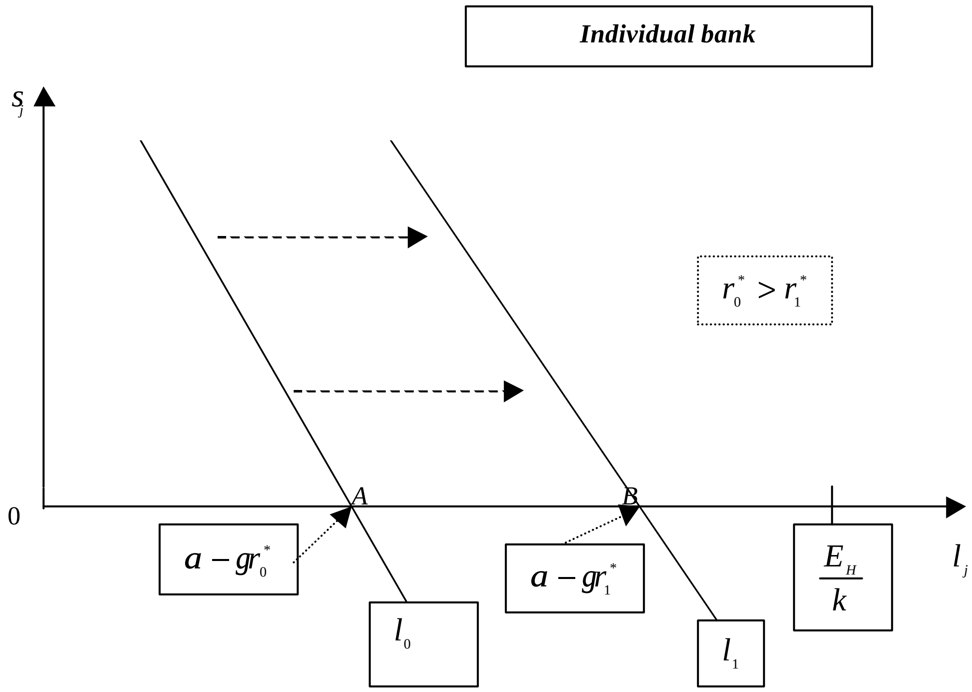


FIGURE 2 – MONOPOLISTIC COMPETITION: EQUILIBRIUM 1 $(u = 0)$

Adjustment following a reduction of *i*



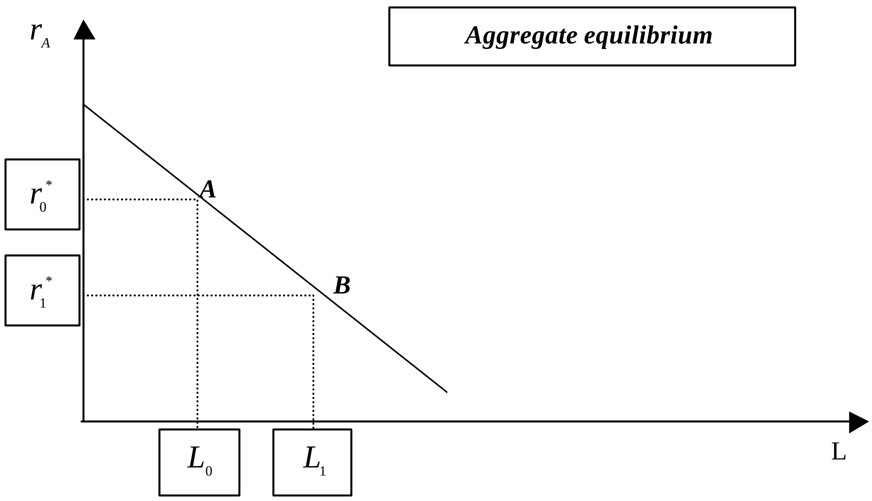


FIGURE 3 – THE MULTIPLIER EFFECT

Adjustment following a reduction of *i (with u=0)*

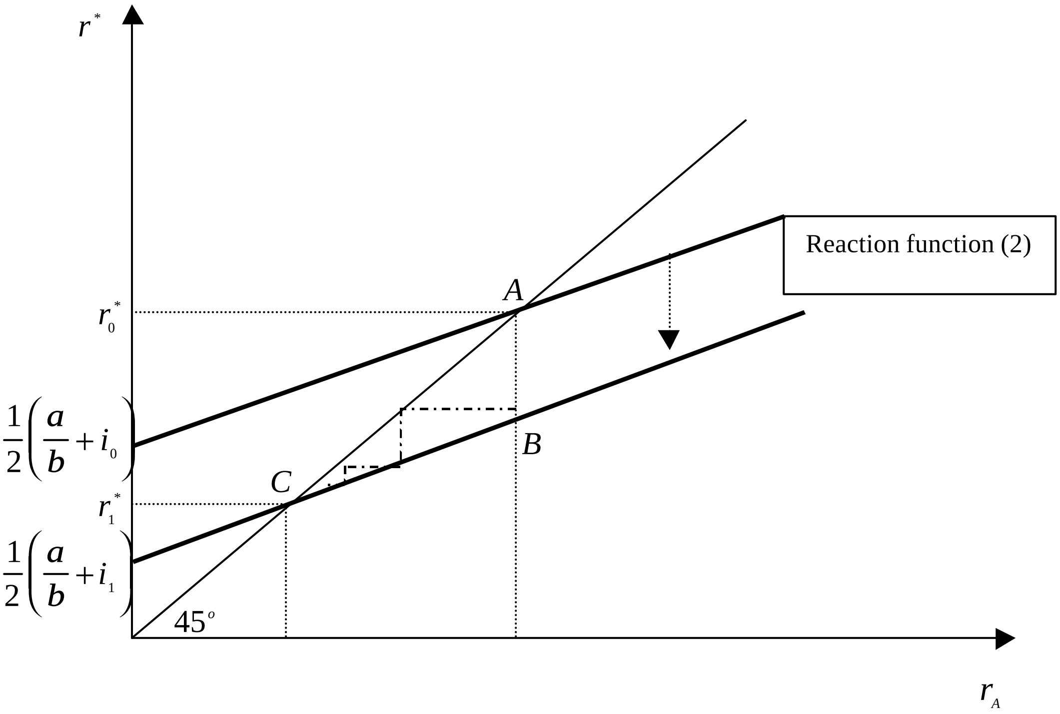
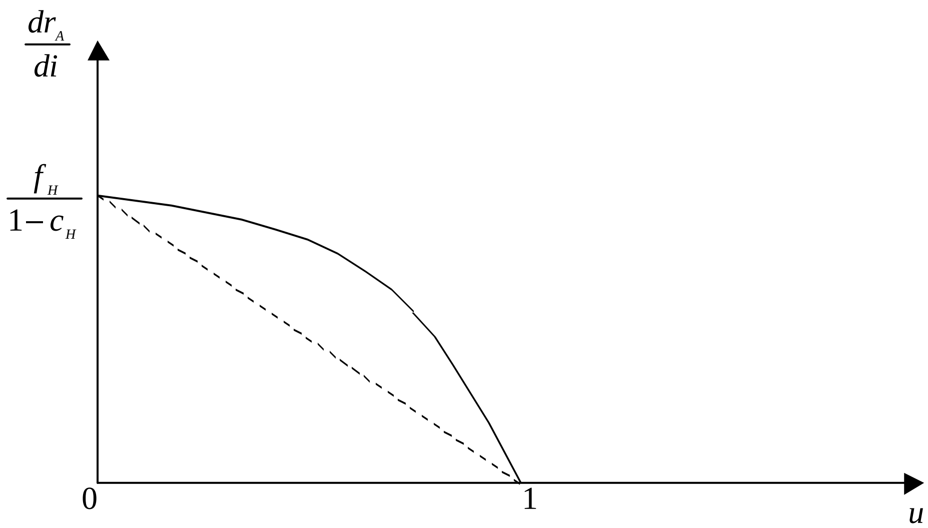


FIGURE 4 – MONETARY POLICY EFFECTIVENESS

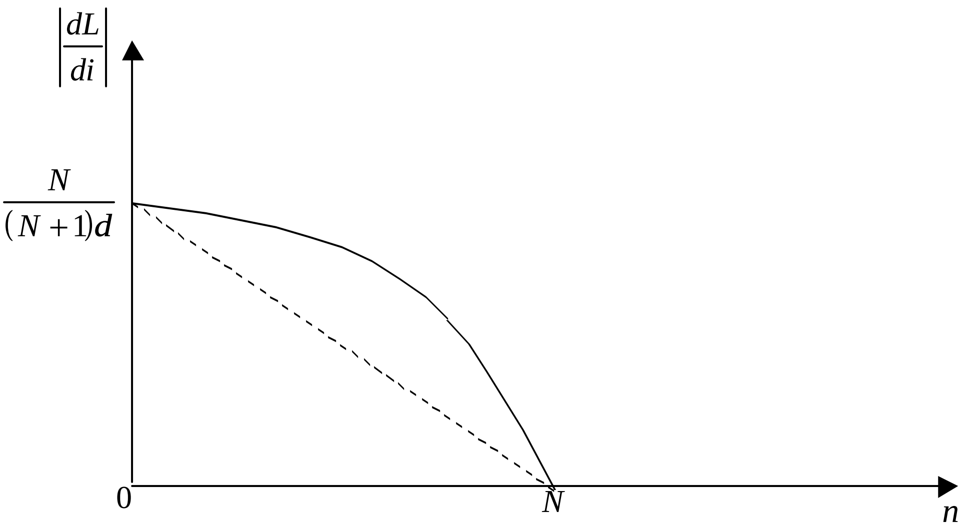
Figure 4-A: Monopolistic competition



Mixed equilibrium: aggregate impact of monetary policy (eq.12)

Average effect of monetary policy (eq.11)

Figure 4-B: Oligopoly

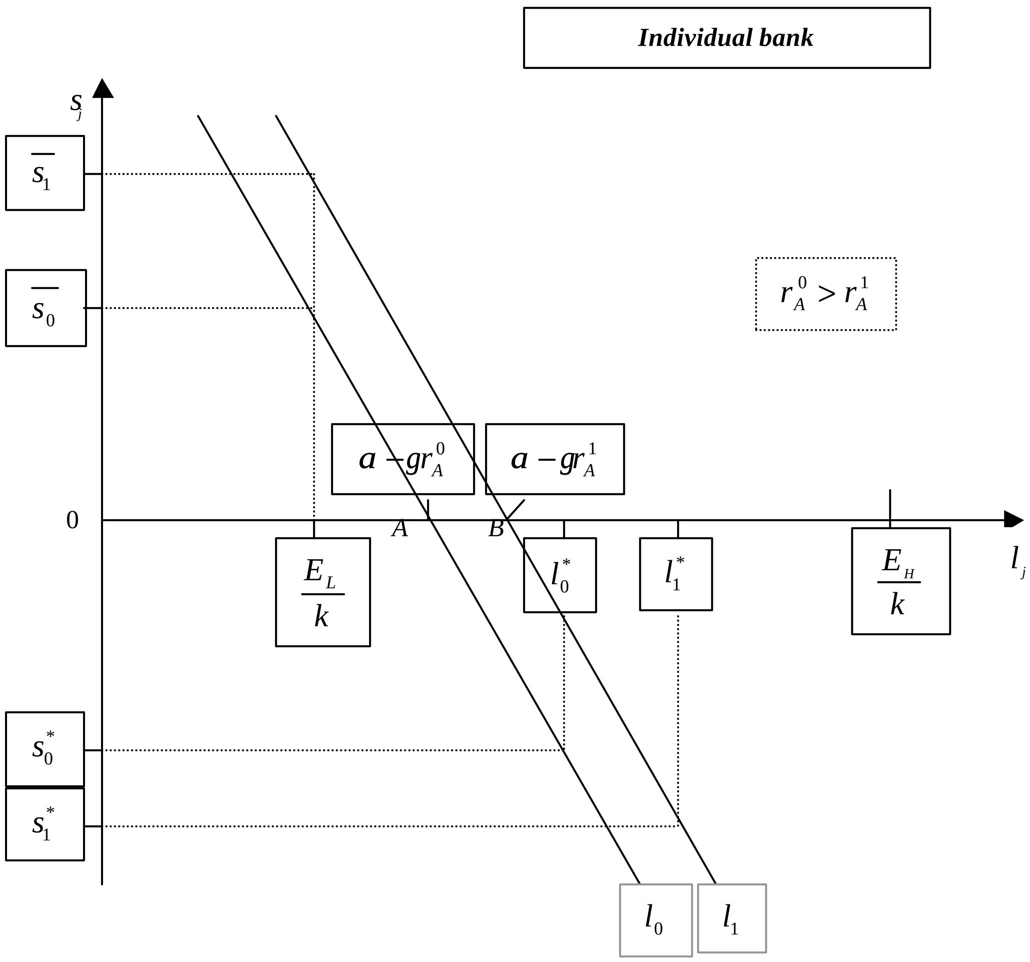


Mixed equilibrium: aggregate impact of monetary policy (eq.25)

Average effect of monetary policy (eq.23)

FIGURE 5 – MONOPOLISTIC COMPETITION: THE MIXED EQUILIBRIUM $(0 < u < 1)$

Adjustment following a reduction of *i*



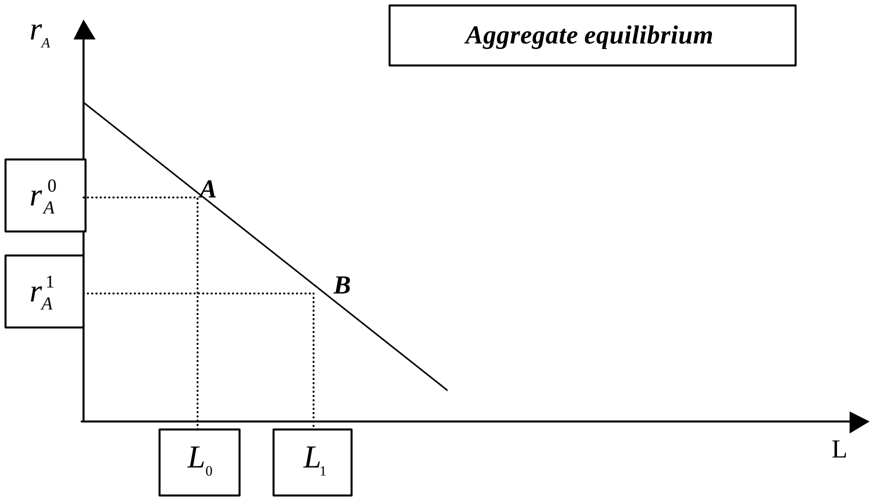


FIGURE 6 – STRATEGIC SUBSTITUTABILITY AT WORK: THE DUOPOLY CASE

Adjustment following a reduction of *i (with n=0)*

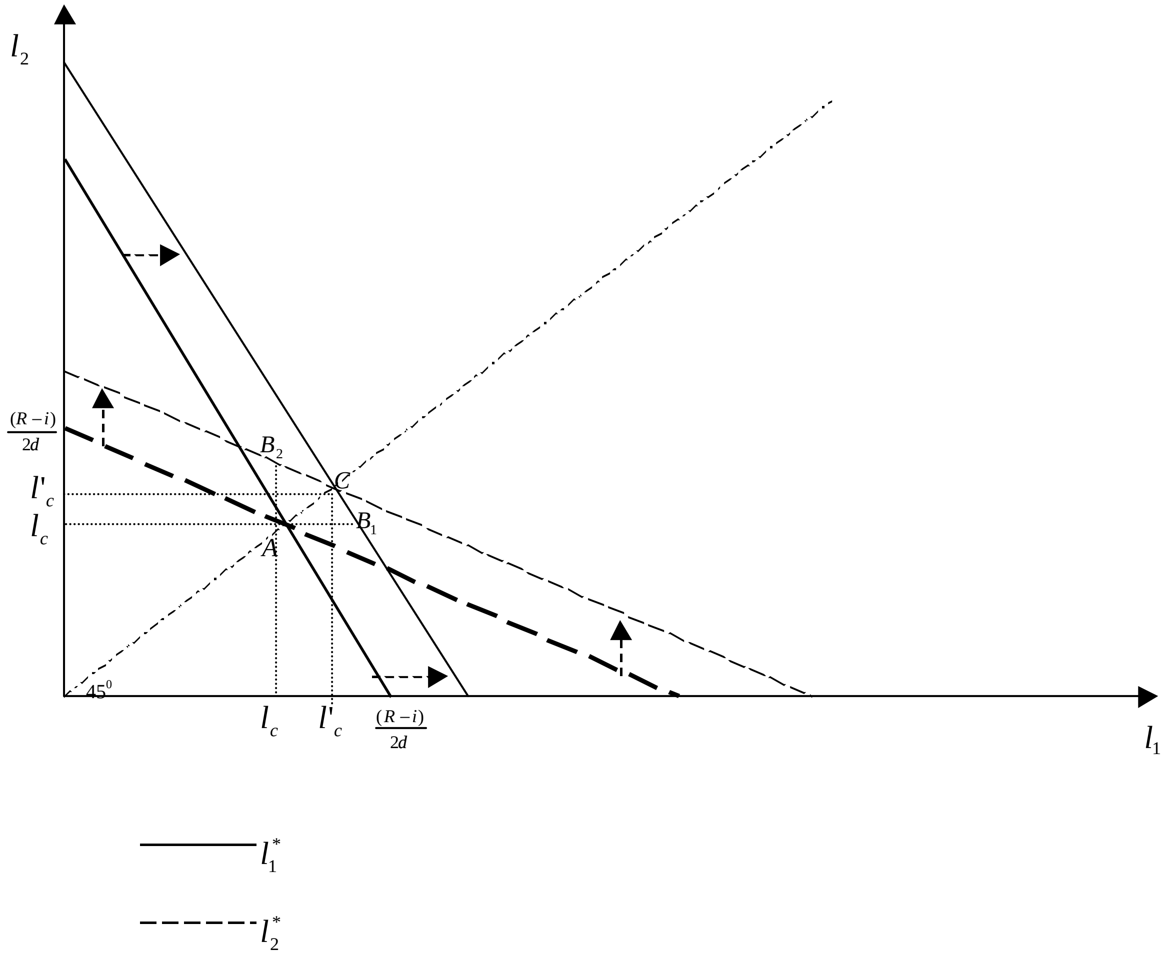


FIGURE 7 – DUOPOLY: THE CONSTRAINED EQUILIBRIUM (n=2)

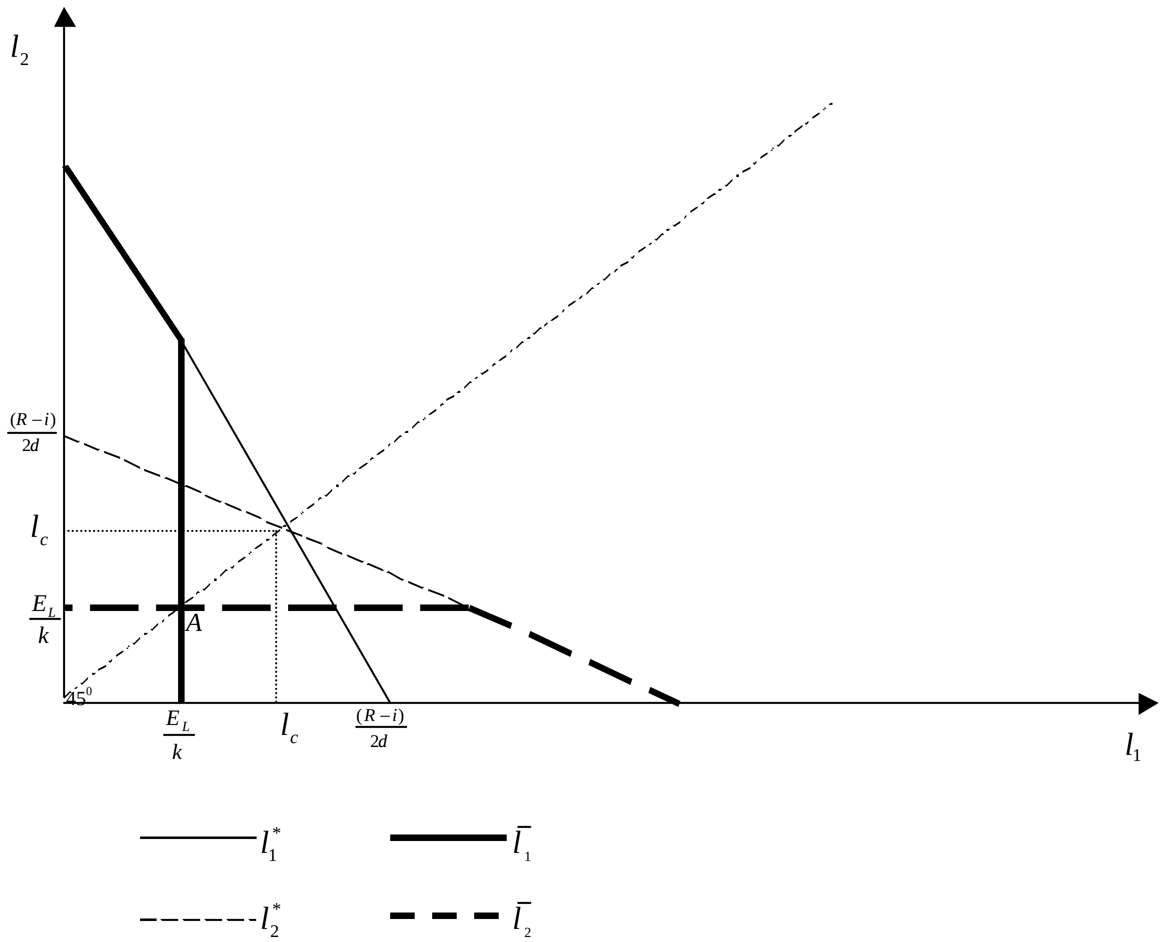
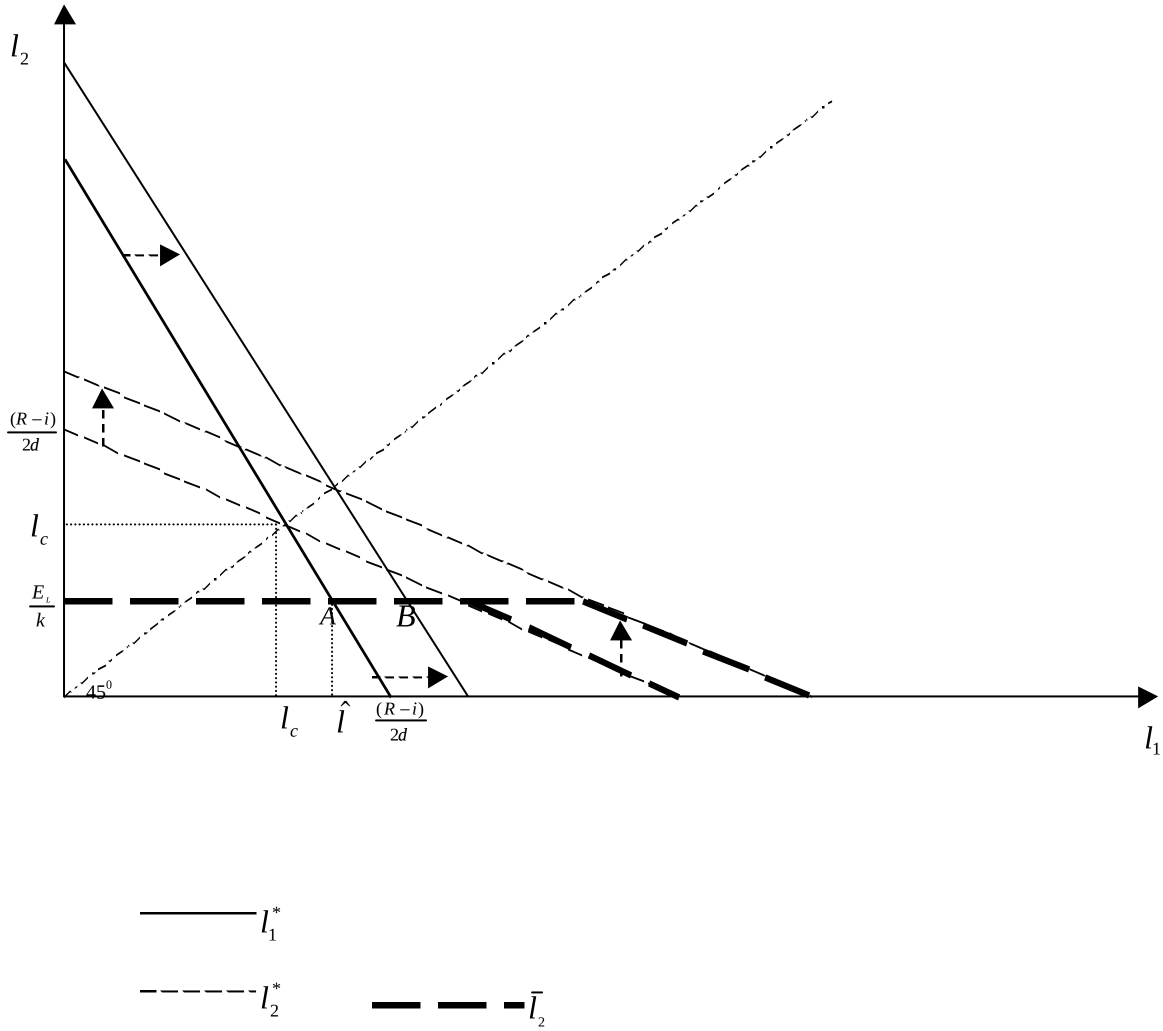


FIGURE 8 – DUOPOLY: THE MIXED EQUILIBRIUM (n=1)

Adjustment following a reduction of i



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