# *Economics Synopsis*
# Why is price stability a key goal of central banks?

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January 2019

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Central banks place great emphasis on maintaining low inflation. A primary objective of central banks in advanced economies is to keep inflation low and stable. This is often defined as inflation near 2% in the medium-run. Here we investigate if this primary objective is consistent with the theoretical literature[1]. We find that the literature confirms that a low and stable level for inflation is efficient.

When money is demanded for transaction purposes, and there is a complete set of tax instruments the optimal nominal interest rate is zero. This policy, also known as the Friedman rule, implies an optimal rate of inflation that is negative and equal in absolute value to the real rate of interest. A negative inflation has the extra advantage of promoting equity, as the inflation tax is a regressive tax. Moreover, a negative inflation can correspond to the growth that maximizes society's welfare. However, if the set of tax instruments is not complete then the Friedman rule may not be optimal. The optimal inflation level depends on which tax instrument is not available and on the particular model (and calibration considered). In many of these cases inflation is still low or negative. But there are reasons to have a positive inflation too. For instance, effective stabilization may require a safety margin, or positive inflation level, because nominal interest rates have a lower bound.

The remainder of the survey proceeds as follows. First, we describe the arguments for a low level of anticipated inflation and later we review the reasons for a stable inflation. We start by providing an explanation of the

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Acknowledgements: This paper uses previous work done in co-authorships with André Silva, Isabel Correia, Sandra Gomes and Sofia Saldanha. I thank Nuno Alves, Isabel Correia, António Antunes and Miguel Gouveia, for valuable comments and suggestions. The opinions expressed in this article are those of the author and do not necessarily coincide with those of Banco de Portugal or the Eurosystem.

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1. We leave outside of this survey the less conventional literature on search models of money. Typically, the optimal inflation rate in these type of models is low too and the costs of inflation even higher than in the standard models. See Lagos and Wright (2005).

Friedman rule. After, we show that the inflation prescribed by the Friedman rule in addition to being efficient promotes equity too. Poor households are better off when inflation is low. Next, we describe why restrictions in the tax system can invalidate the Friedman rule. These restrictions can take various forms and imply higher optimal inflation rates than the one associated with the Friedman rule. We look at a great number of them and conclude that they in general do not justify high inflation targets for the central banks. Later, we review the relationship between inflation and growth. Finally, we argue that surprises in inflation should be avoided.

**Money demand**

The most celebrated result in this literature is due to Milton Friedman (1969). Milton Friedman provided a simple rule for determining the optimal rate of inflation in the long run. He started with the observation that money provides valuable services, as it makes it easier and more convenient for consumers to do transactions. In many transactions the sellers accept both money and credit cards as payment for goods and services, but some only accept cash. A consumer could probably get by with credit cards alone, but this would be more cumbersome because it would imply spending more time seeking out sellers that accept them. Having some money in one's pocket saves the time and inconvenience of doing so. Moreover, some consumers only have access to money as they are not eligible to have a credit card.

Although money is useful for carrying out transactions, it is costly to hold. Monetary instruments, like currency or checking accounts, in general earn less interest than riskless short-term securities such as Treasury bills. The decision to hold more money means investing less in securities that pay more interest, and the opportunity cost of holding money depends on how much interest income is lost. In order to decide how much money to hold, consumers must trade off the benefits of the ease and convenience in carrying out transactions against the cost in terms of forgone interest earnings. In their choices economic agents balance these two factors, holding more money when the opportunity cost is low and less when it is high. But as long as monetary instruments pay less interest than other securities, money will be costly to hold and consumers will have an incentive to economize on its use. In other words the money demand is lower the higher the difference between the interest paid on the other securities and the one paid on money.

But being frugal on the use of money is not socially optimal. Money is costly to hold, but it is essentially costless for central banks to produce. A central bank could make everyone that uses its money better off at no cost by increasing the quantity of real balances (i.e., the nominal quantity of money divided by the price level). The consumers would benefit from additional real balances, because money is more convenient to carry out transactions,

and it is costless for the central bank to provide. Thus, the optimal policy involves eliminating incentives to economize on the use of money. To do so, the central bank should eliminate the difference between interest rates on monetary instruments and on other securities, because then money would be costless to hold.

Since most types of money pay little or no interest, the optimal policy calls for setting nominal interest rates on short-term riskless bonds equal to zero. Setting the nominal interest rate to zero implies that the inflation rate should be equal in absolute value to the real rate of interest. This follows from the fact that in the long run, to a first approximation, the nominal interest rate equals the real interest rate plus inflation. Thus, if the real interest rate were around 2 to 3%, Friedman's arguments suggest that the central bank should follow a negative inflation rate for the economy at a rate of -2 to -3%.

**Inflation tax and other taxes**

Edmund Phelps (1973) criticized the Friedman rule on the grounds that it ignores considerations related to taxation and guessed that the inflation tax should be part of an overall optimal tax scheme. Phelps argued that inflation is a source of tax revenue for the government and that if inflation were reduced other taxes would have to be increased in order to replace the lost revenue. He also conjectured that some inflation would be desirable. That would be the case if the distortions associated with the inflation tax were less costly than the distortions associated with other taxes that the government might resort to.

Phelps raised very important questions. Why is inflation a source of tax revenue? Do the other taxes produce less distortions than the inflation tax? We start by addressing the first question. The government can borrow either by issuing debt or issuing money. In general, borrowing by issuing money is cheaper, as the government pays no interest on money. The revenue from the inflation tax, also known as seigniorage, is the amount the government saves by issuing money instead of debt. Formally, it is the product of the outstanding money times the interest rate (on government bonds). The tax base of the inflation tax is the stock of money and the tax rate is the nominal interest rate. Similarly to the other taxes, there is a Laffer curve for seigniorage. For low levels of interest rate, the real seigniorage increases with the interest rate, but for very high levels of the interest rate, it decreases with the interest rate as the real stock of money decreases more than proportionally with the interest rate.

Phelps argued that the other taxes introduce distortions of their own, which may outweigh the benefits of deflation. What is the nature of these distortions? Taxes distort private economic decisions because they create incentives on the economic agents to alter their behavior in order to avoid the tax. For example, a tax on bread increases the after-tax price that consumers

pay but decreases the pre-tax price that firms receive. An increase in the after-tax price reduces the quantity consumers want to buy, and a fall in the pre-tax price reduces the quantity firms are willing to supply. The tax makes firms worse off because they receive less per unit and produce less units. The tax also makes consumers worse off because they pay more per unit and consume less units. Typically, the government collects revenue from the tax and uses it to provide public goods and services, but the losses of those who pay the tax exceed the revenue collected. The difference between the losses of those who pay the tax and the revenue raised is known as the "deadweight loss" of the tax, and one principle of public finance is that taxes should be chosen in a way that minimizes these losses.

The Friedman rule would certainly not be optimal if the inflation tax was replaced by other tax increases that were even more distortionary. On the other hand, the fact that governments must choose among distortionary taxes does not necessarily invalidate the Friedman rule. The optimal mix depends on how distortionary the various taxes are. Phelps conjectured that at low rates of inflation, distortions associated with the inflation tax might be minor and that replacing the inflation tax with other taxes might result in greater deadweight losses. It turns out that Phelps's conjecture was inaccurate. The inflation tax is more distortionary than the other taxes.

Two set of results from public finance justify the Friedman rule even when all taxes are distortionary: the Diamond and Mirrlees (1971) optimal taxation rules of intermediate goods and the taxation rules of final goods developed by Atkinson and Stiglitz (1972). Intermediate goods are those goods which are used in the production of other goods and services. Taxes on these commodities are inefficient, according to Diamond and Mirrlees (1971), because they introduce two sets of distortions. First, they reduce production efficiency and increase the cost of producing final goods. Second, as this increase in cost affects the final goods prices, they distort final goods markets as well. As an alternative, the same revenue can be obtained by taxing final goods directly, and while this would distort final goods markets, it would not distort production efficiency. The optimal commodity taxation of final goods was established by Atkinson and Stiglitz (1972). According to them, under certain conditions, the optimal commodity taxation of final goods should be uniform. All final goods should be taxed at the same *ad valorem* rate.[2]

Economists have been modelling money in different ways. There are economists that classify money as an intermediate good and there are other economists that classify it as a final good. The first set of economists say that money, unlike a consumption good, is intrinsically useless. Money is valuable because it facilitates transactions, and as such it should be considered an intermediate good. Thus, according to Diamond and Mirrlees (1971) rule, the

2. An *ad valorem* tax is a tax whose amount is based on the value of the transaction.

inflation tax is really an indirect tax on other goods and taxing those goods directly is more efficient. The Friedman rule is a corollary of this public finance rule.

Other economists consider monetary models with less reasonable micro foundations, in which money is a final good. In this case the rules on optimal taxation, described by Atkinson and Stiglitz (1972) could justify Phelps' insight. These rules apply to *ad valorem* taxes on costly goods, and involve the comparison of the marginal excess burdens of alternative taxes that give the same revenue. However, the application of these rules to money is not straightforward for two reasons. Money has a negligible production cost and the inflation tax is a unitary tax, not an ad valorem tax.[3] Correia and Teles (1999) explain why the Friedman rule holds even when money is a final good. Here is their intuition. Assume a world with two consumption goods. One unit of good 1 can be produced with one unit of time while one unit of good 2 can be produced with $\alpha$ units of time. According to Atkinson and Stiglitz (1972) the optimal ad-valorem taxes on good 1 and 2 are equal to some positive tax $\tau$. Measured in units of good 1 the unitary tax rate of good 2 is $\alpha\tau$. If the production costs of good 2 converges to zero, i.e. $\alpha$ goes to 0, then the unitary tax rate on good 2 when measured in units of good 1 is zero. Thus, also in a world where the alternative taxes are all distortionary, it is the zero marginal cost of producing money that implies a zero opportunity cost of holding money, that is a zero inflation tax.[4]

**Incomplete set of tax instruments**

One reason why the Friedman rule might not be optimal is when the tax system is incomplete. Phelps (1973) conjecture for inflation is valid when there are restrictions on taxation, that is, when there are factors of production, goods, monopoly profits or rents that cannot be taxed optimally. The optimality of the zero inflation tax is denied because the general conditions under which the two rules of public finance hold are violated. The production efficiency is undermined by the impossibility of setting taxation at an optimal level for some final goods or services. Various examples of this type of situation have been studied in the literature.

For instance Schmitt-Grohe and Uribe (2004) show that if the government is unable to fully tax pure monopoly profits, then deviating from the Friedman rule may be desirable. Taxing fully profits is optimal because it is a lump-sum

3. An unitary tax rate is based on the physical units transacted.

4. Burstein and Hellwig (2008) considered a model with money in the utility function and estimated the welfare costs of a 10% inflation to be about 1.3% to 2% of consumption. Lucas (2000) considers a shopping time model of money and reports welfare costs around 1%. Lagos and Wright (2005) in a search model of money report welfare costs between 3 and 4%.

tax, i.e. it does not have distortionary effects. When the government is unable to optimally tax profits, positive inflation may be a desirable instrument to tax the part of income that is sub-optimally taxed. The reason is that because at some point all types of private income are devoted to consumption, and because inflation acts as a tax on consumption, a positive nominal interest rate represents an indirect way to tax all sources of income. The higher the profits the higher will be the optimal inflation level. Schmitt-Grohe and Uribe (2004) determine that an optimal rate of inflation of 2% would require a mark-up, between cost and price, exceeding 30 percent, which is on the high end of the empirical estimates for most developed countries.

Adão and Silva (2018) provide another example, they show that when there are government transfers the Friedman rule fails too. Some government transfers, which represent pure rents, should be taxed by inflation. The optimal inflation rate increases significantly with the amount of these transfers. When transfers (net of income taxes) as a percentage of GDP are 5%, the optimal inflation rate is about 80 basis points but when they are 10% of GDP the optimal inflation rate is around 6%.

The failure of the Friedman rule due to tax evasion was established by Nicolini (1998). He considered a model with an underground economy sector in which firms evade income and consumption taxes. This underground sector generally consists of unregistered companies and small businesses that are usually owner-operated and that typically do not engage in illegal activities. They are just not regulated or taxed by the government. The firms operating in the underground economy enjoy a pure rent given by the amount of taxes that they manage to evade. Given that the underground economy uses cash intensively and is difficult to reach with other tax instruments, the government could indirectly tax these pure rents by imposing a positive inflation tax.

To understand the intuition it is helpful to consider the extreme case where cash is only used to purchase goods in the underground economy while purchases in the rest of the economy are made with credit. Then a consumption tax would only affect credit transactions. In this case uniform commodity taxation could be achieved by imposing, in addition to the consumption tax, a positive inflation tax. However, in the real world, where cash and credit are used for transactions in the above-ground economy, there is a trade-off between the consumption tax and the inflation tax. A positive nominal interest rate can partially balance tax rates across commodities by redistributing the tax burden from the consumption tax to the inflation tax on cash purchases in the underground economy.

Schmitt-Grohe and Uribe (2011) compute that for a 10% share of underground economy, which is regarded as reasonable for a developed economy, the optimal rate of inflation is only 50 basis points above the one associated with the Friedman rule. An inflation of 2% would require an underground economy around 1/3 of the total economy, which is

unrealistically too high. On the other hand, Cavalcanti and Villamil (2003), using a different monetary model with an informal sector[5], find that the optimal inflation is around 0% when the share of the underground economy is about 10%, and the optimal inflation is 6% when the share of the underground economy is 30%.

These three examples have in common that the monetary authority finds it optimal to use inflation as an indirect levy on pure rents that would otherwise remain untaxed. The literature has quantitatively evaluated them and found that depending on the fiscal instrument that is missing, the size of source of income that cannot be taxed and the monetary model that is used the departure from the Friedman rule can be timid or substantial.

**The inflation tax is regressive**

The evidence indicates that the income elasticity of the demand for money is less than one, which means that the poorer households hold a larger fraction of their income in money and conduct a bigger share of their transactions with money than the richer households. Based on this evidence Erosa and Ventura (2002) and Adao and Correia (2012) show that anticipated inflation has redistributive effects, which can justify a negative inflation. In Adao and Correia (2012) it is assumed that households perform transactions using either cash or costly credit. As transactions with credit exhibit economies of scale, optimality implies that a larger consumption level uses a larger share of credit. The transaction costs per unit of consumption decrease with the volume of consumption as they use a higher share of credit. Since high income households consume more than low income households they pay a higher fraction of their purchases with credit, pay lower transactions costs per unit of consumption, and hold less money as a fraction of total assets than low income households. Because high income households are better at avoiding the inflation tax than those with low incomes it follows that inflation is a regressive tax. This channel, therefore, is likely to put downward pressure on the optimal rate of inflation, insofar as the objective function of the policymaker is egalitarian.

Adão and Correia (2018) calibrate their flexible price model to the U.S. wealth and income distribution quintiles. They find that the effects on equity tend to reinforce the effects on efficiency. There is no trade-off: a lower inflation increases efficiency and equity. Moreover, they confirm that the impact of a moderate inflation varies across the quintiles. For a 10% inflation, after taking into account all costs with transactions and consumption taxes, the poorest

5. The two models differ with respect to the shopping time transaction technologies and production functions. The calibrations considered in the two papers are different too.

quintile of the population pays 3% more per each unit of consumption than the richest quintile. For low levels of inflation the difference is small. For instance, for an inflation of 2% this difference is about 0.3%.

**Menu costs, sticky prices and relative price dispersion**

There is a large and more recent literature, the neo-Keynesian literature, which in general abstracts from the role that money has in facilitating transactions and gives more importance to the interaction between inflation and nominal rigidities in the form of sluggish price adjustments. The models in this literature assume that some prices and wages cannot move so as to clear markets. Instead, firms change prices infrequently because it is costly to change them, even if these costs are small. These costs are referred to as menu costs and the models that incorporate these costs explicitly (or implicitly) are known as sticky price models. The typical example given is that of a restaurant, which must print new menus whenever it changes its prices. Printing menus is costly and this causes the restaurant to change prices only once in a while.

The majority of the models in this literature does not incorporate explicitly the menu costs in the pricing decision of the firms. Instead, they simplify the problem of the firms. They assume that in each period only a fraction of the firms can adjust their price, which will be invariant for some time in the future, until they have the opportunity to change it again. This implies that prices fail to adjust promptly and uniformly to changing market conditions. Such nominal rigidities in general lead to relative price dispersion. For instance, if in the presence of positive inflation some firms do not change their prices while others do. The firms that do not change their prices will have prices too low relative to the average price. This price dispersion, not caused by changes in preferences or technology, leads to a misallocation of resources. The best policy in this case is to minimize price dispersion by setting inflation to zero.

The welfare costs of a positive steady-state inflation in a sticky price model without explicit menu costs are somewhat different from the costs in those models that incorporate them explicitly. In the first type of models, higher inflation leads to greater price dispersion which leads to a more inefficient allocation of resources among firms, thereby lowering aggregate welfare. In the second type of models, there is an additional channel affecting welfare. Firms change their prices more frequently the higher is inflation, and this decreases welfare because firms incur in menu costs more often.[6]

6. Burstein and Hellwig (2008) determine that the welfare costs of inflation are much higher in an economy with Calvo style price staggering, than in a menu cost economy. In their benchmark model with money in the utility function and menu costs the welfare costs of a 10% inflation

More realistic monetary models incorporate both frictions, the price stickiness and the transactional demand for money. In such models the optimal rate of inflation falls in between the one determined by the money demand friction, deflation at the real rate of interest, and the one determined the sticky price friction, zero inflation. The intuition behind this result is simple. The benevolent government faces a trade-off between minimizing price adjustment costs and minimizing the opportunity cost of holding money. Khan, King and Wolman (2003) were the first to quantify the optimal policy. For their benchmark calibration the inflation under the optimal policy is -76 basis points. Thus, the quantitative analysis suggests that the trade-off is decided in favour of price stability.

Correia, Nicolini, and Teles (2002) point out that these neo-Keynesian models are also models with an incomplete set of tax instruments. They consider a neo-Keynesian model with money as a facilitator of transactions and prove that if the government can set state-contingent consumption taxes, then it is optimal to set the nominal interest rate to zero at every date and state. The basic intuition is the following. If there were no costs of changing prices then all firms would change their price after a shock and there would not be any relative price distortion. However, if prices are sticky, some firms would change their prices (incurring in menu costs) while others would not, which originates a relative price distortion. They show that this price distortion can be avoided by the government if the prices gross of consumption taxes change in response to the shock in such a way that no firm has the incentive to change its own price.

**Downward nominal rigidities in factor prices**

One reason to target a positive inflation is the presence of downward nominal rigidities. Allocative efficiency requires that relative prices should reflect the relative marginal costs of production. If these relative costs change then the relative prices should change too. If nominal prices are downward rigid, and contingent consumption or labor income taxes are not available, then any relative price change can only happen with an increase in the aggregate price level. Since variations in relative prices are efficient, a positive rate of inflation, aimed at accommodating such variations is welfare improving. An important example of a downward rigid price is the nominal wage. There is evidence for several developed economies of downward nominal wage rigidity,[7] which

are 1.3% in terms of consumption-equivalent variation. Calvo-style staggered pricing raises the welfare costs to 3.4%.

7. The downward nominal wage rigidity is due to the stringency of the employment legislation, the high coverage of collective agreements, and the dominance of sector-level bargaining and widespread extension procedures. Additionally, the downward nominal wage rigidity might be

acts as an obstacle to labour market adjustments.[8] Positive inflation alleviates this problem by allowing real wages to adjust in face of negative shocks, even if nominal wages do not fall, and avoid an increase of unemployment. A natural question, therefore, is how much inflation is necessary to 'grease the wheel of the labor market.' The answer appears to be not much. An incipient literature using estimated macroeconomic models with downwardly rigid nominal wages finds optimal rates of inflation below 50 basis points.[9]

Inflation rates can differ across regions of large countries (or monetary unions), reflecting among others: normal adjustment processes (such as price convergence or the Balassa-Samuelson effect), different cyclical position of the region, different composition of consumption, economic distortions resulting from segmented markets and insufficient competition. In the presence of frictions that make market changes more difficult, like downward nominal wage rigidities, adjustments within a large country (or monetary union) are easier if the central bank has a higher target for inflation. It would be easier as it would avoid having regions with extremely low inflation or even deflation, when that is not optimal. To our knowledge no fully fledged model has been built to address this specific question.

**Zero bound on nominal interest rates**

Stabilization is another main goal of central banks. Stabilization increases welfare because it reduces the spurious fluctuations of the main macroeconomic variables and promotes economic growth.[10] Central banks use the nominal interest rate to stabilize economic activity. Since prices take time to adjust when a central bank changes the nominal interest rate it affects temporally the real interest rate and the aggregate demand. Thus, in response to a negative shock to economic activity, central banks reduce the nominal interest rate as a way to decrease the real interest rate and foster aggregate demand.

Common sense would indicate that the lower the inflation rate the higher the risk of the nominal interest rate hitting the zero lower bound. Thus, a central bank's ability to conduct successful stabilization policy can be restricted if the rate of inflation is very low. To determine rigorously the

related with the "morale effects" associated with wage cuts (see Bewley (2002)). Du Caju et al. (2008) measure the strength of employment protection laws in 23 EU countries and concludes that it ranges from the high level of Spain, Portugal and Greece to the very low level of Ireland.

8. Evidence based on micro data and firm surveys suggests significant nominal wage rigidity in developed countries. See ECB (2009) for a survey of the evidence for Europe.

9. For instance, Kim and Ruge-Murcia (2009) quantify this effect, and get an optimal inflation rate of 35 basis points.

10. Gadi Barlevy (2004) argues that fluctuations can affect welfare, by affecting the growth rate of consumption. He estimates that the welfare effects are likely to be substantial, about 8% of consumption, much larger than Lucas' original estimates.

inflation level that enables a successful stabilization policy it is necessary a macroeconomic model calibrated (or estimated) to fit a real economy and a central bank that follows a reasonable (or optimal) monetary policy. A few exercises of this sort have been done. Most of these studies recommend an inflation rate below 2%. Coibion et. al. (2012) calibrate a sticky price model to broadly match the moments of macroeconomic series and the historical incidence of hitting the zero lower bound in the U.S., and solve for the rate of inflation that maximizes welfare. For plausible calibrations of the structural parameters of the model and reasonable properties of the shocks driving the economy, the optimal inflation rate is less than 2%. The result is robust to changes in parameter values, as well as to the stabilization policy followed by the central bank.

There are other factors that should be taken into account when considering the impact of the zero lower bound on the optimal inflation level, which current models in general do not contain. One is that unconventional monetary policy can mitigate the constraint posed by the zero lower bound. The quantitative evaluation of the strength of the unconventional monetary policy is still work in progress, but the existing results point towards the effectiveness of the unconventional monetary policy, though the evidence regarding the degree of effectiveness is mixed.[11] [12] Another argument has to do with the idea that in a higher inflation environment agents adjust their holdings of money and prices more frequently, reducing the impact of changing the policy rate on the real rate and thus on the macro variables. This feature is usually not included in macro models used to evaluate the relevance of the zero lower bound constraint, which typically assume that the frequency of adjusting prices does not change and that there is no opportunity cost of holding money. If one considers this type of adjustment, a higher target may not necessarily provide a larger buffer against the zero lower bound.[13] Finally, when there are downward nominal wage rigidities firms that experience large negative shocks will have to adjust not by cutting wages but by laying off more workers. Thus, the nominal aggregate wage, or the unitary labour costs,

11. The existing studies vary on the degree of unconventional monetary policy success that is found. Some find that the effects are more moderate than conventional monetary policy while others find that they are comparable if not greater. For instance Chen, Cúrdia and Ferrero (2012) find that the unconventional monetary policy is less powerful than the conventional policy, but on the other hand Gilchrist, López-Salido and Zakrajsek (2014) find that the efficacy of unconventional monetary policy in lowering real borrowing costs is comparable and in some cases is twice as large as that of conventional policy (like for real corporate borrowing costs).

12. Dorich et al. (2015) results with the Bank of Canada's main macroeconomic model find that the possibility of using unconventional monetary policy basically offsets the need to increase the inflation target due to a fall in the real rate.

13. For instance Adão and Silva (2015) estimate for the US in 2000 that an unanticipated temporary decrease of 30 basis points in the nominal interest rate would decrease the real interest rate after one month by only 3 basis points, while in 2013 the same shock would decrease the real interest rate by 12 basis points.

do not fall by as much when there are downward nominal wage rigidities. As a result, by moderating declines in nominal wages, downward nominal wage rigidities moderates changes in prices and consequently in policy rates.[14] This dampening effect reduces the frequency of zero lower bound episodes for any given inflation target and, therefore, the case for a high inflation to avoid zero lower bound episodes is not as strong.[15]

**Growth rate and inflation**

There are many empirical studies that examine the relation between inflation and economic growth. Most of these studies report a negative correlation between inflation and economic growth during periods of high inflation (2 digits). For periods of low inflation the correlation tends to be statistically insignificant. On the other hand, there are few theoretical studies on this relationship. Recently, Oikawa and Ueda (2018) provided a model with a negative correlation between anticipated inflation and growth. In their model inflation (and deflation) has real growth effects. They consider an endogenous growth model with sticky prices due to menu costs. In the model growth is positively correlated with R&D investment. The higher the present value of the profits associated with R&D investment is, the higher its level will be.

In their model the growth rate of the nominal variables is equal to $n = g + \pi$, where $g$ is the real growth rate of the economy and $\pi$ the inflation rate. Everything else equal, the higher the nominal growth rate, the more often the firms have to change the price of their products and incur more menu costs. If the growth rate of the nominal variables is different from zero, firms would like to change their prices, which would reduce the reward for innovation and lower the level of R&D investment. As such the optimal solution in this model is to have a nominal growth of zero. In this case, firms abstain from changing their prices and avoid paying the menu costs.

In the model there is a relationship between the nominal growth rate and the real growth rate, i.e. $g$ is a function of $n$, $g(n)$. On a balanced growth path for a given inflation rate, the real and nominal growth rates have the relationship $\pi = n - g(n)$. The pair of growth rates is pinned down by choosing an inflation

14. If the Taylor rule has a high weight on inflation's deviations from target and a low weight on output fluctuations then it is possible that with downward nominal wage rigidities the inflation target could be lower.

15. When both frictions are considered simultaneously (zero lower bound and downward nominal wage rigidities) the optimal inflation level might be smaller. Amano and Gnocchi (2015) find that by adding downward nominal wage rigidities into a sticky price model which already incorporates the zero lower bound, the optimal inflation target decreases. More specifically, without any of these two frictions the optimal inflation target is 0%, with the zero lower bound only is 4.5%, with the downward nominal wage rigidities only is 1% and with both frictions is 1.5%.

rate. The optimal inflation rate is the one that corresponds to the growth level that maximizes the households' welfare. Oikawa and Ueda (2018) calibrate their model to the U.S. economy and obtain interesting results. The optimal inflation rate is very close to the growth-maximizing inflation rate, which is around -2%. The cost of suboptimal inflation is substantial, on the balanced growth path, the growth rate is reduced by half at about 10% inflation or deflation.

**Other arguments discussed in the literature:**

***Tax collection costs***

Other arguments have been suggested in the literature to justify a positive inflation tax. One is the tax collection costs, which is an important difference between the traditional fiscal instruments and the inflation tax. While raising revenue with the inflation tax is costless, raising revenue with the other tax instruments implies higher costs. These costs include the burden of organizing the tax system and enforcing it. When these costs are taken into account then the Friedman rule is not optimal. De Fiore (2000) quantifies how important these are. She reports that under the most unfavorable (and unrealistic) case, where these costs are all variable costs and tax collection requires throwing away 20 percent of the government revenue, the optimal inflation tax remains below 1%. A different study, Yesin (2004), considers simultaneously tax collection costs and the presence of an informal sector and obtains that for the U.S. the optimal inflation is around 4%.

***Foreign demand for domestic currency***

A few countries, like the US and the E.U., have a currency with a positive foreign demand. For instance, it is estimated that more than half of U.S. currency circulates abroad. The Friedman rule is not optimal once there is a foreign demand for the domestic currency. The intuition is that the deflation implied by the Friedman rule would represent a transfer of real resources by the domestic economy to the rest of the world, as nominal money balances held abroad increase in real terms at the rate of deflation. Inversely, a positive inflation would entail collecting resources from foreign residents. Thus, the benefit of inflation is the resources collected abroad, while the cost would be a higher opportunity cost of holding money which would increase transactions costs for domestic agents. It turns out that the marginal benefit and marginal cost are equated for an inflation larger than the Friedman rule inflation.

The fraction of the seigniorage paid by foreigners is proportional to the fraction of domestic currency held abroad. The higher the fraction held by foreigners and the more inelastic is the foreign demand the larger is the benefit

of inflation and larger is the optimal rate of inflation. Schmitt-Grohe and Uribe (2011) quantify the optimal rate of inflation. Using a range of empirical estimates for the size of foreign demand for U.S. currency they come up with optimal rates of inflation between 2 and 10%. The value of 10% is obtained for a very high demand of foreign currency. Again, this argument for a relatively high inflation rate does not apply to the majority of countries because they do not have an international demand for their currency.

### *Quality improvements and measured inflation*

The quality of the goods improves over time but, the price observed by the statistical agencies is the price of a physical unit of the good not the price of the good per unit of quality. This implies that if there is not a quality adjustment in the measured prices, the consumer price index will overstate the true inflation. The classic example used to illustrate this potential quality bias in inflation is the evolution of the price of the personal computer. The quality of personal computers, measured by characteristics such as memory, processor speed, and screen quality, increases every year. Suppose that the price of personal computers between 2017 and 2018 increased 2%. If the statistical office in charge of producing the consumer price index did not adjust the price index for quality improvements, then it would report a 2% inflation in personal computers. However, because a personal computer in 2018 provides more services than does a personal computer in 2017, the quality-adjusted rate of inflation in personal computers is lower than 2 percent.[16]

In the presence of improvements in the quality of goods, to guarantee price stability, and welfare maximization in a sticky price economy, the central bank might target either a positive, or a zero or a negative inflation. It will depend on two things: (i) whether the price stickiness is in the non-quality or in the quality adjusted prices and (ii) whether the statistical agency in charge of computing the price index used to determine inflation adjusts or not the prices for quality. The intuition is provided below.

Assuming there is a positive degree of price stickiness in the economy then the optimal policy should try to keep the prices of the goods that are sticky constant over time to avoid inefficient price dispersion. If the price stickiness is in the non-quality adjusted prices then the optimal policy should try to keep these prices constant over time. If the statistical agency responsible for constructing the consumer price index does not correct the prices for the quality of the goods then targeting a zero inflation rate is efficient. On the other

16. The difference between the reported rate of inflation and the quality-adjusted rate of inflation is called the quality bias in measured inflation. In 1996, the Boskin report (Boskin et al. (1996)) estimated the quality bias to be around 0.6 percentage points for the US. This bias is not constant over time as it depends on the economy's structure as well as on the index methodology used. Nowadays, this bias seems to be negligible for many developed countries.

hand, if the statistical agency adjusts the index to reflect quality improvements then to guarantee the non-quality adjusted price does not change, the price index should be falling at the rate of quality improvement. This means that the optimal deflation rate is equal to the rate of quality improvement. Thus, the optimal inflation is either zero (when the statistical agency does not correct the price index for quality improvements) or negative at the rate of quality improvement (when the statistical agency does correct the price index for quality improvements).

However, if instead it is the quality-adjusted prices that are sticky, then the optimal inflation is either zero (when the statistical agency does corrects the price index for quality improvements) or positive at the rate of quality improvement (when the statistical agency does not correct the price index for quality improvements). Ultimately, it is an empirical question whether it is the non-quality adjusted or it is quality adjusted prices that are stickier.[17] Nonetheless, given that at the present most statistical agencies correct for quality, the optimal inflation level should be either negative or zero.

**Costs of unexpected inflation**

Thus far we have discussed the optimal long-run level for inflation. We now address the importance of a stable inflation. An important recommendation in the literature on the optimal inflation is that inflation should be stable in order to avoid inflation surprises. Unexpected inflation has welfare costs. A stable rate of inflation is good for everyone, because it facilitates the use of prices in making decisions by all agents in the economy. A variable inflation rate makes it difficult to distinguish changes in the relative prices from changes in the aggregate price, which implies an efficiency loss in the allocation of the resources in the economy. For instance in Lucas (1972), when firms observe the price of the good they produce increasing more rapidly than expected, they might believe that there was an increase in the demand for their product. That will lead firms to increase aggregate supply which leads to a too high level of output in the economy. Also, if workers know in advance the rate of inflation, that helps them determining the purchasing power of their wages, and take better employment decisions. Similarly with homebuyers, knowing future inflation helps determining the real cost of a particular mortgage loan. Lenders and borrowers also benefit from knowing how much of a particular interest rate represents real interest. In short, stable inflation improves welfare by eliminating one source of uncertainty in economic life.

Unanticipated inflation may also have important distributional effects. Surprises in the inflation rate lead to redistributions of income and wealth

17. This question has not been fully addressed by the empirical literature on price rigidities.

between various groups of the population. Unanticipated higher inflation leads to a redistribution of wealth from lenders to borrowers, and unexpected lower inflation redistributes wealth in the opposite direction. Typically, the government sector is a nominal borrower while households are savers. As a result, an unexpected increase in the rate of inflation causes a redistribution from the latter to the former. In addition, there is also a redistribution of wealth inside the household sector, from the old generation (that usually holds higher amounts of nominal assets) to the new generation. This principle applies to other nominal contracts besides loan contracts. Two examples: an inflation above what was expected implies for the pensioners a deterioration in their real pension and for workers a deterioration in their real wage.

If inflation was observable and contracts could be indexed then the two problems described above could be eased substantially. With observability of inflation the economic agents could distinguish between relative price changes and aggregate price changes. Inflation indexation could alleviate the arbitrary redistributions of income. However, observability and indexation only offer a partial resolution to the problems caused by inflation.

There are two reasons for this. First, there is not perfect observability of inflation. Data on current inflation is not available in real time. Typically in developed countries, the CPI is estimated monthly and released in the middle of the following month, while the GDP deflator, which is more relevant for firms, is estimated quarterly and released in the middle of the following month. Second, there are many different possible measures of the price level, depending on the bundle of goods used in calculating the price index. A suitable measure for one economic agent might not be suitable for another. Unexpected changes in relative prices through time will favor some households at the expense of others, depending on the bundle of goods they consume. Indexing using the CPI for example may hurt a particular borrower if the CPI falls but the bundle of items that person consumes nevertheless rises in price. Also, in general, employers and workers will not agree on which basket of goods to target either. Employers will not be willing to provide full indexation to workers, because firms' costs and revenues will not rise in the same amount with the CPI inflation. Lender banks, of course, can lose in a similar way. Alternatively, maybe the borrower is interested in what he can afford to pay back; in that case he wants the contract indexed to the nominal wage.

Thus, indexing does not eliminate completely the risk. Both parties must expect that their risk of loss will be reduced with indexation to inflation, on average, but not completely eliminated. On the other hand, the costs of writing contracts indexed to inflation are higher than the costs of non-contingent contracts. These costs include: (i) bargaining costs over which indexes to adopt and the respective weights, and (ii) monitoring those indexes. In periods when the unanticipated movements in the price level are likely to be small, the risks from indexing and the risks from unanticipated inflation are of

the same order of magnitude. On the other hand, indexing is meaningful if unanticipated price level movements are large and frequent. In this case, the risks of unanticipated inflation exceed the risks associated with adopting a particular index. Indexing is therefore more likely to be observed in countries which tend to experience a lot of price level variability and less likely in countries whose inflation rates have tended historically to be quite stable.

Inflation interacts with the tax system in many ways, and as the various taxes are typically not fully indexed to inflation, it can cause additional distortions. We exemplify this with three examples. It might increase the effective marginal income tax rate of a progressive tax system, if the personal income tax brackets are not fully indexed to inflation. When nominal income increases, due to inflation, people may move to a higher tax bracket ending up paying higher taxes rates even though their real income is unchanged. Moreover, inflation decreases the net rate of return of the equity market and raise the cost of capital to firms, as it increases the effective capital gains tax rate. Even if the real value of a firm is unchanged, the owners of this firm's equity loose with inflation as capital gains are computed as the difference between the sale price and the buying price. Finally, depreciation allowances are based on book values and not on the current replacement cost of capital. As a result, inflation drives a wedge between the book value and the replacement cost of capital by understating the true cost of depreciation and overstating the profits for tax purposes, and thus reducing the incentive to invest in capital equipment.

## Conclusion

This paper surveys whether the objective of central banks in maintaining a stable and low inflation is consistent with the literature on the optimal rate of inflation. It provides quantitative values for the optimal average inflation rate as well as the intuition. The literature in this topic is vast, and the papers can be divided into three groups: (i) those that find the inflation rate should be negative, (ii) those that find the average inflation should be zero, and (iii) those that find the inflation rate should be positive. Typically, in the first set of papers the Friedman result, that the optimal nominal interest rate is zero, holds. The optimal inflation rate is the negative of the real rate of interest. The optimal nominal interest rate is zero, so people feel no incentive to economize on money holdings. Included in this group are other papers that show that a negative inflation rate can promote growth and improve income and wealth equality.

In the second group of papers, the zero inflation is optimal. These papers consider sticky prices, which implies welfare costs either from inflation or deflation. In these models, price changes lead to price dispersion across firms and this results in demand being too high for some firms and demand being

too low for others. With zero inflation firms do not have to change prices. The third group of papers consider various reasons for a positive inflation rate. Reasons for a positive inflation can be: an incomplete set of tax instruments, downward nominal rigidities in factor prices, tax collection costs, foreign demand for domestic currency, and the zero bound on nominal interest rates.

Each of the papers surveyed provides a model for a particular optimal inflation rate. The policy makers should understand and know the model behind each optimal inflation rate. With that knowledge, the policy maker must then determine an optimal inflation rate that balances the various models. The 2% percent target for inflation that central banks follow can be thought as being determined in this way.

Based on the literature surveyed the 2% target cannot be ruled out as an optimal inflation level. We find that the 2% target followed by most central banks is in accordance with the literature as the papers surveyed estimate that the optimal rate of inflation ranges from minus the real rate of interest to 6%. Nevertheless, it can be argued that the 2% target is on the upper side of the recommendations, as the majority of the papers find the optimal inflation rate to be negative or zero.

One reason for a target is to "anchor expectations." According to this reasoning a justification for the target is not that the 2% is the precise optimal level of inflation. The justification is that a central bank must choose a number for the target and maintain it for a long period of time, even if it is no longer at the precise optimal level. The central bank makes this commitment, which should not be abandoned later, because otherwise it loses credibility. As such the rule should be that the inflation target should not be moving in reaction to changing macroeconomic conditions. Inflation targets should be changed infrequently, and only for very good reasons.

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