Journal Pre-proof

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PII: S0022-1996(20)30027-1

DOI: https://doi.org/10.1016/j.jinteco.2020.103308

Reference: INEC 103308

To appear in: *Journal of International Economics*

Received date: 4 April 2018

Revised date: 29 January 2020

Accepted date: 29 January 2020

Please cite this article as: M. Fratzscher, C. Grosse-Steffen and M. Rieth, Inflation targeting as a shock absorber, *Journal of International Economics*(2020), https://doi.org/10.1016/j.jinteco.2020.103308

Inflation Targeting as a Shock Absorber*

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DECEMBER 2019

We study the characteristics of inflation targeting as a shock absorber, using quarterly data for a large panel of countries. To overcome an endogeneity problem between monetary regimes and the likelihood of crises, we propose to study large natural disasters. We find that inflation targeting improves macroeconomic performance following such exogenous shocks. It lowers inflation, raises output growth, and reduces inflation variability compared to alternative monetary regimes. This performance is mostly due to a different response of monetary policy and fiscal policy under inflation targeting. Finally, we show that only hard, but not soft, targeting reaps the rewards: deeds, not words, matter for successful monetary stabilization.

Key words: Monetary Policy, Central Banks, Inflation targeting, Inflation, Natural disasters.

JEL classification: E42, E52, E58, F41, Q54.

* *Acknowledgements*. We are grateful to two anonymous referees and the editor for helpful comments and to Boris Hofmann for discussing the paper. We thank Philippe Andrade, Agnès Bénassy-Quéré, Kerstin Bernoth, Fabio Canova, Michael Burda, Athanasios Orphanides, Christian Proano, Federico Ravenna, Ricardo Reis, Francisco Ruge-Murcia, Willi Semmler, Lutz Weinke and participants of seminars and conferences at Computing in Economics and Finance New York USA 2017, International Association of Applied Economics Sapporo Japan 2017, Verein für Socialpolitik Vienna 2017, European Economic Association Lisbon 2017, Banque de France, DIW Berlin, and Humboldt-Universität zu Berlin for helpful discussions. The views expressed in this paper reflect the opinion of the authors and do not necessarily express the views of the Banque de France or the Eurosystem.

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1. Introduction

Inflation targeting has become a dominant framework for monetary policy since the 1980s. It is praised not just for its success in bringing down inflation, but also increasing the credibility and accountability of policymakers (Bernanke and Mishkin, 1997; Ball, 2010). Its popularity is reflected in an increasing number of countries adopting inflation targeting (IT). However, the global financial crisis dramatically changed the perception of IT as an optimal framework for achieving macroeconomic stability, especially when the economy is confronting large real or financial shocks. It is argued that IT, by focusing narrowly on inflation, may contribute to a build-up of financial instability (Taylor, 2007; Frankel, 2012), leading central banks to neglect other objectives, such as employment (Stiglitz, 2008), and constraining those monetary authorities dealing with deep recessions (Borio, 2014). As a result, scholars and policymakers call for refining the IT framework to allow for more flexibility (Svensson, 2009).

While many studies analyze whether inflation targeting affects economic performance, no clear-cut consensus has emerged. The focus of most papers in the literature is on the performance of IT during the relatively good times of the 1990s through the beginning of the 2008 global financial crisis. During those two decades of the "great moderation," with declining and low inflation rates amid strong economic growth, few countries operating under IT experienced a deep economic or financial crisis. A different, and arguably at least equally important, question is whether IT helps countries and their central banks in dealing with crises, that is, whether it allows stabilizing inflation and output in response to large adverse shocks.

This paper focuses on this question and analyzes whether countries operating under IT have a better macroeconomic performance in response to large adverse shocks than those with non-IT regimes. Thereby, we empirically respond to the question whether IT is a perpetrator, bystander, or savior in the wake of a crisis (Reichlin and Baldwin, 2013). We limit the analysis to the effects of natural disasters, such as earthquakes or windstorms, as these are the most exogenous large adverse shocks that can be identified and as they are shown to have a large impact on the macro-economy (Noy, 2009; Felbermayr and Gröschl, 2014). Natural disasters have a direct negative effect through the destruction of physical capital and durable consumption goods. The analysis can be extended to include other types of shocks, such as financial shocks, though this would entail the risk of endogeneity to the monetary regime. At the same time, natural disaster shocks share similar patterns to capital depreciation rate shocks. The latter type of shocks are used to analyze financial crises (Liu et al., 2011).

Natural disasters can be considered exogenous to the choice of the monetary regime because they are largely unpredictable and not caused by economic conditions. These features allow us to identify the conditional effects of IT using relatively weak and verifiable assumptions about the distribution of the unobserved factors that determine macroeconomic outcomes and about the systematic relation between natural disasters and monetary regimes. In terms of the treatment literature, we assume that, conditioned on country characteristics, the "treatment" in form of a natural disaster is random, but instead of focusing on the effects of the treatment, we study whether alternative monetary regimes imply different responses to the treatment. To obtain a measure of such shocks, we derive a shock variable from the estimated damage to property, crops and livestock contained in the EM-DAT dataset, which documents natural disasters globally. We match them with quarterly macroeconomic data for 76 countries over the period 1980Q1-2015Q4. We then estimate a set of dynamic panel models to trace out the responses of key variables.

We find that disaster shocks are contractionary and inflationary on impact, followed by a short-lived boom in consumption and investment activity. The empirical patterns resemble adverse supply shocks in a New Keynesian model due to the destruction of physical capital and a decline in productivity (Keen and Pakko, 2011). The interpretation as an adverse supply shock is in line with microeconomic evidence hinting toward economic disruptions that also cause indirect losses. Inoue and Todo (2017) show that the Great East Japan earthquake of 2011 was propagated via supply chain disruptions to other regions. The substitution of production inputs poses a drag on firm productivity. The subsequent investment boom we find in the data can be understood through the lens of the Solow (1956) model as catch-up growth.

We document important differences in the dynamic responses of countries under IT (*targeters*) and under alternative monetary regimes (*non-inflation targeters*) to the shocks. Targeters perform significantly better regarding both the level and the volatility of output and prices. While GDP drops immediately under both regimes, the initial decline is smaller under IT and the subsequent recovery is stronger and faster. Moreover, consumer prices increase significantly less for targeters. These dynamics are reflected in significant differences across monetary regimes in average GDP growth and inflation following large shocks. The mean quarterly growth rate is higher under IT, and average inflation is lower in the four years following a large shock. Moreover, the standard deviations of inflation and components of domestic absorption following a natural disaster are significantly lower under IT than under alternative monetary regimes, thus lowering aggregate volatility.

The main aim of this paper is to provide these stylized facts and we are agnostic about the precise channels leading to the main results. Nevertheless, we also provide evidence on the potential mechanisms through which IT affects the adjustment processes. The results suggest that the shock propagation is positively affected in IT countries by more stable inflation expectations and lower risk premia, potentially due to lower volatility. Further, targeters rely on a different monetary-fiscal policy mix. While we find no direct evidence that better anchored inflation expectations allow for more monetary accommodation conditional on a large shock, fiscal policy seems better capable of stabilizing output.

In contrast, non-targeting monetary authorities tend to ease monetary policy more aggressively and persistently in an effort to stabilize output, while fiscal policy is contractionary. The adverse effects of private credit risk and term premia reduce the effectiveness of monetary policy for non-inflation targeters such that overall this policy mix induces lower output growth, higher inflation, and more volatility. The existence of cross-effects between IT and fiscal policy is documented by Combes *et al.* (2017). Our findings depict that they also shape the policy mix in response to large disaster shocks. Importantly, we extensively control for institutional quality, which is often held responsible for pro-cyclical fiscal policy in middle-income countries (Frankel *et al.*, 2013), as well as for fiscal rules and alternative financing capacities of countries.

Finally, we find that only hard targeters perform better. Countries that have introduced inflation targeting, but deviate from their target for a prolonged period of time, do not reap the rewards. This difference between hard and soft targeting is important as it suggests that it is not the fact that a central bank formally adopts IT that allows a superior performance. Instead, our findings suggest that it is the track record and the ensuing credibility of an IT central bank that allows it, as well as the fiscal authority, to respond differently and more successfully to the economic shock induced by a natural disaster.

Our paper relates to the large literature on the impact of IT on macroeconomic outcomes. Most of the literature focuses on the unconditional effects of inflation targeting.

In a seminal contribution, Ball and Sheridan (2004) find no significant differences in inflation and growth between IT and non-IT countries in a sample of OECD member states and based on a difference-in-difference approach. Similarly, Lin and Ye (2007) detect no effect of IT on either inflation or inflation variability in industrial countries when employing propensity score matching. Using OLS to study the impact of IT on disinflation periods in OECD countries, Brito (2010) concludes that inflation targeters are not able to bring inflation down at less output costs than non-targeters. On the other hand, Gonçalves and Carvalho (2009) find, in a sample of OECD countries, that inflation targeters suffer significantly smaller output losses for reducing inflation when using Probit or Heckman regressions. Moreover, Lin and Ye (2009) and Lin (2010) show evidence that, based on propensity score matching, IT lowers inflation and inflation variability in developing countries. Regarding different country samples, De Mendonça and e Souza (2012) find, based on propensity score matching, that IT may be particularly beneficial in developing countries, suggesting that IT might work if it helps improve the credibility of monetary authorities. Overall, this literature seems to conclude that IT matters, especially for developing economies, but is less relevant for advanced economies. Our results differ from this literature by focusing on the conditional effects in the aftermath of large shocks. Further, we show in a robustness section that the baseline results hold for both country groups.

There is also no consensus in the literature that studies the performance of IT during the global financial crisis. While Rose (2014) finds that IT did not substantially change how a country weathered the crisis, Carvalho Filho (2010) and Andersen *et al.* (2015) present evidence that IT countries fared significantly better during this episode. Our findings support the latter view, since IT helps to buffer large disaster shocks better than alternative monetary regimes. We separate from the existing work as our results are obtained conditional on large exogenous shocks, thereby addressing the endogeneity problem related to the episode of the global financial crisis.

To the best of our knowledge, our paper is the first to analyze whether inflation targeting is effective as a shock absorber in response to large real shocks. Our econometric approach, which is not previously used to study the macroeconomic impact of IT, has several advantages. First and foremost, estimating the conditional effect of IT, given an exogenous event, bypasses the need to directly deal with the potentially endogenous choice of the monetary regime to macroeconomic conditions as it "nets out" the unconditional impact of IT on the response variables. The methodological approach is inspired by Ramcharan (2007), who uses disasters to evaluate the effects of exchange rate regimes on the adjustment to real shocks in developing countries.

The remainder of the paper is structured as follows. Section 2 formulates the main hypotheses, describes the empirical strategy, and introduces the data. Section 3 contains the core results. Section 4 provides extensive sensitivity analysis, before the final section concludes.

2. The link between inflation targeting and natural disasters

In this section, we characterize the notion of inflation targeting and how it can affect the policy response to, and propagation of, large natural disasters. This reasoning is used to derive our empirical hypotheses in the next section.

2.1. Inflation targeting under discretionary monetary policy

The literature on monetary policy delegation establishes that, under discretionary monetary policy,[1] a central bank suffers from a so-called inflation bias that renders the allocative outcome inferior to monetary policy committed to an optimal rule. The inflation bias arises if the central bank inherits society's preferences about inflation and employment, since society's employment target typically lies above the natural rate (Barro and Gordon, 1983). The presence of this bias further renders optimal policy time-inconsistent in the presence of forward looking expectations (Kydland and Prescott, 1977).

Svensson (1997) shows that there exist alternative institutional arrangements that improve the outcome under discretion, among which is the adoption of an inflation target. To illustrate the role of an inflation target in the process of delegating monetary policy to an independent central bank, assume a standard quadratic loss function that represents society's preferences:

$$L(\pi, n;\ \pi^*, n^*, \lambda) = \frac{1}{2}[(\pi_t - \pi^*)^2 + \lambda(n_t - n^*)^2], \tag{1}$$

where π^*, n^* denote the socially desirable levels of inflation and employment, respectively, and λ>0 is the relative weight given to employment stabilization over inflation stabilization. Further, let economic dynamics be described by an expectation-augmented Phillips curve according to

[1] Under a discretionary regime, the monetary authority optimizes period by period since it cannot make any binding commitment over its course of action.

$$n_t = \rho n_{t-1} + \alpha(\pi_t - \pi_t^e) + \varepsilon_t, \tag{2}$$

with rational inflation expectations $\pi_t^e = E_{t-1}[\pi_t]$. In (2), employment n_t is persistent if $\rho \in (0,1)$, and ε_t is a mean zero and *i.i.d* supply side shock. Svensson (1997) shows that under commitment the optimal rule for inflation, i.e. the instrument of the central bank, is

$$\pi_t = \pi^* - b^* \varepsilon_t,$$
$$\text{with } b^* = \frac{\alpha\lambda}{1+\lambda\alpha^2 - \beta\rho^2}. \tag{3}$$

This decision rule achieves a second-best outcome under the social loss function (1). The first-best is not achieved given that there remain distortions from the natural level of employment being below the socially desirable level of employment.

In contrast, solving the problem under discretion leads to the central bank decision rule

$$\pi_t = a - b\varepsilon_t - c\, n_{t-1},$$
$$\text{with } a = \pi * + \frac{\alpha\lambda n^*}{1-\beta\rho-\beta\alpha c}, b = \frac{\alpha\lambda + \beta\alpha c^2}{1+\lambda\alpha^2 - \beta\rho^2+\beta\alpha^2 c^2}, \tag{4}$$

with c being a positive constant.[2] Comparing decision rules under commitment (3) and discretion (4) reveals an inflation bias $(a - \pi^* - cn_{t-1})$ that can be decomposed into average inflation bias $a - \pi^*$ and a state-contingent inflation bias $-cn_{t-1}$ related to past employment levels. Further, central banks under discretion respond more to employment fluctuations arising from ε_t than under commitment since $b > b^*$ in the presence of employment persistence $\rho > 0$. This stabilization bias introduces an additional wedge present in policies under discretion. As a result of the two biases present in the decision rule under discretion, the value of the social loss function (1) that can be achieved under discretion represents a fourth best outcome. While several institutional arrangements are able to improve the outcome under discretion, we briefly discuss the two most prominent ones: (i) a weight-conservative central banker; and (ii) the adoption of an inflation target.

Rogoff (1985) shows that a weight-conservative central banker reduces the inflation bias under discretion. A weight-conservative central banker optimizes over the loss function $L(\pi_t, n_t;\ \pi^*, n^*, \lambda^b)$, where λ^b denotes the central banker's weight for employment stabilization, which is lower than society's, formally $0 < \lambda^b < \lambda$. The solution of (4) assuming no persistence then changes to $a^{wc} = \pi^* + \alpha\lambda^b n^*$, $b^{wc} = \alpha\lambda^b/(1 + \alpha^2\lambda^b)$ and $c = 0$, which leads to a lower inflation rate than under full discretion. However, the lower inflation bias $\alpha\lambda^b n^*$ needs to be traded-off against higher employment variability from the Philipps curve (2), such that only a third best is achieved.

[2] Specifically, $c = \frac{1}{2\,\alpha\beta\rho}\left[1 - \beta\rho^2 - \sqrt{(1-\beta\rho^2)^2 - 4\lambda\alpha^2\beta\rho^2}\right] \geq 0.$

Second, society can delegate monetary policy to a central bank with an inflation target that would set inflation by optimizing over a modified loss function

$$L(\pi_t, n_t;\ \pi^b, n^*, \lambda) \tag{5}$$

with $\pi^b < \pi^*$, i.e. it has a lower inflation target than desired by society (inflation-target conservative target). Svensson (1997) shows that for the case without persistence, a constant inflation target $\pi^b = \pi^* - \alpha\lambda n^*$ establishes the second best outcome. Since the elimination of the inflation bias by an inflation target does not induce an employment variability trade-off, it is preferable over a weight-conservative central banker.[3]

2.2. Inflation targeting and the effects of large natural disasters

In line with the literature on natural disasters, we interpret a natural disaster as an adverse shock to physical capital and durable consumption goods.[4] The empirical response to such a shock is affected by two factors: the propagation of the shock within the economy and the policy response to the shock. We suppose that both are affected by the choice of the monetary policy regime.

Inflation targeting might affect the policy response to natural disaster shocks along two dimensions. First, it imposes constraints on policymakers. Following the notation in the previous section, the commitment to a numerical target π^b or target range for the inflation rate over a specific time horizon removes the inflation bias. The modified central bank loss function (5) also leads to a different policy rule for inflation. This is why monetary policy under IT is often described as 'constrained discretion' (Bernanke and Mishkin, 1997; Kim, 2011). In order to make the announced inflation target credible, IT in practice is associated with enhanced communication standards of monetary authorities with the public and aims at increasing accountability, possibly through implicit incentives or explicit contracts for central bankers (Svensson, 2010). The monetary authority also explicitly communicates that low and stable inflation is its main goal, bases its decisions on inflation forecasts, and enjoys a high degree of independence.

In the New Keynesian model of Clarida et al. (1999), higher central bank credibility, resulting either from commitment or from institutional arrangements that achieve the

[3] The presence of employment persistence can resurrect a weight conservative central banker since only a combination of a state-contingent inflation target and a weight-conservative central banker eliminates the average and state-contingent inflation bias as well as the stabilization bias, see Svensson (1997) for details.

[4] These shocks share essential features with shocks to the quality of capital or the capital depreciation rate, which were at the heart of the global financial crisis. One important caveat applies to this generalization. Liu *et al.* (2011) show in an estimated DSGE model of the US economy that while a shock to the rate of capital depreciation contracts output, it is also disinflationary. In contrast, our natural disaster shock leads to a rise in inflation on impact in the data, as we show below.

same end, allows the central bank to affect agents' inflation expectations directly. Lower and better anchored inflation expectations, in turn, reduce the short-run tradeoff between inflation and output (Walsh, 2009). According to a forward looking Phillips curve, inflation depends on future output gaps. A natural disaster lowers potential output through the destruction of productive capital. This lowers potential output and employment while raising inflation. The central bank would like to give the signal that it will be tough in the future without reducing demand much today. This strategy can lower inflation today, while keeping output and employment closer to potential. However, such a strategy is only credible under commitment, which IT facilitates to attain.

IT can affect the propagation of natural disaster shocks at least through two channels. As Bernanke and Mishkin (1997) highlight, lower uncertainty about future inflation not only supports savings and investment decisions, it also reduces the riskiness of nominal financial and wage contracts. In first the propagation channel, lower nominal uncertainty in wage contracts might allow for higher employment following disasters. Strulik and Trimborn (2019) show in a macro model that the GDP impact of natural disasters is affected by households' labor response. In their model, a disaster destroys physical capital and durable consumption goods, such as residential housing. Households want to provide more labor in order to rebuild housing, which enters their utility function directly and exhibits a high relative marginal utility. This response in labor supply partially off-sets the negative effect on GDP due to the destruction of physical capital. The off-setting effect is stronger if firms are more willing to demand labor, which is more likely if they face less nominal wage uncertainty. This can dampen the drop in GDP under IT, while simultaneously leading to a rise in durable goods demand and production.

Along a second propagation channel, investment activities in a reconstruction-led boom can be positively affected by IT through lower riskiness in nominal credit contracts and higher savings (Benson and Clay, 2004). While this has a dampening effect on the short-run decline in GDP in response to a natural disaster, the literature is inconclusive whether there is a medium to long-term positive growth effect from natural disasters, either through substitution into human capital investment (Skidmore and Toya, 2002) or faster adoption of new technologies (Hallegatte and Dumas (2009). Finally, the response of investment to natural disasters also depends on countries' capacities to fund the reconstruction (Kousky, 2014). IT might lower credit constraints through higher savings and lower nominal uncertainty, supporting the recovery.

2.3. Interactions between inflation targeting and fiscal policy

So far, we only discuss the role of monetary policy in an IT regime in response to large natural disasters. The existing literature on policy delegation and the determination of the price level suggests that there are meaningful interactions between inflation targeting and fiscal policy. As these interactions could play out during episodes of large natural disasters, they are briefly discussed here.

The literature on the fiscal theory of the price level (FTPL) shows that coordination between monetary and fiscal policy is necessary to provide a nominal anchor in the form of a well-defined price level in conjunction with stable government liabilities (Canzoneri et al., 2010). Sargent and Wallace (1981) present this coordination as a game of chicken. Since money and government bonds are nominal assets, a balanced budget can be achieved either through cautious spending or inflationary monetary policy that generates seignorage. If monetary policy follows an inflation targeting regime, fiscal policy needs to be passive in the parlance of the FTPL (Leeper, 1991).

One way to render fiscal policy passive is to constrain discretion, similar to the case of monetary policy in the absence of commitment, as discussed in Section 2.1. Dixit and Lambertini (2003) analyze the problem of delegating monetary policy when there is a fiscal authority that may not share the conservatism by the central bank. If the central bank operates under commitment while fiscal policy has discretion, then the latter undermines the gains of the former. As a result, when monetary policy operates under an inflation target, the second best can be achieved only if fiscal policy can commit to a policy rule. Combes et al. (2017) argue that such coordination problems call for a joint determination of institutions that lead to constrained discretion for fiscal and monetary authorities.

The take away of the literature on monetary-fiscal policy interactions for our empirical analysis is that inflation targeting might not just lead to a different monetary policy reaction to large natural disasters, but potentially also to a different fiscal policy response due to fiscal institutions that are prerequisite for IT.

3. Empirical strategy and data

The theoretical considerations from the previous section lead us to the following hypotheses. When a country is hit by a large natural disaster, we expect that inflation targeting, first, dampens the increase in inflation and cushions the drop in output growth, and, second, reduces the variability of both inflation and output growth. In this section, we present the data as well as the empirical strategy to test these hypotheses.

3.1. Large Natural Disaster Shocks

We use the EM-DAT database from the Center for Research on the Epidemiology of Disasters (CRED) to select large natural disasters.[5] The database provides detailed information on natural disasters, including earthquakes, floods, and storms, among others, which occurred worldwide since 1900. To construct the baseline sample, we use them from 1980Q1 onwards to reduce the risk of structural breaks and non-random under-reporting in earlier years. We start 1980Q1 to have a sufficient number of observations for early IT adopters (starting in the early 1990s, see below) before they operated under IT as our baseline empirical model will contain country fixed effects implying that we use the within-variation of the data. The results are robust to starting the sample in 1985Q1 or 1990Q1, or to excluding the global financial crisis, as the Online Appendix shows.

The data on disasters is compiled from various sources, including UN agencies, non-governmental organizations, insurance companies, research institutes, and press agencies. There are low reporting criteria for events. One condition out of the following four needs to be met: 10 or more people are killed; 100 or more people are affected; there is a declaration of a state of emergency; or there is a call for international assistance.

We follow the existing literature on the macroeconomic consequences of disasters (Noy, 2009) and use the estimated damage variable (in thousand US dollars), which is the direct damage to property, crops, and livestock, valued at the moment of the event. We interpret the estimated damage variable as a proxy measure of the direct macroeconomic effects of natural disasters. To be as precise as possible, we weight the estimated damage according to the occurrence of the event within a quarter, reflecting that a natural disaster taking place at the beginning of the quarter has a larger impact on quarterly output, say, than one toward the end. The weighted estimated damage is calculated as $wDAM = DAM(3-OM)/3$, where OM denotes the onset month, that is, the reported starting month of the natural disaster. In the sensitivity analysis, we show that our results are robust to alternative weighting schemes. Next, we sum over all weighted damages across events

[5] Guha-Sapir, Below, Hoyois – EM-DAT: International Disaster Database – www.emdat.be – Université Catholique de Louvain, Brussels, Belgium.

within the same quarter that are classified as natural disasters.[6] This is motivated by our focus on the economic consequences of extreme shocks in general, abstracting from the specific type of event. We standardize the disaster size by dividing the weighted and aggregated estimated damage by the level of nominal GDP in US dollars one year prior to the event. Thereby, we obtain a continuous variable interpretable as a shock in percent of GDP.

The selection of disasters leaves us with 1,375 events between 1980 and 2015. We further reduce the number of events as we are interested in the economic adjustment process to real shocks that are of national economic relevance and to eliminate noise in the reporting of disasters. Therefore, we concentrate on the upper 50th percentile of the damage variable, dropping disasters with smaller direct costs, and we remove outliers through a 97.5% winsorization. This leaves us with 605 events, which are evenly distributed between countries adopting IT at some point (305) and non-targeting countries (300). In the sensitivity analysis, we show that our main results hold when using alternative percentiles as cutoffs for the damage variable.

3.2. Inflation targeting

Regarding the monetary regime, we distinguish between inflation targeting and non-inflation targeting regimes. The dates when countries adopted IT feature some heterogeneity in the literature, depending on the criteria used. While some studies classify a monetary authority to follow IT after simply having announced numerical targets for inflation, others use dates denoting when IT was effectively implemented. This implementation implies that other nominal anchors like exchange rate targets are abandoned.[7] We follow Roger (2009) and create a dummy variable for the quarter-country pairs with an effectively implemented IT regime.[8] Euro area member countries, which introduced IT before joining the euro, are classified as targeters only for that period, and as non-targeters after the adoption of the common currency. Table A1 in the Online Appendix provides an overview of IT and euro adoption dates. We have 25 IT and 51 non-IT countries in the sample.

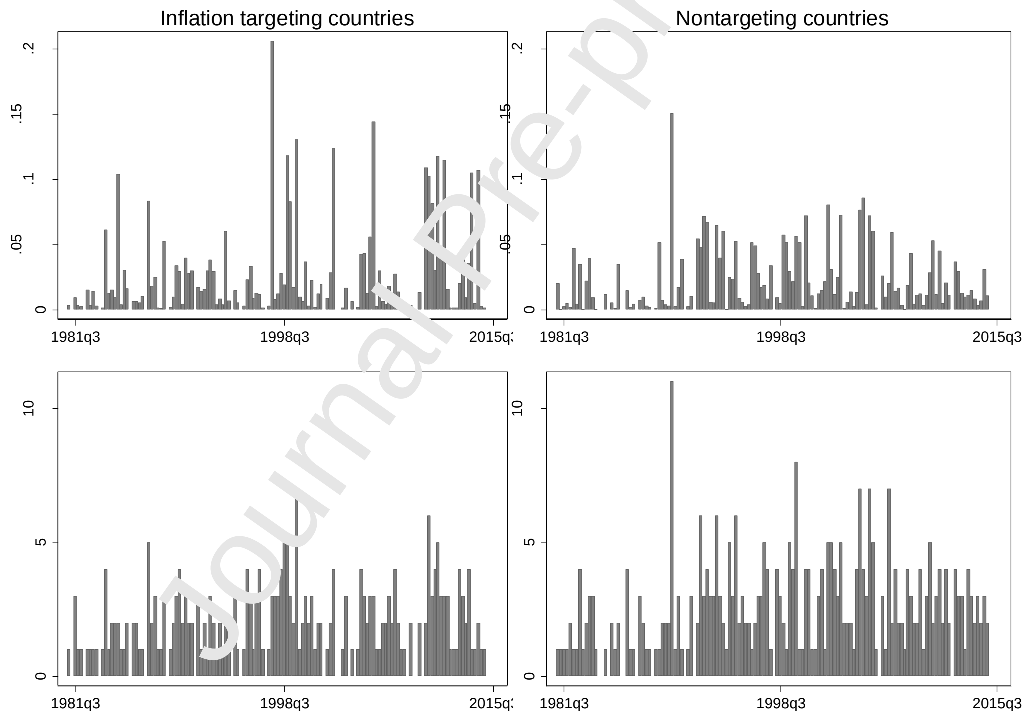
[6] These fall in either of the following categories: geophysical, meteorological, hydrological, climatological, biological, and extraterrestrial (i.e. hazards caused by asteroids or meteoroids). We exclude technological disasters.

[7] The difference between these two dating conventions is referred to in the literature as '*soft IT'* versus '*fully fledged IT'* (Vega and Winkelried, 2005).

[8] We update this list with countries that have adopted inflation targeting since 2007 by collecting data available from central bank websites.

Figure 1 brings together the data on natural disasters and IT. It shows the distribution of the mean size and the number of large disasters for targeters and non-targeters over time. We label countries that adopt IT at some point as inflation targeters for the entire sample. Both groups are affected similarly strongly and frequently by disasters. Importantly, there are large and numerous shocks in the IT group both before and after the spreading of this monetary regime in the 1990s and 2000s, suggesting that we have a reasonable number of events for each regime to estimate the differential impact of disasters depending on the monetary regime reliably. Finally, the figure indicates an overall increase in the number disasters over time. This is a well-known fact in the literature, which we aim to capture through time fixed-effects.

Figure 1: Distribution of large disaster shocks in targeting and non-inflation targeting countries over time



Note: The figure shows the mean shock in inflation targeting and non-inflation targeting countries as percent of GDP(t-4) and the total number of large natural disasters in both country groups over time. For the construct of this graph, we label countries that adopt IT at some point as inflation targeters for the entire sample.

3.3. Other macroeconomic data and controls

We collect macroeconomic data at a quarterly frequency for the 1980Q1 to 2015Q4 period. The cross-section contains 76 countries, mostly advanced economies and emerging markets. The country coverage is dictated by the joint availability of the main variables used in the analysis. Hence, even though the sample contains the global financial crisis, the sample is likely to be influenced by the "great moderation" period.

Table A2 in the Online Appendix lists the countries in the sample. We obtain real and seasonally adjusted data on output, private consumption, governmental consumption, investment, exports, and imports from both OECD national accounts statistics and national sources. If seasonal adjusted data are not available, we make this transformation. We obtain CPI price indices and longer term sovereign yields from the IMF International Financial Statistics. We compute CPI-based real exchange rates relative to the US using bilateral nominal exchange rates and CPI differences as real effective exchange rates are not available at our country sample and frequency. Policy rates are from Datastream.

We clean the data with respect to periods of extraordinary large nominal fluctuations. Specifically, we drop all observations for a given country during periods of extremely high nominal volatility, when either the policy rate, the inflation rate, or the nominal exchange rate exceeds a given threshold of quarterly rate of change. We set relatively high thresholds with the aim at only eliminating periods of large volatility that are due to hyperinflations and not the result of large disasters or the global financial crisis. After dropping these periods, we also country-wise drop observations that are separated along the time dimension from the longest continuous sequence of observations to ensure that the country time-series are uninterrupted. Thereby, we mostly eliminate some periods of exceptional nominal volatility in emerging markets during the 1980s and 1990s. Only for six countries do we drop data spanning the global financial crisis and these episodes are driven by extraordinary country-specific events, e.g. in the Ukraine in response to the Crimea conflict post 2014. Moreover, we verify that our results are largely insensitive to alternative thresholds.[9] Finally, we collect a number of control variables that are motivated by the literature on measuring the macroeconomic impact of natural disasters and IT. The Online Appendix provides an overview of the variables and sources (Table A3) and additional robustness analysis (see Figures A2 to A5).

3.4. Empirical model and identification

To measure the dynamic effects of IT following disasters, we use the following model:

[9] The main results are based on thresholds of 20 percent for the quarterly change of inflation, 35 percent for the nominal exchange rate, and 20 percent for the policy rate. The results hold when changing the thresholds by ±10 percentage points.

$$\Delta y_{i,t} = c + \sum_{j=0}^{J}\left[\beta_j S_{i,t-j} + \delta_j IT_{i,t-j} + \gamma_j IT_{i,t-j} S_{i,t-j} + \vartheta_j GDPpc_{i,t-j} S_{i,t-j}\right] \\ +\nu_i + \nu_Y + \phi X_{i,t-1} + \textstyle\sum_{l=1}^{L} \mu_l \Delta y_{i,t-l} + \varepsilon_{i,t} \ . \tag{6}$$

$\Delta y_{i,t}$ denotes the quarterly rate of change in the dependent variable for country i in quarter t. The main endogenous variables of interest are changes in GDP and consumer prices. The shock is captured by $S_{i,t-j}$ and the inflation targeting indicator by $IT_{i,t-j}$. Moreover, the model contains a set of interaction terms $IT_{i,t-j}S_{i,t-j}$. The main parameters of interest are the $\gamma_j{}'s$, which capture the difference between the dynamic effects of large real shocks under inflation targeting and non-inflation targeting regimes.

We also interact GDP per capita in 1990Q1 with the shock variable for the full impulse response horizon. These additional interaction terms control for the strength and consistency of the macroeconomic framework as an alternative shock absorber, or, more technically, for omitted nonlinearities. GDP per capita is typically highly correlated with the quality of institutions and the level of development (Hall and Jones, 1999).

The two sets of interaction terms relax the standard assumption in panel data models of common slopes across all panel units. We further account for time-invariant country characteristics, such as the geographic exposure to large natural disasters through country fixed-effects ν_i. Moreover, we let year fixed-effects ν_Y correct for common unobservable time-varying factors such as global growth and inflation trends as well as climate change. To remove possible autocorrelation in the error term, we include lags of the dependent variable. This makes our approach similar to the single-equation regressions of Romer and Romer (2004) and Kilian (2008) for the analysis of monetary policy and oil supply shocks, respectively. In the sensitivity analysis, we use alternative estimators to confirm that our results do not suffer from the Nickell bias (Nickell, 1981), as can be expected in our sample where T>30 (Judson and Owen, 1999). We add several time-varying control variables in the vector $X_{i,t-1}$. These include the degree of urbanization, population density, as well as measures for the level of democracy, capital account openness, and the FX regime. They enter with one lag in order to prevent endogenous feedback with disaster shocks.

We set *J = 15* and *L = 4* to obtain impulse responses over a horizon of four years and to ensure that the residuals are free of autocorrelation. We estimate (6) by OLS based on a within-transformation, assuming that the error term $\varepsilon_{i,t}$ is independent and identically distributed. Throughout, we base statistical inference on 500 Monte Carlo draws.[10]

To illustrate the identification strategy, we consider the case of $J = L = \vartheta_0 = 0$ and summarize all control variables in (6) in the vector $Z_{i,t}$. Further, we define as $\mathrm{E}(\Delta y_{i,t}|S_{i,t} > 0, Z_{i,t})$ the expected value of $\Delta y_{i,t}$ given that a natural disaster occurred and conditioned on the set of co-variates $Z_{i,t}$. Following Ramcharan (2007), the average effect of the disaster is then

$$\begin{aligned}\mathrm{E}(\Delta y_{i,t}|S_{i,t} > 0, Z_{i,t}) - \mathrm{E}(\Delta y_{i,t}|S_{i,t} = 0, Z_{i,t}) &= \beta_0 S_{i,t} + \gamma_0 \mathrm{E}(IT_{i,t}|S_{i,t} > 0, Z_{i,t}) S_{i,t} \\ &+ \delta_0 [\mathrm{E}(IT_{i,t}|S_{i,t} > 0, Z_{i,t}) - \mathrm{E}(IT_{i,t}|S_{i,t} = 0, Z_{i,t})] \\ &+ [\mathrm{E}(\varepsilon_{i,t}|S_{i,t} > 0, Z_{i,t}) - \mathrm{E}(\varepsilon_{i,t}|S_{i,t} = 0, Z_{i,t})].\end{aligned} \tag{7}$$

We make two assumptions to simplify (7). First, the residual $\varepsilon_{i,t}$, which captures unobserved drivers of $\Delta y_{i,t}$, is unrelated to the occurrence of the disaster shock $S_{i,t}$. The assumption is motivated by the random nature of these shocks and our strategy of accounting for country characteristics that capture the general susceptibility to these shocks. Then, $\mathrm{E}(\varepsilon_{i,t}|S_{i,t} > 0, Z_{i,t}) = \mathrm{E}(\varepsilon_{i,t}|S_{i,t} = 0, Z_{i,t}) = 0$.

Second, natural disaster shocks do not systematically affect the choice of the monetary regime. This assumption is motivated, on the one hand, by the remarkable stability of inflation targeting as a monetary regime (Rose, 2007; 2014). No country that adopted IT has ever abandoned it. This stability rules out the possibility that a country abolished IT in response to a large natural disaster. On the other hand, it is easy to check whether in our sample countries adopted IT (in the four years) following a large shock. We find only three such cases and excluding them from the analysis does not change the results. Thus, we can essentially exclude the possibility that the decision to target inflation depends on disaster realizations and assume that $\mathrm{E}(IT_{i,t}|S_{i,t} > 0, Z_{i,t}) = \mathrm{E}(IT_{i,t}|S_{i,t} = 0, Z_{i,t}) = IT_{i,t}$. Under these two assumptions (7) simplifies to

$$\mathrm{E}(\Delta y_{i,t}|S_{i,t} > 0, Z_{i,t}) - \mathrm{E}(\Delta y_{i,t}|S_{i,t} = 0, Z_{i,t}) = \beta_0 S_{i,t} + \gamma_0 IT_{i,t} S_{i,t},$$

where γ_0 measures the difference between the average effect of the shock under targeting and non-inflation targeting regimes. However, to attach a causal interpretation to γ_0, we need to carefully control for other potential country features that could affect both the

[10] Following Romer and Romer (2004), we use the estimated covariance matrix of the coefficients to draw new coefficients from a multivariate normal distribution, from which we compute a distribution of impulse responses.

choice of the monetary regime and the response of the economy to the shock. The interaction terms of the shock with GDP per capita serve this purpose in baseline model. In the sensitivity analysis, we extensively control for further potential shock absorbers, focusing on the level of development and fiscal rules.[11]

4. Inflation targeting and macroeconomic performance

In this section, we test whether IT economies respond differently to large natural disasters than non-inflation targeters. Moreover, we highlight several channels through which IT may change the responses. However, before turning to the main results for IT, we briefly summarize the average macroeconomic impact of the shocks to develop a notion of the adjustments process following natural disasters.[12] The underlying estimated responses are shown in Figure A1 of the Online Appendix.

The economic consequences of natural disasters can be viewed as those of a negative shock to the capital stock of an economy, which distorts production. Disasters typically cause direct damages to houses and contents, machinery, and infrastructure as well as indirect impacts due to business interruption. Post-disaster, the replacement of destroyed capital through more productive investments and new technologies, spending of insurance payouts, and possible multiplier effects of increased household and business outlays generates catch-up demand and increases GDP growth. Exports fall and imports increase. As production is interrupted, various products - and labor - are in short supply, and more expensive substitutes are used, thus increasing inflation. Despite the immediate price pressure, central banks, on average, aim at countering the drop in output growth by lowering policy rates, while fiscal policy contracts procyclically.

4.1. The effects of inflation targeting on macroeconomic dynamics

We now assess whether and how IT changes the dynamic adjustment to the shocks. For short, we refer to countries operating under IT as targeters and to economies with non-IT regimes as non-targeters, although technically we are using only the within variation in the data given that the model contains country fixed-effects.

[11] An alternative identification strategy would be to use the natural disasters as an instrument for GDP growth and then assess the differential effects of IT given an exogenous change in GDP growth. However, this approach is not ideal for our research question as we are interested in the response of GDP growth (and volatility) itself under IT.

[12] Our analysis does not aim at contributing specifically to the literature on the growth effects of natural disasters, which has not come to a consensus. Cavallo *et al.* (2013) find no significant effect of large natural disasters on GDP growth once controlling for political turmoil occurring in the aftermath of natural disasters. Loayza *et al.* (2012) find negative growth effects only for a subset of natural disasters, like earthquakes, windstorms, and droughts, while floods tend to have a mildly positive impact. Kousky (2014) provides a survey of this literature.

Table 1 contains the baseline regression results. The dependent variables in models 1-4 are changes in GDP, consumer prices, the policy rate, and government consumption, respectively. The upper part contains the estimated γ_j's, which measure the differential effect of IT following a shock. The middle part focuses on selected additional coefficients. The bottom part contains summary statistics. The latter show that the models generally describe the data decently. The model fit is between 0.10 and 0.86.

Table 1: Regression results for differential impact of inflation targeting.

Column	(1)		(2)		(3)		(4)	
Dependent variable	ΔGDP		ΔConsumer prices		ΔPolicy rate		ΔGovernment consumption	
Explanatory variables	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
IT*Shock in t	-0.33	(-0.99)	-0.10	(-0.49)	0.14	(0.82)	0.61	(0.81)
IT*Shock in t-1	-0.22	(-0.66)	0.09	(0.44)	-0.21	(-1.24)	0.20	(0.27)
IT*Shock in t-2	0.94***	(2.86)	-0.54***	(-2.58)	0.10	(0.60)	1.69**	(2.27)
IT*Shock in t-3	0.22	(0.67)	-0.33	(-1.57)	0.1[illegible]	(1.15)	-0.75	(-1.05)
IT*Shock in t-4	0.01	(0.04)	0.02	(0.09)	0.11	(0.68)	0.08	(0.11)
IT*Shock in t-5	0.02	(0.08)	-0.18	(-0.88)	0.22	(1.34)	-0.12	(-0.18)
IT*Shock in t-6	0.34	(1.09)	0.03	(0.15)	0.02	(0.14)	-0.11	(-0.15)
IT*Shock in t-7	0.24	(0.72)	-0.21	(-0.9[illegible])	-0.01	(-0.08)	0.43	(0.60)
IT*Shock in t-8	0.32	(0.96)	-0.16	(-0.73)	0.00	(0.02)	-1.26*	(-1.74)
IT*Shock in t-9	0.22	(0.62)	-0.51**	(-2.14)	0.01	(0.07)	1.76**	(2.28)
IT*Shock in t-10	0.43	(1.20)	-0.64***	(-2.[illegible]9)	0.03	(0.14)	0.57	(0.74)
IT*Shock in t-11	0.44	(1.17)	-0.30	(-1.18)	0.03	(0.15)	1.02	(1.24)
IT*Shock in t-12	0.28	(0.71)	-0.3[illegible]	(-1.13)	0.19	(0.91)	0.48	(0.59)
IT*Shock in t-13	-0.26	(-0.58)	0.[illegible]0	(0.94)	0.30	(1.18)	-1.51	(-1.59)
IT*Shock in t-14	-0.12	(-0.27)	0.1[illegible]	(0.51)	0.12	(0.48)	2.32**	(2.45)
IT*Shock in t-15	-0.31	(-0.68)	-0.29	(-0.89)	-0.41	(-1.63)	0.53	(0.56)
Dependent in t-1	-0.02	(-1.19)	1.0[illegible]***	(67.60)	0.09***	(5.62)	-0.50***	(-29.81)
Dependent in t-2	0.02	(1.51)	-0.[illegible]5***	(-10.73)	-0.05***	(-3.59)	-0.22***	(-11.84)
Dependent in t-3	0.02	(1.42)	-0.06***	(-2.70)	-0.05***	(-3.17)	-0.10***	(-5.14)
Dependent in t-4	-0.14***	(-9.[illegible]7)	-0.03*	(-1.81)	-0.04***	(-3.11)	-0.09***	(-5.19)
Democracy in t-1	0.22	([illegible].46)	0.17	(0.57)	0.04	(0.15)	-0.48	(-0.34)
Urban in t-1	-0.01	(-0.7[illegible])	0.00	(0.01)	0.01	(0.81)	-0.03	(-0.99)
Density in t-1	-0.00	(-0.90)	0.00	(1.59)	0.00	(0.28)	-0.00	(-0.91)
Cap. acc. open. in t-1	-0.05	(-1.36)	-0.15***	(-5.64)	-0.02	(-0.87)	-0.15**	(-2.08)
FX Regime in t-1	-0.04	(-0.22)	0.33**	(2.34)	0.00	(0.03)	0.15	(0.40)
Further controls (see Table notes)	yes		yes		yes		yes	
Observations	3926		4343		4286		3782	
Degrees of freedom	163		174		174		159	
R2 within	0.132		0.857		0.096		0.241	
Countries	58		69		69		54	
Av. obs./country	67.69		62.94		62.12		70.04	
P-value joint significance interactions IT*Shock	0.38		0.04		0.79		0.03	

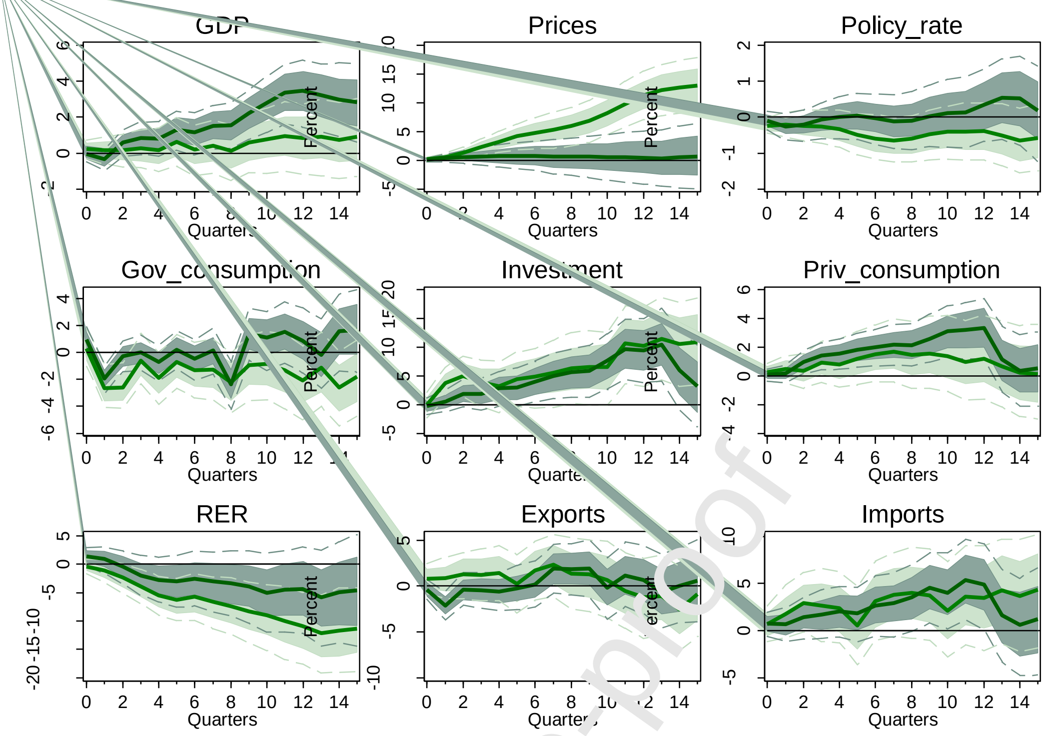
Notes: The table shows the dynamic differential effect of targeting inflation following large natural disasters, measured as γ_j *in* $\Delta y_{i,t} = c + \nu_i + \nu_Y + \sum_{l=1}^{L} \mu_l \Delta y_{i,t-l} + \sum_{j=0}^{J} \left[\beta_j S_{i,t-j} + \gamma_j IT_{i,t-j} S_{i,t-j} + \delta_j IT_{i,t-j} + \vartheta_j GDPpc_{i,t-j} S_{i,t-j}\right] + \phi X_{i,t-1} + \varepsilon_{i,t}$, *where* $\Delta y_{i,t}$ *denotes the quarterly percentage change in GDP (column 1), consumer prices (column 2), the policy rate (column 3) and government consumption (column 4), respectively, for country i in quarter t. J = 15 and L = 4. The natural disaster is captured by* $S_{i,t-j}$. *The model includes country and year fixed-effects,* ν_i *and* ν_Y, *respectively, and a set of control variables* $X_{i,t-1}$, *listed in the first column. The last row shows the p-value of an F-test for the joint significance of* γ_j.

Model 1 shows that the estimated impact of IT on GDP growth following disasters is mostly positive. The coefficient for the third quarter is highly significant at the 1% level. In contrast, the estimated distributed impacts on prices (model 2) are predominantly negative. Several are statistically significant. Moreover, they are jointly highly significant, as the p-value of the corresponding F-test in the bottom row shows. For the policy rate (model 3), the interaction terms are estimated to be mostly small and statistically indistinguishable from zero. Finally, model 4 provides a mixed picture for government spending, with some positive and some negative coefficients.

The middle part shows that the endogenous variables are persistent, as most of the lagged endogenous variables are highly significant. This implies that the autoregressive part of the model is an important determinant of the impulse responses and describes the shock propagation. The common control variables seem particularly relevant for explaining price changes, as the coefficients for capital account openness and FX regime are statistically significant. All in all, the table suggests that IT matters for price dynamics in response to large real shocks, containing price pressure, and for GDP changes, raising growth. In contrast, there is no clear evidence for differential policy responses under IT yet, but we investigate this issue in more detail below.

Figure 2 shows the adjustment of both groups to the shock, derived from the estimated coefficients β_j, γ_j and δ_j from equation (6), and taking into account the autoregressive parts μ_l. There are a number of significant differences between targeters and non-targeters. Primarily, output is higher and prices increase less under IT. In fact, output persistently and significantly rises above the level prevailing in absence of the shock for targeters, whereas it is indistinguishable from the pre-shock level for non-targeters. Consumer prices tend to rise under both regimes, but only mildly and not statistically significantly under IT, while there is a strong, long-lasting, and significant price increase otherwise. These findings support the hypothesis that IT increases GDP growth and lowers inflation.

Figure 2: Cumulative effects of large real shocks in targeting and nontargeting economies

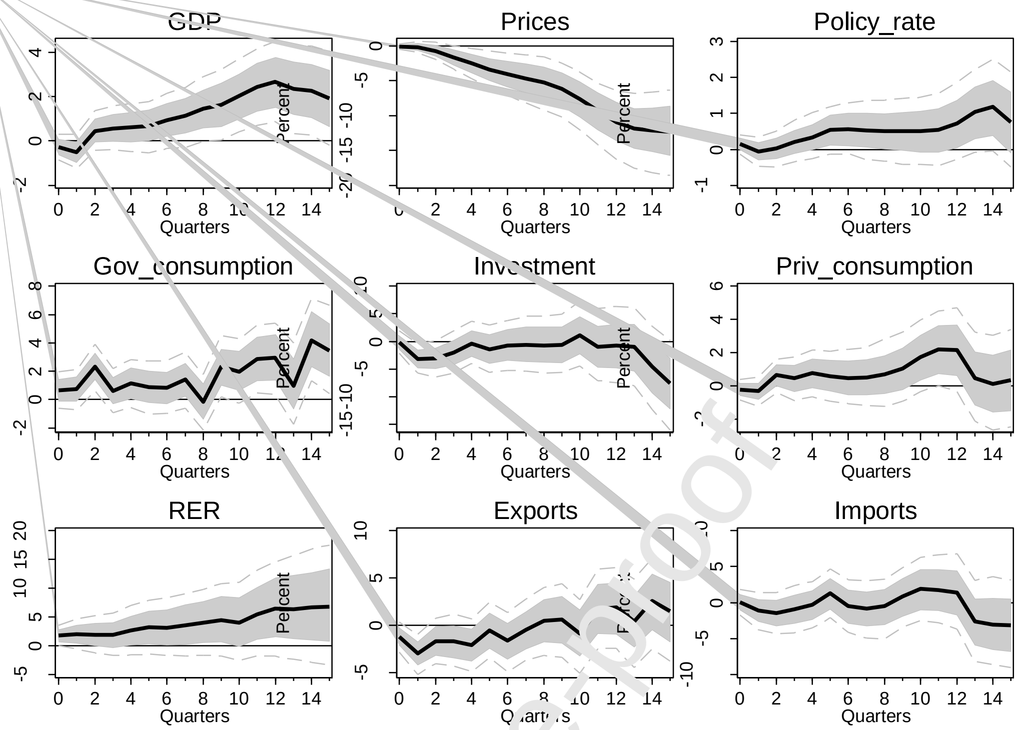


Note: The figure shows the cumulated response of key macroeconomic variables in targeting (dark shaded area) and non-inflation targeting countries (light shaded area) to large natural disasters over the period 1980Q1-2015Q4. Confidence bands refer to the 90 percent level (dashed lines) and a one standard deviation interval (shaded area), based on 500 Monte-Carlo draws.

Regarding policy responses, both country groups tend to rely on monetary policy to buffer the adverse shock. Central banks lower policy rates for several quarters, although the accommodation is not statistically significant. Fiscal policy is supportive initially as well, but then significantly contracts after the initial quarter. The reduction in fiscal spending is somewhat more pronounced in non-targeting economies. Next to public consumption, private consumption contributes to the difference in the output responses between regimes, whereas investment and the external sector largely respond similarly.[13] To test whether the effects of IT are statistically significant, we compute the cumulative differential effects between targeters and non-inflation targeters. Shown in Figure 3, these add to the evidence in favor of the hypothesis that IT leads to a superior macroeconomic performance. GDP is significantly higher under IT and prices are lower. The impact of IT on the dynamics of the other variables is largely insignificant, although there is some indication that fiscal policy is less contractionary.

[13] A decline in the exchange rate implies an appreciation of the currency.

Figure 3: Dynamic impact of inflation targeting in the aftermath of large real shocks



Note: The figure shows the cumulated differential responses between inflation targeting and non-inflation targeting countries of key macroeconomic variables to large natural disasters over the period 1980Q1-2015Q4. Confidence bands refer to the 90 percent level (dashed lines) and a one standard deviation interval (shaded area), based on 500 Monte-Carlo draws.

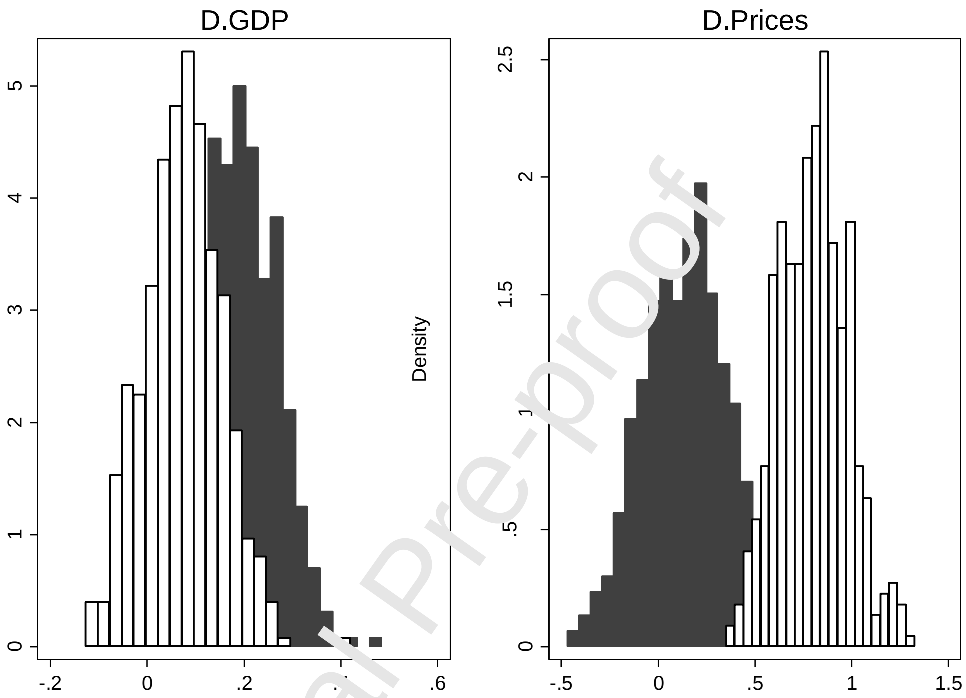
To further evaluate the impact of IT statistically, we compute the mean inflation and output growth rate for targeting and non-inflation targeting economies over the response horizon of four years and test whether the means are different between country groups. As the underlying responses are random vectors with distributions, we first investigate the precision and distribution of our estimates of average inflation and output growth, following Cecchetti and Rich (2001).

Figure 4 plots the empirical density functions of the estimates obtained from the Monte Carlo simulations. The figure corroborates the conclusion based on the impulse response analysis of higher output growth and lower inflation. For each variable, the distributions overlap only marginally. Moreover, it seems reasonable to assume that the true means, which are nonlinear functions of normally distributed variables, are also normally distributed. Therefore, we proceed by estimating the means of the distributions and testing whether they are significantly different.

Table 2 presents the results. It lends further support to the hypothesis that IT improves performance. The average quarterly rate of output growth following a shock is 0.11

percentage points higher under IT and the average quarterly change in the price level is 0.67 percentage points lower. These differences are highly significant according to the corresponding t-statistics and p-values. All in all, we conclude that IT significantly reduces inflation and increases output growth when an economy is subject to large real shocks.

Figure 4: Empirical density function for estimated mean output growth and inflation



Note: The figure shows the simulated density function of mean output growth and mean inflation over a horizon of four years following a large natural disaster in inflation targeting (black bars) and non-inflation targeting economies (white bars).

Table 2: Testing for differences in means following natural disasters

Variable	Mean GDP growth	Mean inflation rate
Targeting economies	0.18	0.14
Non-targeting economies	0.07	0.80
Difference	0.11	-0.67
t-statistic	28.56	-74.77
p-value	0.00	0.00

Notes: The table shows the estimated mean of the (log) change of GDP and consumer prices over four years following natural disasters in inflation targeting and non-inflation targeting economies as well as the differences between the means together with their t-statistic and p-value based on 500 Monte Carlo draws.

4.2. Transmission channels

The finding that IT generates both higher output growth and lower inflation is remarkable given that there is also a contention in the literature whether IT can only reduce inflation at the expense of depressing output (Cecchetti and Rich, 2001; Friedman, 2004; Gonçalves and Carvalho, 2009). However, there are two important features of IT that are thought to contribute to its superiority over alternative monetary regimes (Bernanke and Mishkin, 1997): (i) the attainment of a generally more stable economic environment; and (ii) better anchoring of inflation expectations.

To test the first argument, we assess the effect of IT on macroeconomic volatility. We again rely on the distributions of the estimated impulse responses and compute, analogously to the procedure for mean growth rates, for each variable the distribution of the standard deviation of its growth rate over the response horizon of four years. With the distributions and the implied average standard deviations at hand, we can test whether IT reduces macroeconomic variability in the aftermath of large real shocks.

Table 3. Testing for differences in volatility

Variable	GDP	Prices	Pol. rate	Gov. cons.	Priv. cons.	Investm.	RER	Exports	Imports
IT	0.50	0.34	0.19	1.51	0.35	1.01	1.33	1.30	0.89
non-IT	0.37	0.49	0.15	1.63	0.42	1.81	0.99	1.21	1.55
Difference	0.13	-0.15	0.04	-0.12	-0.07	-0.80	0.34	0.09	-0.66
t-statistic	30.87	-26.66	14.62	-6.75	-12.62	-38.71	19.56	4.96	-37.47

Notes: The table shows the estimated average standard deviation of the (log) change of main macroeconomic variables over four years following a large real shock in inflation targeting and non-inflation targeting economies as well as the differences between the mean standard deviations and the *t*-statistics based on 500 Monte Carlo draws.

Table 3 presents tentative evidence in favor of argument (i). Five out of nine standard deviations are significantly lower under IT. These are the variances of prices and of the components of domestic absorption. Together with the model-consistent superior output and price performance under IT documented in the previous section, these differences in volatility lend empirical support to the idea that IT supports private sector decision making by establishing a more stable macroeconomic environment. This stability could also influence the degree of expectation formation.

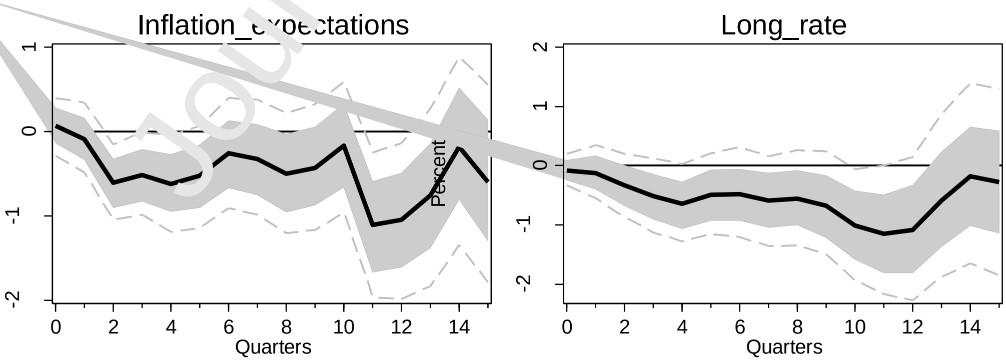
Therefore, we next test whether IT leads to more stable inflation expectations. We use data from the ifo World Economic Survey (WES) for the variable “expected inflation rate by the end of the next 6 months,” which is available from 1991Q3 onwards.

Figure 5 shows the results. Inflation expectations in targeting countries are significantly lower at horizons two to four, with a negative point estimate over the horizon 1 to 15 quarters. In combination with an inflationary impulse in both country groups, inflation expectations are overall better anchored in IT countries, since they tend to be less responsive to the shock.

We also find indicative evidence for lower term premia in IT countries. Figure 5 shows that the long-term rate is lower in targeting countries compared to nontargeters conditional on the disaster shock. The expectations hypothesis of the term structure in its linear form implies that the nominal long-term rate is the sum of the path of the current and future expected nominal short-term rates and the term premium. Since the initial monetary policy response over the horizon is not significantly different across the two country groups, the difference in the evolution of the long rate is most likely due to a different dynamics of term premia.

Overall, the beneficial effects from IT seem to materialize through better anchored inflation expectations and lower risk premia, rather than the monetary policy response directly. In particular, the responses of the policy rates do not indicate that the additional central bank credibility reflected in the muted response of inflation expectations under IT is exploited to provide extra monetary accommodation, as implied by considerations in the theoretical literature. (Svensson, 1997; Clarida *et al.*, 1999).

Figure 5: Differential responses of inflation expectations and long-term rates



Note: The figure shows the difference of the responses to large natural disasters of consumer prices, inflation expectations, and long-term interest rates between inflation targeting and nontargeting economies over the 1980Q1-2015Q4 period. Confidence bands refer to the 90 percent level (dashed lines) and a one standard deviation interval (shaded area), based on 500 Monte-Carlo draws.

5. Economic mechanisms

In this section, we further investigate which economic mechanisms account for the superior performance of IT countries. First, we look at the interactions of monetary and fiscal policies. Then, we analyze whether IT functions differently in developing versus advanced economies, before we ask whether soft or hard targeting makes a difference.

5.1. Fiscal rules and monetary-fiscal coordination

In this subsection, we first carefully control for fiscal rules (FR) as an alternative explanation for the estimated impact of IT. Then, we investigate interactions between IT and fiscal rules. If countries with stronger macroeconomic policy frameworks also adopt fiscal rules, the previous results could reflect an omitted nonlinearity. Fiscal rules could avoid fiscal dominance and attenuate the need for procyclical public spending. Figure 3, for example, shows that government spending tends to be more accommodative under IT. To carefully control for different types of fiscal rules as alternative shock absorbers, we consider the following set of indicator variables: (i) fiscal rule at the national level; (ii) expenditure rule at the national level; (iii) balanced budget rule at the national level; (iv) debt rule at the national level; and (v) fiscal rule at the local level. The indicator variables take on a value of one if the respective rule is in place, and zero otherwise. The underlying data is from the IMF's fiscal rules dataset (Schaechter *et al.*, 2012). We also replicate the 'Strength of Fiscal Rules Index' of the same authors, which maps various information on the implementation of fiscal rules into an index on the interval [0,5], based on different criteria, such as the legal basis, the coverage, the enforcement procedure, and if rules are evaluated by an independent body.

In addition, we construct two variables that measure the size of the government to control for the ability of the public sector to facilitate shock adjustment, for example, through higher direct government spending or through financial assistance payouts to affected firms and households. First, we compute the average share of government consumption in GDP for each country. Second, we generate an indicator that is equal to one whenever a country-quarter observation for the government consumption share is above the full sample median. We add the fiscal measures, one at a time, to model (6) contemporaneously and with all 15 lags and interact each with the corresponding shock lag. Table 4 shows that the main results for the effects of IT remain intact. In all specifications, average GDP growth is significantly higher and average inflation is lower in the four years following the shock, irrespective of the fiscal control variable used.

Table 4: Controlling for fiscal rules as shock absorber

	Mean GDP growth		Mean Inflation	
Controlling for fiscal policy	Difference IT vs. non-IT	*t*-stat	Difference IT vs. non-IT	*t*-stat
Fiscal rules				
Any fiscal rule at national level	0.11	22.37	-0.96	-90.54
Expenditure rule at national level	0.11	25.81	-0.84	-78.11
Budget balance rule at national level	0.09	17.13	-0.83	-77.77
Debt rule at national level	0.14	28.55	-0.87	-77.01
Any fiscal rule at local level	0.15	31.[illegible]	-0.81	-74.78
Strength of fiscal rules index	0.14	28.2[illegible]	-1.18	-106.17
Government size				
Average GDP share gov. consumption	0.07	14.14	-0.89	-74.47
GDP share gov. consumption above median	0.08	18.28	-0.86	-74.90

Notes: The table shows the estimated average difference between mean GDP growth and mean inflation over four years following a natural disaster between inflation targeting and non-inflation targeting economies, together with their *t*-statistics based on 500 Monte Carlo draws.

Next, we assess whether the introduction of IT is particularly beneficial when combined with fiscal rules (Combes *et al.*, 2017). In line with the same authors, we construct the following indicator variables:

— IT_only: 1 whenever IT is in place and no fiscal rule is adopted, 0 otherwise;

— FR_only: 1 whenever at least one fiscal rule (numerical target at the national level on either budget balance, spending, debt, or revenue) is in place and the country does not operate under IT, 0 otherwise; and

— IT_and_FR: 1 whenever IT and at least one fiscal rule at the national level is in place, 0 otherwise.

As these tighter definitions reduce the number of shocks within each regime, we rely on pooled regressions to exploit cross-sectional variation in the policy regime mix. To account for cross-country heterogeneity that might affect the decision to adopt a specific policy framework, we add the following time-invariant observable control variables (Ball, 2010): initial GDP per capita, initial level of inflation, and initial average (over four quarters) GDP growth, all two years before the introduction of IT. We run the following model:

$$\Delta y_{i,t} = \sum_{j=0}^{15}[\,\beta_i S_{i,t-j} + \gamma_j \delta_j IT\_only_{i,t-j} + \delta_j FR\_only_{i,t-j} + \rho_j IT\_and\_FR_{i,t-j} + \lambda_{i,t-j} IT\_only_{i,t-j} S_{i,t-j} + \tau_j Fr\_only_{i,t-j} S_{i,t-j} + \xi_{i,t-j} IT\_and\_FR_{i,t-j} S_{i,t-j}] + \sum_{l=1}^{4} \mu_l \Delta y_{i,t-l} + \phi X_{i,t-1} + \mathrm{c} + \nu_Y + \varepsilon_{i,t}. \tag{8}$$

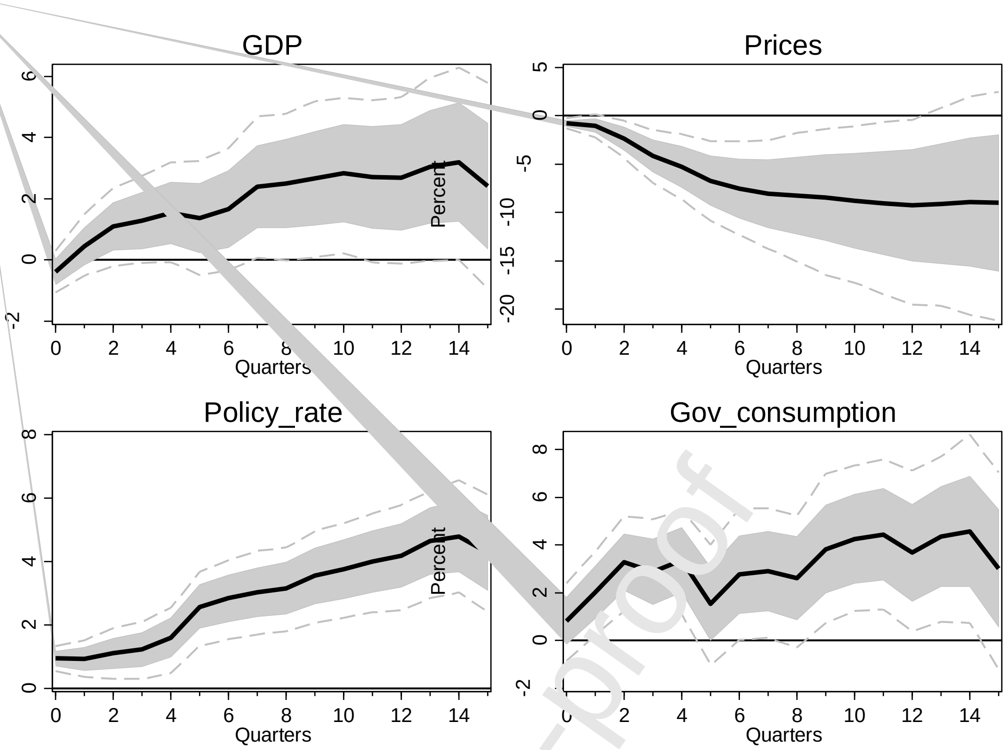
Figure 6 shows statistically and economically significant cross-effects between IT and FR. GDP is significantly higher when both regimes are in place and prices are significantly lower. This is associated with higher monetary policy rates and government spending. The findings are in line with better macroeconomic policy coordination that addresses issues arising from the Fiscal Theory of the Price Level as well as the literature on policy delegation and interaction. Specifically, an inflation targeting central bank and fiscal policy constrained by fiscal rules is akin to `active' monetary policy that, following the Taylor principle, adjusts the policy rate by more than one to one in response to changes in inflation. Conversely, `passive' fiscal policy aims at stabilizing the real level of debt. This policy combination seems attractive as it stabilizes inflation and inflation expectations, thereby reducing macroeconomic volatility, and preventing fiscal profligacy.[14]

Empirically, the cross-effects are reflected in lower prices following the shock than in countries without IT and FR, despite higher government spending. The benefit of fiscal rules and IT in combination could reflect that inflation and spending expectations are anchored. This limits the price pressure in the first place and reduces the risk that higher government spending translates into fiscal profligacy, which in turn would raise the risk of monetarization or default risk. At the same time, fiscal rules imply sound public budgets in good times, thereby creating the space for fiscal accommodation in bad times, especially since most fiscal rules feature escape clauses for extraordinary circumstances. Moreover, in response to the shock, this policy mix better stabilizes GDP, suggesting that more accommodative fiscal policy overcompensates more restrictive monetary policy.

We interpret these findings as a coordinating role of IT for monetary and fiscal policy. This is in line with empirical findings of Minea and Tapsoba (2014), who document that the adoption of IT improves fiscal discipline in developing and developed countries. It is also in line with the theoretical literature on policy delegation, namely that better macroeconomic outcomes are obtained when restricting the discretion of monetary and fiscal policy authorities (Dixit and Lambertini, 2003).

[14] When differentiating between different types of fiscal rules, we find that the findings of Figure 6 are mostly driven by balanced budget regimes. However, the results for the specific rules are less precisely estimated, reflecting the lower number of observations for each specific regime combination.

Figure 6: Cross-effects between inflation targeting and fiscal rules



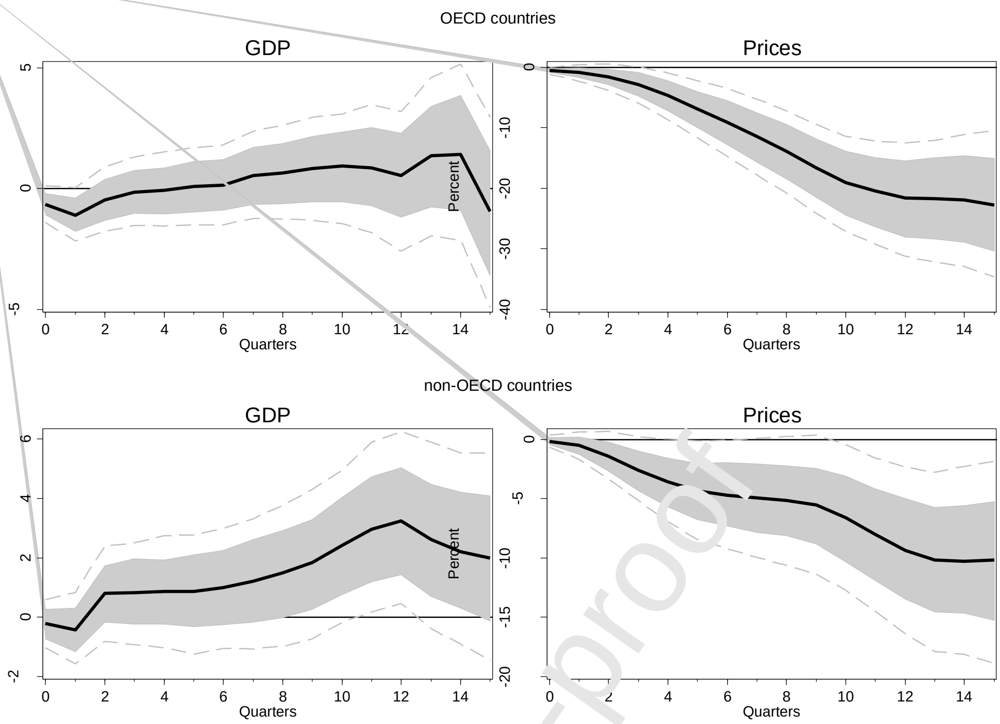
Note: The figure shows the cumulative effects of inflation targeting and fiscal rules jointly, captured by the $\xi_{i,t-j}$'s in model (8), on macroeconomic variables following natural disaster shocks. Confidence bands refer to the 90 percent level (dashed lines) and a one standard deviation interval (shaded area), based on 500 Monte-Carlo draws.

5.2. IT in advanced and developing economies

We return to the baseline model (6) and definition of IT, but split the sample into OECD and non-OECD countries to find out whether one of the groups is driving the results.[15] We start the sample in 1970Q1 to increase the number of observations within each group. The motivation for the sample split is that, on the one hand, richer economies might be more likely to adopt IT given their more developed democratic and financial institutions, and are better prepared to weather large disasters. On the other hand, there is evidence that the introduction of IT has a stronger impact on economic performance in developing economies (Ball, 2010; De Mendonça and e Souza, 2012). Lin and Ye (2007), for example, find no effect of IT in seven industrial countries, whereas Lin (2010) detects a significant impact of IT in developing countries.

[15] OECD sample (20 countries): Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, the United Kingdom, and the United States; see Table A2.

Figure 7: Dynamic impact of IT in advanced and emerging market economies



Note: The figure shows the differential impact of inflation targeting versus alternative monetary regimes on GDP and consumer prices following large natural disasters in OECD (upper panel) and non-OECD countries (lower panel). The sample is 1970Q1-2015Q4. Confidence bands refer to the 90 percent level (dashed lines) and a one standard deviation interval (shaded area).

Figure 7 contains the differential responses of GDP and consumer prices under IT and non-IT regimes for OECD countries (upper panel) and non-OECD members (lower panel). In both sub-groups, the impact of IT is qualitatively and quantitatively similar to the baseline results. GDP tends to be higher and prices increase less under this monetary regime. In terms of statistical significance, the results for GDP, in particular for OECD countries, are weaker. The price response is significant in both sub-groups. We conclude that IT improves macroeconomic performance following large real shocks in both developed and developing economies – especially with regard to inflation dynamics.

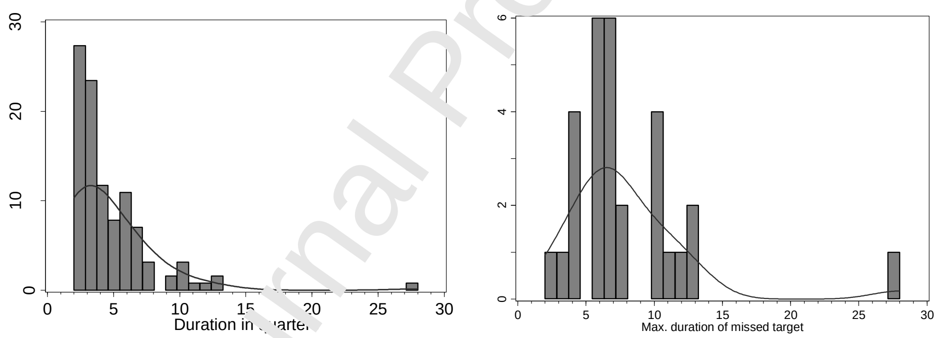
5.3. Does hard or soft targeting make a difference?

As a next step, we try to determine whether the adoption of IT, *per se,* generates macroeconomic improvements. Such analysis puts the "conservative window-dressing" hypothesis to a test, which postulates that the features of IT have little effect on output or inflation, rather it is the stronger emphasis of the central bank on inflation and its corresponding monetary policy conduct that achieves the better outcomes (Romer, 2006).

To test this argument, we split the IT group into a hard targeting group that, *ex post,* complies more strictly with the inflation target versus a soft targeting group that, *ex post,* complies less with the inflation target. We measure compliance as the maximum time span of consecutive inflation rates outside the target corridor.[16] Figure 8A shows the histogram of the average duration of target misses in the sample. There is no country with an average duration of target misses at zero or one quarter; the highest density is at two quarters, rapidly declining to 14 quarters. There are outliers of up to 27 quarters of continual misses. Figure 8B exhibits the maximum one-sided duration spell of each IT country, the measure we use to separate hard from soft inflation targeters. It is expressed as percent over the total number of quarters under IT. We split the sample according to the 50th percentile of the maximum duration spell of target misses to obtain a similar number of countries in both groups. Those countries with a maximal one-sided deviation from target exceeding this threshold are declared to be soft IT countries.

Figure 8: Duration of missed inflation targets

A. Average duration of spells of missed target B. Max. duration of missed target



Note: **PANEL (A)**: Density of average duration spells where the inflation rate is outside the target corridor in the sample of countries operating under an inflation targeting regime. "Target misses" are defined as observed CPI inflation rates outside of the target corridor. The solid line represents the kernel density estimate of a Gaussian kernel function with a bandwidth of 2 and 0.05, respectively. **PANEL (B)**: Density plot of the longest time period of a one-sided, continued realized inflation rates outside of the corridor per country in the sample operating under IT. The maximum duration of a missed inflation target is expressed as percent of the total number of quarters under IT.

The challenge for a measure of compliance to an inflation target is that inflation targets are usually defined over the medium term, which explicitly allows for temporary deviations. Since monetary policy can only move inflation with some lag, typically deviations from the target persist. With an important *ex ante* element in its definition, any *ex post* measure will face severe limitations. Additionally, many bands around inflation targets are not chosen to increase the probability of successful achievement. Freedman

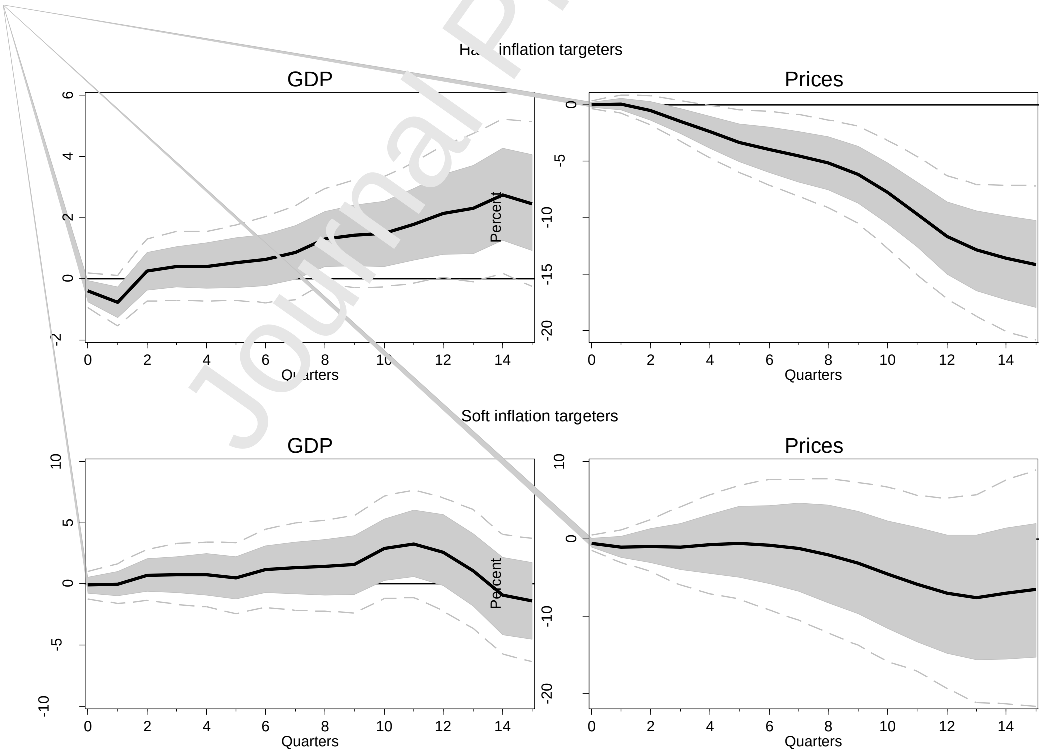
[16] We compiled a database for the inflation targeting countries as well as their respective target rates and target corridors. Where no corridors are used for the conduct of IT, we constructed a symmetric and hypothetical corridor around the target rate with the average size of target corridors across countries. Figure A6 and Figure A7 in the Online Appendix illustrate this for the entire sample of IT countries.

(1995) highlights that the adoption of a ±1 percent target band in many countries is primarily due to communications needs and to maximize the impact on expectations.

Despite these challenges, we argue that facing a persistent one-sided deviation from target should result in an enhanced effort by the central bank to restore the target. This is in line with Blinder (2000), who emphasizes that track records are the primary way for central banks to establish credibility. Thus, we thus think that the maximum one-sided duration of inflation outside the target range is a good proxy for the commitment to maintaining and defending the inflation target.

The top panel of Figure 9 contains the differential effects of hard IT versus all non-IT economies, and the bottom panel those of soft IT against all non-IT regimes. The comparison shows that the baseline results are mostly driven by the group of hard targeters. GDP is higher, although only borderline significant, and prices are lower. In sharp contrast, soft targeting does not affect the adjustment to the shock. We conclude that it is the actual conduct of monetary policy that matters for successful macroeconomic stabilization and not the *de jure* monetary regime.

Figure 9: The impact of hard and soft inflation targeting



Note: The figure shows the effect of hard (upper panel) and soft (lower panel) inflation targeting on GDP and price responses following large natural disasters relative to nontargeting economies. Confidence bands refer to the 90 percent level (dashed lines) and a one standard deviation interval (shaded area), based on 500 Monte-Carlo draws.

6. Sensitivity analysis

In this section, we describe one main sensitivity test. The Online Appendix contains additional robustness analyses. The main test shows that the results hold when we (i) employ different sample periods; (ii) control for factors determining the decision to adopt inflation targeting; (iii) use alternative lag lengths for the autoregressive component of the model or an alternative estimator; and (iv) consider modified shock definitions.

As outlined in Section 3.4, a crucial ingredient for attaching a causal interpretation to the impact of IT is the control for alternative channels that potentially affect the response to natural disasters. In the baseline model, we use GDP per capita interacted with the shock for all lags for that purpose. To assess the robustness of our results to changing the measure of economic development, we use alternative proxies for this concept. Specifically, we replace GDP per capita in model (6) successively with the level of democracy and different indicator variables that are equal to 1 whenever a country is part of the G7, OECD, or advanced economies, respectively, and 0 otherwise. Table 5 shows that our main results hold. Mean GDP growth and inflation following a shock are significantly higher and lower, respectively, under IT.

Table 5: Sensitivity to controlling for alternative shock absorbers

	Mean GDP growth		Mean Inflation	
Controlling for alternative shock absorbers	Difference IT vs. non-IT	*t*-stat	Difference IT vs. non-IT	*t*-stat
Level of economic development proxied by				
G7 dummy	0.12	29.05	-0.75	-72.28
OECD dummy	0.13	33.42	-0.77	-68.70
Advanced economy dummy	0.15	37.19	-0.75	-72.74
Level of democracy	0.14	35.69	-0.76	-70.99
Geographic and other country characteristics				
Exchange rate regime	0.14	30.57	-0.79	-76.93
Central bank independence	0.09	20.76	-0.77	-62.74
Unconditional frequency of shocks	0.10	26.11	-0.75	-74.82
Island dummy	0.15	36.25	-0.66	-64.15

Notes: The table shows the estimated average difference between mean GDP growth and mean inflation over four years following a natural disaster between inflation targeting and non-inflation targeting economies, together with their *t*-statistics based on 500 Monte Carlo draws.

As a second sensitivity test, we control for alternative country characteristics that might change shock absorption. Instead of GDP per capita, we correct for the exchange rate regime as Ramcharan (2007) shows that flexible exchange rates are conducive to weathering natural disasters. We use a dummy variable that is equal to one in case of a flexible exchange rate and zero otherwise.[17] The unconditional correlation with IT is essentially zero. There are many targeters with freely floating currency, like Australia and the UK, as well as nontargeters with fixed exchange rate, like Kenya and Singapore. Both combinations induce a positive correlation. However, there are also some targeters with not fully floating exchange rates, like Thailand and Mexico, as well as many nontargeters with flexible exchange rates, like the US and Japan. These two combinations induce a negative correlation. The insignificant unconditional correlation between flexible exchange rates and IT already suggests that our main results are not driven by the exchange rate regime. The table confirms this formally.

One might suspect that the beneficial effects of IT could arise in any country with a similarly independent central bank as under an IT regime. To control for this possibility, we interact a central bank independence index with the shock variable. We use the aggregate index on legal central bank independence proposed by Cukierman et al. (1992) [p.358-359], constructed using the dataset of Garriga (2016). The corresponding line in Table 5 shows that the results under IT are robust to this additional control, thus it is not driven by central bank independence.

Finally, we replace per capita GDP with the unconditional frequency that a country is hit by shocks or a dummy for islands. These interaction terms capture geographic characteristics that potentially affect both the choice of the monetary regime and the response to the shock. The bottom row shows that the results hold.

7. Conclusions

We present robust empirical evidence for the hypothesis that inflation targeting leads to better economic outcomes. When hit by large adverse shocks in the form of natural disasters, economies under an inflation targeting regime experience significantly lower inflation and inflation variability than under alternative monetary policy regimes. At the same time, higher output growth is experienced. The results are robust to various sensitivity tests, including if we control for the quality of institutions and the presence of fiscal rules. The success of inflation targeting rests on a number of pillars.

First, predominantly hard targeting stabilizes the economy, while soft targeting has only limited effects. Second, inflation expectations are better anchored in IT countries

[17] We use the measure of Ilzetzki *et al.* (2017) and map their classification, which describes exchange rate regimes on the interval (1,6) into the exchange rate regime dummy variable according to Ramcharan (2007). Specifically, regimes ≤3 are classified as fixed (dummy =0), while 4 and 6 are classified as flexible (dummy=1). We exclude 5=freely falling from the sample.

following natural disaster shocks. Third, IT reduces macroeconomic volatility following the shocks, thus lowering term premia. Finally, IT, with its focus on price stability, seems to be coupled with a stronger orientation of fiscal policy toward output stabilization.

To summarize, beneficial effects from IT appear to materialize primarily through shock propagation and policy coordination. We find no empirical evidence that greater policy space arising from better anchored inflation expectations is used under IT to respond with more monetary accommodation. All in all, our findings show that inflation targeting is "alive and well." The documented benefits play a part in the remarkable success of this monetary regime.

The paper contributes to the literature by analyzing the different economic outcomes under alternative monetary policy regimes conditional on large natural disasters, which are exogenous to the choice of the monetary regime. This approach to the question is novel as the existing literature focuses on the unconditional effects of inflation targeting (Walsh, 2009; Ball, 2010). The departure from looking at the average effect also explains why the beneficial effects from IT arise in both OECD member countries and in non-OECD countries, since the former are more often in the hard-IT group.

The findings of the paper have multiple implications for central banks. They show that while IT may not strictly be a superior policy mandate in open economies in normal or tranquil times - as concluded by the existing literature - it is a better mandate in times of crisis, at least when the domestic economy is hit by a large real shock, such as a natural catastrophe. The better shock adjustment suggests that IT was more of a savior during the global financial crisis than previously thought. However, this only holds if central banks do not merely pretend to follow an IT strategy, but if it has gained credibility through a successful track record of IT. Therefore, the debate on reforming present IT frameworks should consider that increased flexibility, allowing for prolonged deviations from the target range, can come at a cost in terms of lower shock resilience.

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