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Working Paper Series Nº 2019-18

DEPARTMENT OF ECONOMICS, FEA-USP
WORKING PAPER Nº 2019-18

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There is some confusion in the literature about how to calculate sacrifice ratios (SRs), and we show that correcting for this problem implies that the way computed by Ascari and Ropele (2012) generates values four times larger than the way reported by most of the empirical studies. Therefore, contrary to their claim, their baseline simulations with the medium-scale New Keynesian model with past inflation indexation do not generate realistic sacrifice ratios, and simulations with plausible but less frequently used parameters can only reach the very low end of the range of the estimates obtained in the empirical studies

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The New Keynesian Model and Sacrifice Ratios: Some Measurement Issues

(Long version)

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Abstract

There is some confusion in the literature about how to calculate sacrifice ratios (SRs), and we show that correcting for this problem implies that the way computed by Ascari and Ropele (2012) generates values four times larger than the way reported by most of the empirical studies. Therefore, contrary to their claim, their baseline simulations with the medium-scale New Keynesian model with past inflation indexation do not generate realistic sacrifice ratios, and simulations with plausible but less frequently used parameters can only reach the very low end of the range of the estimates obtained in the empirical studies.

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This paper is an extended version of a paper with the same title.

The New Keynesian Model and Sacrifice Ratios: Some Measurement Issues

1. *Introduction*

Historical episodes of disinflation are usually costly since they are accompanied by temporary recessions (output losses / unemployment hikes). A formal way to measure the costs associated with disinflation is the concept of the sacrifice ratio (hereafter, SR). There is a vast empirical literature documenting the SRs for historical disinflations in different countries and employing different methodologies (e.g., Gordon and King (1982), Ball (1994a), Andersen and Wascher (1999), Cecchetti and Rich (2001), Corbo *et al*. (2001), Cuñado and de Gracia (2003), Durand *et al*. (2008), Gonçalves and Carvalho (2009), Brito (2010)).

The related, more theoretical literature investigates the ability of different versions of the New Keynesian (NK) model to explain SRs. Since Ball (1994b), it seems clear that the nominal rigidities of the canonical New Keynesian model do not explain SRs, and contributions such as those from Fuhrer and Moore (1995) have shown that it does not fit with the inflation persistence shown in the data either. Adding real rigidities does not solve the problem either (Ascari and Merkl (2009)). As a result, imperfect credibility (e.g., Ball (1995), Erceg and Levin (2003), and Goodfriend and King (2005)) and sticky information (e.g., Mankiw and Reis (2002) and Coibion and Gorodnichenko (2015)) became the favorite explanations for the SRs.

Meanwhile, a particular form of indexation by past inflation was inserted in the model to obtain inflation persistence (e.g., Smets and Wouters (2003, 2007) and Christiano, Eichenbaum, and

Evans (2005)), and some other mechanisms were added as well in what came to be called the "medium-scale New Keynesian model" (e.g., Smets and Wouters (2003, 2007), and Christiano, Eichenbaum, and Evans (2005)).

Ascari and Ropele (2012a, hereafter, AR) compare the sacrifice ratios generated by the simulations of this model with those reported in the empirical literature, and these authors conclude that the NK model generates realistic SRs. We argue in this paper that AR's result relies on a possible mistake: the methodology usedy by AR to calculate the SRs implies numbers four times larger than those obtained in the way they are most often calculated. The problem arises because AR divide the sum of the quarterly output gaps by the change in the annualized inflation rates, while most empirical papers compare the yearly inflation rates with yearly output gaps.

The structure of the paper is as follows. Following this Introduction, section 2 presents the calculation of the SRs according to Ball (1994a) and contrasts this calculation to AR's. Section 3 compares AR's estimates of the SRs to the empirical literature. The paper closes with a final section on the conclusions.

2. *Sacrifice ratio calculations: Contrasting Ball and AR*

The sacrifice ratio measures the output costs of disinflation. There are different methodologies used in the calculation of SRs, but one of the most popular is the procedure proposed by Ball (1994a).

AR, for example, claim that "our model-consistent SR is then constructed coherently with the definition in Ball" (p. 459). The procedure Ball uses to calculate the SRs is the following:

i) Quarterly trend inflation series is calculated where the value of the series in quarter t is the average inflation from $t - 4$ up to $t + 4$;

ii) Peaks and troughs in this trend series are identified, and a disinflation episode is defined when the difference between a peak and a trough is at least 2%;

iii) SR is calculated in the following way: "the denominator of the sacrifice ratio is the change in trend inflation over an episode – the difference between the peak and the through. The numerator is the sum of the output losses – the deviations between actual output and its 'full employment' or trend level." (p. 160); and

iv) Trend or 'full employment' output is given by a log linear line connecting the log of the output at the beginning of a disinflationary episode (the peak) and the period four quarters after its end (the trough). Therefore, the sum of the output losses (the numerator of the SRs) continues up to four quarters after the end of the disinflation.

Ball asserts that assuming that the full employment is reached four periods after the trough is a conservative estimate of the losses in the episode (that is, this estimate would be more likely to underestimate the SR than to overestimate it),[1] and some other papers such as that of Zhang (2005) agree with this.

Thus, the SR is the sum of the losses in terms of the output gaps divided by the reduction in the inflation rate in a disinflationary episode. An important measurement issue involved in the SR

[1] See the first paragraph on page 161.

calculation is related to the frequency of the data (e.g., quarterly or yearly) and the reporting of the SRs in terms of the annual or quarterly output losses.

This measurement problem came up in the literature because, even though the inflation rate is always measured in yearly terms, sometimes the numerator of the SR is calculated as the sum of the output gaps of each quarter (AR procedure), while the criterion is calculated most often as the sum of these losses converted to an annual basis. The former criterion yields SRs that are four times larger than the latter. As an example, if there is an average output gap of 1% during eight quarters, and the fall in the yearly inflation rate is 2%, the SR will be 4 when the first criterion is used and 1 when the second criterion is used.

Formally, the two criteria are

$$SR^{Q} = \frac{(\sum_{t=0}^{T} y_t)}{\pi_{high} - \pi_{low}} \tag{1}$$

$$SR^{A} = \frac{(\sum_{t=0}^{T} y_t)/4}{\pi_{high} - \pi_{low}} = \frac{SR^{Q}}{4} \tag{2}$$

where π_{high} is the yearly inflation rate at its peak, π_{low} is the yearly inflation rate at the trough, y_t is the output gap of each quarter, $t = 0$ is the quarter when π_{high} occurs, and $t = T$ is the quarter when output is presumed to be back to the long term trend ('full employment'), which is supposed to happen ρ quarters after π_{low} is reached. Ball (1994a) assumes that ρ = 4 (that is, as mentioned above, he assumes that the economy returns to 'full employment' four quarters after π_{low} is reached).

In SR^A, the sum of the quarterly output gaps is divided by four because this average is the annualized output gap.[2] SR^A makes more sense because it compares output gaps and inflation rates over the same length of time, and it is the criterion used both by Ball (1994a)[3] and in most studies in the literature.

The main point of our paper is that AR use SR^Q to calculate the SRs of their simulations, and they compare their calculated SRs with those reported in the empirical literature, which, in turn, use either SR^Q or SR^A, but mostly SR^A. The use of SR^Q in AR is deduced from their equation (1), figure (1) and Table 1.[4] Equation (1) shows that the sum of the quarterly output gaps is not divided by four in the numerator of the sacrifice ratio, and the integrals of the output gaps shown in the respective graph of figure 1 are compatible with the SRs shown in its table 1 only if the criterion that is used is SR^Q. We replicated AR's simulations and we verified that they are actually reporting SR^Q in their table 1.[5]

3. *The size of SRs in the empirical literature and in AR's simulations*

[2] When annual data is used to compute SRs, no adjustment is needed since, in this case, the calculated SR is already measured in terms of annual output loss.
[3] This occurs even though, curiously, in the working paper version of the article, Ball (1993) uses SR^Q.
[4] AR inform that the parameter values used in the simulations come from Christiano *et al*. (2005), in which, these authors either calibrate or estimate them using U.S. quarterly data.
[5] Our simulations are available upon request.

We start our quantitative assessment by reproducing different SR calculations for the disinflationary episodes identified by Ball (1994a). We tried to replicate the SR estimates for these episodes using the currently available quarterly data from the IMF's *International Financial Statistics* (the source used by Ball(1994a)), complemented by the FRED of the Federal Reserve of Saint Louis and by the OECD data (when *IFS* data was not available). Table 1 shows the results. We report our own calculations for the two SR definitions from the previous section, SR^Q and SR^A, by closely following Ball's procedure.

The first column in Table 1 reports Ball's original findings. While AR's favorite estimate for SRs, as extracted from their simulations, is approximately 1 when calculating SR^Q, table 1 shows that Ball's (1994a) average estimate of the SRs is 1.47. However, the comparison between these two values is misleading because Ball is actually reporting a different measurement of SR, namely, SR^A. The use of the annual (SR^A) rather than quarterly (SR^Q) output costs is confirmed not only by our recalculation but also by the comparison between Ball (1994a) and Ball (1993), which is the preliminary working paper of this article. In the working paper, Ball's sacrifice ratios were exactly four times higher than those in Ball (1994a) – clearly because the latter used SR^A, while Ball (1993) used SR^Q. This implies that Ball's estimates of the SRs with the actual disinflation data are around six times larger than AR's estimates of the SRs with calibrated simulations.

Column SR^Q overestimates the SRs due to the lack of adjustment for the costs in terms of the annual output. The average value of the SRs we obtained for the Ball episodes according to this measure is 6.23. Finally, our estimates of SR^A for these episodes, as shown in the last column, eliminate the source of overestimation and present values that are close to those shown in Ball (1994b). The average SR for all the episodes reported by Ball (1994a) is 1.47. Our own calculation for the same episodes yields an average SR of 1.66 when SR^A is used.

Table 1: Comparing Ball's (1994a) and Ascari and Ropele's (2012a) calculations of SRs

Episode	Ball (1994)	SRQ	SRA
Australia			
74:2-78: 1	0.72	2.15	0.54
82: 1-84: 1	1.28	5.60	1.40
Canada			
74:2-76:4	0.63	3.71	0.93
8 1:2-85:2	2.37	9.16	2.29
France			
74:2-76:4	0.91	4.24	1.06
8 1: 1-86:4	0.60	0.54	0.13
Germany			
65:4-67:3	2.56	9.47	2.37
73:l-77:3	2.64	9.94	2.48
80:1-86:3	3.56	13.83	3.46
Italy			
63:3-67:4	2.65	16.57	4.14
77:1-78:2	0.98	4.29	1.07
80: 1-87:2	1.60	5.95	1.49
Japan			
62:3-63:1	0.53	2.87	0.72
65:1-67:2	1.66	10.94	2.74
70:3-71:2	1.27	11.79	2.95
74:1-78:3	0.61	2.38	0.60
80:2-83:4	0.02	(3.05)	(0.76)
84:2-87:1	1.48	6.51	1.63
Switzerland			
73:4-77:4	1.85	7.20	1.80
81:3-83:4	1.29	8.76	2.19
United Kingdom			
61:2-63:3	1.91	12.66	3.17
65:2-66:3	(0.01)	0.97	0.24
75:1-78:2	0.87	5.13	1.28
80:2-83:3	0.29	1.90	0.48
84:2-86:3	0.87	4.55	1.14
United States			
69:4-71:4	2.94	11.65	2.91
74:1 76:4	2.19	8.84	2.21
80: 1-83:4	1.83	7.88	1.97
Average of episodes	**1.47**	**6.66**	**1.66**
Baseline simulations of Ascari and Ropele		**0.92 to 1.13**	

AR report SRs in the range of 0.92 to 1.13 (see their Table 1, p. 462) after simulating the disinflationary episodes in their New Keynesian DSGE model. Since AR compute SR^Q as given by (1), their reported SRs should be compared to one of the SR^Q measures we report in Table 1. It is then quite remarkable how far AR's estimates of SRs are from their empirical equivalent for the Ball episodes. AR's range of values for the SRs are close to the SRs reported by Ball (1994a) and to our own replication in column SR^A. Nevertheless, our main point of contention is that such a comparison is unwarranted due to the different methods for the computation of the SRs involved. We therefore cannot agree with their conclusion that their model "is able to quantitatively match the empirical estimates of the cost of disinflation, namely, the sacrifice ratio". (p. 466)[6]

AR also compare their SRs with other estimates from the empirical literature. However, as the comparison with Ball (1994a) makes clear, one has to be very careful and check whether the reported SRs from the empirical papers actually follow the criteria that are close to those that AR use when computing their SRs. It turns out that not all of the empirical literature quoted by AR report that their SRs are computed in the same way as AR computed theirs.[7]

We compare the empirical literature according to the dimension mentioned in the previous section: whether the output costs are measured in terms of quarterly (SR^Q) or annual (SR^A) output. Table 2 displays the empirical literature quoted by AR, specifying which criterion – SR^Q or SR^A – each paper used. Table 2 also shows the magnitudes of the SRs reported by them.

[6] Ascari and Ropele (2012b) also report sacrifice ratios obtained from a simulated quantitative model calibrated for quarterly data. The reported SRs are as in SR^Q, i.e., with no adjustment for costs in terms of the annual output.
[7] AR mention eight empirical references in the last paragraph of p. 462 and in footnote 8 on the same page.

Table 2: Estimates of the SRs in the main contributions of the empirical literature

Paper	SRQ or SRA	Methodology	Episode/Sample	Mean Estimates
Gordon and King (1982)	SRA	Structural seven equation model estimation	US. Estimated over 1954-80 and simulated over 1981-92	3 to 4.8
Andersen and Wascher (1999)	SRA	Slope of short-run supply, Structural price and wage equations, Actual disinflations	19 OECD split into the 1980s and 1990s	1.1 (1980s) 4.0 (1990s)
Cuñado and De Gracia (2003)	SRA	Slope of the Phillips curve	Annual data for 11 EMU countries for 1960-2001	0.55 to 1.96
Ball (1994b)	SRA	Disinflation episodes	Quarterly data for 9 OECD countries over 1960-1991	1.47
Zhang (2005)	SRA	Disinflation episodes considering long-lived effects	G-7 countries' quarterly data over 1960-1999	2.67
Cecchetti and Rich (2001)	SRA	Structural VAR (SVAR)	US quarterly data over 1959-1997	1 to 10
Durand et al. (2008)	SRA	Structural VAR (SVAR)	Quarterly data for 12 EMU countries over 1972-2003	0.57 (whole sample) 0.45 (72 to 93) 1.22 (94 to 03)
Corbo et al. (2001)	SRA	Disinflation episodes	Annual data from 25 countries over 1980-1999	0.6 (IT countries)
Gonçalves and Carvalho (2009)	SRQ	Disinflation episodes	OECD countries over 1980-2006	5.6 (whole sample) 1 (IT countries)
Brito (2010)	SRQ	Disinflation episodes	OECD countries with IT	1.54 (2 quarters after IT) 6.61 (all cases with IT)

The values in Table 2 imply that SR^A is estimated to be within a wide range with mean values between 0.45 and 10. If one considers individual country estimates from Table 1 or confidence intervals for the SVAR literature, the range of possibilities becomes even wider, including situations with negative or zero values for the SRs.

The estimates using structural VARs are less robust, with the main reference, Cecchetti and Rich (2001), obtaining estimates ranging from 1 to 10 of the yearly output (that is, calculated according to SR^A) depending on the structural assumptions made for the VAR. The wide range obtained for SVAR, without a clear clue about which set of restrictions or which structural model is better, leads Cecchetti and Rich (2001) to conclude that "we are skeptical that current data and econometric techniques can provide a meaningful set of estimates" (p. 427) with respect to SVARs for SRs.

Excluding the SVAR estimates and the old contribution by Gordon and King, the range of estimates of the SR^A becomes an interval from 0.55 to 4.0, while AR assumed that the reference from the empirical literature ranges from 0.5 to 3.0 (p. 458).

The AR baseline calibration, with the Calvo parameters for optimal price and wage readjustments set respectively at 0.6 and 0.64, and with 100% indexation for both, implies a SR^Q's range between 0.92 and 1.13 (see their Table 1); this finding is equivalent to 0.23 to 0.28 under SR^A. When the Calvo parameters are both changed to 0.75 (implying optimal readjustments, on average, at each four quarters), SR^Q reaches 2, which is equivalent to a SR^A of 0.5. AR made the error of not distinguishing SR^Q and SR^A, and they reported their baseline SR^Q of 1 to be relatively in line with the empirical evidence. However, this value implies a 0.25 value for SR^A, which is clearly below the 0.5-4.0 or the 0.5-3.0 intervals. The simulations with the Calvo parameters set at 0.75 are, in turn, at the low end of the empirical estimates.

It is also worth observing that some of the references in this literature (e.g., Ball (1994b), Andersen and Wascher (1999), Cuñado and de Gracia (2003), Durand *et al*. (2008)) indicate that SRs increase as the targeted inflation approaches zero, and this supports the policy of central banks around the world to set the targeted inflation to values above this level, such as 2% a.a..

Some references suggest, as mentioned by AR, that inflation targeting (IT) reduces SRs, but some others contradict that. One of the papers that favor IT, Corbo *et al*. (2001), reports SRs close to 0.6 for those countries that adopted IT in the early 1990s.[8] However, there are two main sources for the underestimation in their calculation of the output gap. First, they compute the potential output according to the HP filter. This is problematic because the HP filter is designed precisely to smooth output fluctuations out. Ball (1994a) argues that "since these methods minimize deviations from trend, they appear to understate or even eliminate recessions" (p. 160). In addition to that, a second source of underestimation in the computation of the output gap is that they assume that the economies return to the trend output ('full employment') at the moment of the troughs of the inflation rate, while Ball (1994a) assumes that this happens four periods latter. In the results of AR, the output returns to the steady state five quarters after the inflation rate stabilizes at its new steady state.[9]

In addition, Corbo *et al*. (2001) use annual data and therefore report SR^A. On this account, compared to the use of SR^Q by AR, their reported SRs underestimate those simulated by AR by a factor of four. Thus, converting Corbo *et al*.'s (2001) estimates of the SRs to the SR^Q criterion implies a

[8] Nine IT countries are included in this group: Australia, Canada, Chile, Finland, Israel, New Zealand, Spain, Sweden, and the United Kingdom.
[9] Output takes 11 quarters after the shock to reach its new steady state, while inflation takes 6 quarters to reach its new steady state (p. 462).

value of 2.4, which, even with the two sources of underestimation that were mentioned previously, is still clearly above AR's estimates.

The other IT paper mentioned by AR is by Gonçalves and Carvalho (2009), who study 61 disinflationary episodes for 30 OECD countries over 1980-2006. They report an average SR of 5.6 for all countries and a drop to 1 for IT countries. Gonçalves and Carvalho (2009) follow Ball (1994b) in the identification of the disinflationary historical episodes and in the assumptions for both the potential output (linear growth in the episode) and the return to trend after four quarters after the inflation through.

Gonçalves and Carvalho compute quarterly output losses (SR^Q) that are, in this dimension at least, compatible with AR. However, Brito (2010) argues that there are great selection problems in the IT cases considered by Gonçalves and Carvalho. These authors take into account only the IT disinflationary episodes that occur at least two quarters after the adoption of IT. The alleged reason was that some time is required for agents to learn about the IT regime and to believe it is credible. They identify only 5 IT disinflationary episodes, which are reported in Table 3.

Table 3: Sacrifice ratios for inflation targeting countries

Country	Episode	IT adoption	SRQ	Disinflation after IT adoption		Disinflation during IT adoption
				Gonçalves and Carvalho	Brito	Brito
Australia	95:3-98:2	Apr/93	1.18	Yes	Yes	Yes
Czech Republic	01:1-03:2	Jan/98	3.53	Yes	Yes	Yes
Germany	91:3-96:2		-1.03	Yes		
New Zealand	95:4-98:4	Mar/90	1.82	Yes	Yes	Yes
Turkey	03:4-05:1	Jan/02	-0.38	Yes	Yes	Yes
Canada	91:1-94:1	Feb/91	11.3			Yes
Czech Republic	98:1-00:1	Jan/98	2.89			Yes
Iceland	01:2-03:3	Mar/01	8.25			Yes
Korea	98:1-00:1	Jan/98	12.06			Yes
New Zealand	90:1-92:4	Mar/90	8.44			Yes
Spain	94:4-98:2	Nov/94	16.89			Yes
Hungary	01:3-03_1	Jun/01	-0.84			Yes
Mexico	99:1-05:1	Jan/99	0.69			Yes
Poland	99:1-03:2	Oct/98	-1.41			Yes
Sweden	93:1-97:4	Jan/93	19.59			Yes
Average SR				**1.02**	**1.54**	**6.61**

Brito (2010) raises two objections to the IT disinflationary cases selected by Gonçalves and Carvalho. The first objection is the inclusion of Germany among the IT countries even though Germany never formally adopted this monetary framework. When Germany is excluded from the

IT group, the average SR for the 4 remaining countries increases from 1 to 1.54 (see Table 3). The second objection raised by Brito (2010) is that the exclusion of many disinflationary episodes concomitant to the adoption of IT would be *ad hoc*. Gonçalves and Carvalho (2009) identified 10 such episodes which, nevertheless, were not considered to be part of the IT group. When these disinflationary experiences are added to the 4 cases (ex., Germany) considered by Gonçalves and Carvalho, the average SR increases to 6.61 (measured as the costs of the quarterly output). We add the observation that four countries constitute a very small sample to represent the effects of IT, but other authors that analyze this theme with larger samples also did not find evidence that IT significantly reduces SRs (e.g., De Roux and Hofstetter (2014), and Mazumder (2014)).

One final comparison we want to make is with the literature closest to AR, i.e., with the literature that reports SR estimates obtained from quantitative New Keynesian models. AR mention nine articles using some variant of New Keynesian models to address the output costs of disinflation.[10] Only Erceg and Levin (2003) compute the SRs from a quantitative calibrated model, thereby making a direct comparison with AR unfeasible for the other references.[11]

Erceg and Levin (2003) develop a quantitative New Keynesian model with imperfect credibility/observability of the targeted inflation to simulate a Volcker-type disinflation. Therefore, instead of using the standard way of indexation used in new Keynesian models (often considered

[10] See page 458 of their article. The New Keynesian literature quoted by AR include the following: Taylor (1983), Ball (1994a), Ball (1995), Burstein (2006), Erceg and Levin (2003), Goodfriend and King (2005), Nicolae and Nolan (2006), Mankiw (2001), and Mankiw and Reis (2002).

[11] Taylor (1983) is concerned with costless disinflation in the context of staggered wage contracts. Thus, the simulated disinflation embed zero sacrifice ratios by assumption. Ball (1994a) and Ball (1995) compute the SRs for a stylized economy. Goodfriend and King (2005) simulate the impacts of a disinflationary episode on output but do not report the SRs. The same ocurs with Mankiw and Reis (2002), with Burstein (2006), and with Nicolae and Nolan (2006). Mankiw (2001) offers a selected survey of the literature without paying attention to the quantitative measurements of SRs.

ad hoc), the persistence of inflation is generated by a persistence in expected inflation. They simulate the output gap response to a 6 p.p. drop in inflation (from 10% to 4%). Erceg and Levin (2003) observe that "our calibrated model yields a sacrifice ratio of 1.7 during the 5 years after the disinflation shock" (p. 933). The accumulated output gaps they report (in Figure 6, p. 933) amount to approximately 42. When this value is divided by 6 (the drop in the annual inflation), it gives a SR of 7 measured in terms of the quarterly output costs (our SR^Q measure). When this value is divided by 4, one gets an SR of 1.75 measured in terms of the annual output costs (our SR^A measure). Thus, unlike AR, Erceg and Levin make the adjustment we advocate to calculate the implied SR from his model.

We conclude, therefore, that after adjusting for a correction in the calculation, the simulations of the SRs from the medium-scale New Keynesian model with full indexation, as found in AR, do not generate sacrifice ratios consistent with the empirical literature when the most usual parameters for calibration are utilized, while with higher, but still plausible, degrees of price and wage stickiness, it matches the very low end of the spectrum of the empirical SR estimates.

Still examining the calibration, an attenuation for these outcomes is given by the stylized fact that the effects of monetary policy on output are asymmetric,[12] and this was not taken into account by AR. Since it is larger in contractions than in expansions, using a coefficient with the average effect underestimates the SRs obtained with simulations.

[12] See, e.g., Santoro et al. (2014) for an updated survey on the issue and a proposed explanation.

4. Conclusion

The present paper shows that, after adjusting for a correction in the calculation criteria, the simulations of SRs with the medium-scale New Keynesian model with its standard way of modeling indexation, as in the work of AR, do not generate sacrifice ratios with sizes compatible with the literatures that they quote. This happens even with full indexation of both wages and prices, which is the main case that AR discuss. When higher degrees of price and wage stickiness are used for calibration, AR simulations reach the lower end of the empirical observed SR's. In addition, AR claim that the SRs of their simulations are compatible with those obtained in disinflationary episodes with IT, but the comparison AR make with the empirical literature is subject to problems related with both calculation and robustness.

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