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Exploring the potential benefits of inflation overshooting

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Introduction

The Bank of Canada responded aggressively to the economic damage that the COVID-19 pandemic caused. In March 2020, the Bank lowered the policy interest rate to its effective lower bound (ELB), where it has since remained. At the same time, to help support the proper functioning of financial markets and keep long-term interest rates low, the Bank also engaged in lending operations with financial institutions and large-scale asset purchases in core funding markets. Despite this unprecedented monetary stimulus, containment measures forced businesses to close and workers to be laid off. To further support an economic recovery, the Bank began providing guidance about the expected path of its policy interest rate conditional on the economic outlook. In particular, the Bank announced that the interest rate would be held at its ELB "until economic slack is absorbed so that the 2 percent inflation target is sustainably achieved." Given the lag in the monetary policy transmission mechanism, this suggests that the Bank would permit a period of excess demand and inflation to temporarily rise above (overshoot) its 2 percent target some time into the future.

The Bank's mandate is to achieve an inflation objective, so why would it conduct monetary policy in a way that allows inflation to miss its target? One reason is the potential for achieving better economic outcomes. A range of standard models suggests that allowing inflation to temporarily rise above its objective after a period at the ELB could help promote a faster recovery and support a better balance between stable inflation and full employment.[1] Moreover, richer analyses that distinguish between different segments of the population demonstrate that an inflation overshoot can be shown to improve the economic outcomes of more vulnerable groups relative to a monetary policy that aims directly for the inflation target.

In this note, we review research showing that an inflation overshoot can be desirable because of the constraint the ELB imposes on monetary policy. Indeed, the literature presents a variety of mechanisms through which aggressive monetary policy could result in improved economic

[1] Indeed, the Bank must account for short-run real effects that may arise from its monetary policy decisions. In particular, a 1992 parliamentary committee reviewed the *Bank of Canada Act* and rejected the idea of a narrow price-stability mandate and, instead, concluded that "[m]onetary policy has powerful [real] effects in the short-run…[and] ought not to be absolved of responsibility for [them]" (Canada 1992). See Amano, Carter and Schembri (2020) for more details.

outcomes after severe downturns. These include alleviating the rise in income and consumption inequality and the incidence of labour force non-participation and long-term unemployment. We supplement this review by demonstrating the presence of these mechanisms in the Canadian economy. To do so, we use labour market microdata and a stylized model built from key macroeconomic relationships to draw parallels between the Canadian economy and findings in the literature.

We find that the recent ELB episode in Canada is characterized by highly uneven outcomes for the labour market. Workers in the bottom income quartile experience the most severe and persistent employment losses, while workers in the top income quartile face negligible losses. These uneven outcomes have been accompanied by a persistently large decline in the employment-population (E-P) ratio and the labour force participation rate, especially among younger workers, as well as an unprecedented rise in the long-term unemployment rate. Such outcomes align with those that the literature finds to be conditions under which an inflation overshoot is optimal. We end the note with an illustrative example demonstrating that it is optimal for monetary policy to allow inflation to overshoot its target in a stylized model that differentiates between short- and long-term unemployed workers.

We emphasize that our conclusions depend on three key assumptions. First, the central bank credibly commits to an inflation overshoot despite the potentially time-inconsistent nature of the policy. Second, agents find this commitment credible and raise their inflation expectations accordingly, thus allowing the central bank to lower real interest rates even at the ELB. Third, inflation expectations will shift back down after the temporary overshoot.

The note is structured as follows. The next section describes the standard logic pertaining to the potential benefits of an inflation overshoot after a period at the ELB. We then review research that examines the implications of an inflation overshoot for three labour market phenomena often associated with more vulnerable groups: income inequality, labour market participation and long-term unemployment. We conclude with an illustrative exercise to study optimal monetary policy using a stylized model estimated from Canadian data.

Standard macroeconomic interpretation

According to standard monetary theory, central banks should lower their nominal policy interest rate whenever inflation is expected to be below its target or output is below its potential level. The nominal policy interest rate, however, has an ELB, typically near zero.

Eggertsson and Woodford (2003) show that allowing inflation to overshoot its target when the economy is facing an ELB episode helps promote a faster recovery in real economic activity. At the heart of their argument is the idea that utilization of economic resources (such as labour) corresponds negatively to the real interest rate (which equals the nominal short-term interest rate less expected future inflation). In particular, because nominal prices are sticky in Eggertsson and Woodford's framework, prices take time to respond to a negative demand shock, resulting in underutilized economic resources. The standard policy prescription in this type of framework is to lower the nominal policy interest rate because this also lowers the real interest rate and stimulates output so that resources return to their potential levels.

However, as in the 2008–09 global financial crisis or the COVID-19 pandemic, when the economic shock is so severe that the nominal interest rate can be constrained by the ELB, real interest rates cannot decline by as much as economic conditions warrant.[2] In other words, the real interest rate is too high for the economic situation. To make matters worse, elevated economic slack puts downward pressure on both inflation and inflation expectations, which in turn push the real interest rate higher, triggering even more economic slack.

Eggertsson and Woodford's insight was to see that, despite the ELB, policy-makers can bring about a lower real interest rate if they can generate higher inflation expectations. One way central banks can raise inflation expectations is to conduct monetary policy by targeting the price level or an average of inflation. Both of these approaches lead to an inflation overshoot as the economy recovers.

Another way for the central bank to generate higher inflation expectations is to maintain its inflation target but communicate its intention to keep the nominal policy interest rate low for

[2] Moreover, recent research has found that the real interest rate for Canada has recently declined (see, for example, Holston, Laubach and Williams [2017] and Matveev, Mc Donald-Guimond and Sekkel [2020]). This implies that, all else equal, ELB episodes could become more frequent than they were in the past.

longer than a return to target would require. Indeed, this is how the Bank responded to the risk of deflation brought about by the COVID-19 crisis—by putting in place exceptional forward guidance. As a consequence of communicating that it will tolerate a temporary overshoot of its inflation objective, the Bank can also induce a greater decline in the real interest rate and thereby help stabilize the economy faster than by returning inflation directly to its target.

How inflation overshooting can affect more vulnerable groups

Economic inequality

Households do not share the costs of recessions equally. Some segments of the population, such as young people, women and low-wage employees, tend to experience greater unemployment and more severe income losses during recessions and weaker job prospects during recoveries (Aaronson et al. 2019; Lemieux et al. 2020). This is particularly true in the COVID-19 recession where employment of low-wage workers remains remains 20 percent below its pre-pandemic level, whereas it has fully recovered for other workers. More vulnerable groups typically have little precautionary savings buffers and are less able to insure against a decline in income. Therefore the share of consumers who live hand-to-mouth will rise in a downturn, making the recession more severe. This provides policy-makers with an incentive to find strategies that reduce the frequency, duration and severity of ELB episodes and to design policies that allow the economy and labour market to recover as quickly as possible.

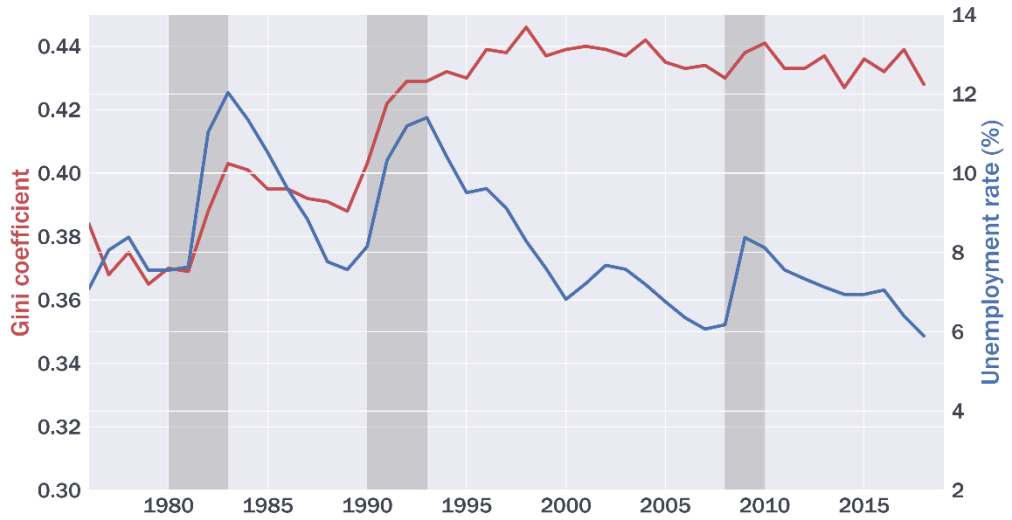
Feiveson et al. (2020) find that distributional considerations strengthen the case for following monetary policy rules that induce overshooting the inflation target. They use a heterogeneous-agent New Keynesian (HANK) model with endogenous hand-to-mouth consumers and find that make-up strategies (overshooting inflation) generate greater improvements for more vulnerable households and thus potentially have lasting effects on their economic well-being. Compared with a standard Taylor-type monetary policy rule, the temporary overshoot of the inflation target results in a stronger and faster recovery and reduces the degree of economic inequality. When consumers raise their expectations about

inflation accordingly, the commitment to overshoot inflation in the future lowers real interest rates and stimulates additional spending at the ELB. In the HANK model, the additional spending by consumers who are more sensitive to the interest rate raises the incomes of hand-to-mouth consumers and prevents sharper and self-reinforcing reductions in spending and employment.

Another related study is Acharya, Challe and Dogra (2020). They study optimal monetary policy in an environment where individuals face uninsurable and countercyclical income risk. Unlike in a representative-agent New Keynesian framework (RANK), monetary policy affects consumption inequality in addition to output and prices. For example, accommodative monetary policy can increase output during periods of large income risk, raise self-insurance through reduced borrowing costs, and lower interest payments. These outcomes serve to increase consumption among constrained or high-debt households. As a result, in a recession where consumption inequality is high, optimal monetary policy is more accommodative (relative to RANK) in order to reduce inequality through (inefficiently) higher output at the expense of higher inflation.

The role overshooting inflation plays in helping reduce inequality is particularly relevant during recessions in Canada where downturns have been characterized by a rise in income inequality, which in turn can lead to greater consumption inequality. This can be seen in **Chart 1,** which shows a rise in the Gini coefficients on market income during the three recessions before 2020. Similarly, the COVID-19 crisis has disproportionately affected specific demographics of workers, with women, youth, less-educated and low-wage workers in high-contact occupations experiencing more widespread job losses (Chan, Morissette and Qiu 2020; Cortes and Forsythe 2020; Beland, Fakorede and Mikola 2020; Lemieux et al. 2020). **Chart 2** depicts the exceptionally uneven nature of the COVID-19 crisis, illustrating how employment evolved during the pandemic according to income quartile. It shows that low-wage workers who experienced the largest decline in employment are also experiencing the slowest recovery. In contrast, high-wage workers did not experience severe job losses and showed a near-complete recovery by the end of 2020.

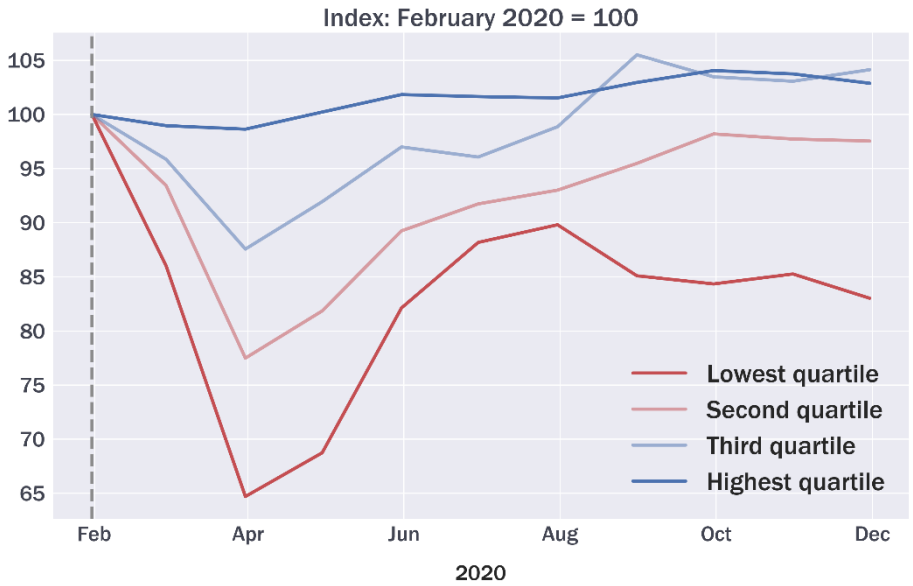
Chart 1: Inequality in Canada over the business cycle



Note: The left axis plots the Gini coefficient for market income, and the right axis plots the unemployment rate.

Sources: Statistics Canada and Terajima and Wilkins (2020)

Chart 2: Employment by income quartile in Canada



Note: This chart plots employment levels of workers when grouped by hourly wages. Thresholds are set to quartiles of hourly wages in February 2020.

Source: Statistics Canada Labour Force Survey

Participation

In the previous section, we discussed the potential importance of considering economic inequality when thinking about monetary policy after a period at the ELB. In the same spirit, Erceg and Levin (2014) argue that broader measures of slack beyond the unemployment rate should be taken into account.

The traditional focus on the unemployment rate as a primary business cycle indicator is based on the fact that, historically, the labour supply of prime-age and older workers has been largely acyclical. Similarly, optimal monetary policy has relied on the view that both the unemployment gap and the output gap closely track each other. These views, however, are overturned by labour market fluctuations observed during the global financial crisis, which saw a sharp decline in the US labour force participation rate because discouraged workers stopped searching for jobs given the prolonged recession. This resulted in the E-P ratio remaining depressed five years after the onset of the recession despite the strong recovery of the unemployment rate. This raises an important question: Should monetary policy respond to a broader measure of labour market slack that includes the cyclical component of labour force participation?

Using state-level data on employment, Erceg and Levin (2014) empirically document that the decline in labour force participation during the global financial crisis can be attributed to cyclical factors. After controlling for demographic trends and structural factors, they find that in early 2013 the participation gap remained elevated at -2 percentage points. This implies that, at that time, the unemployment gap and the participation gap each accounted for half of the observed employment gap. Importantly, the main insight here is that cyclical movements in the employment gap during such episodes were no longer entirely attributable to the changes in the unemployment gap.

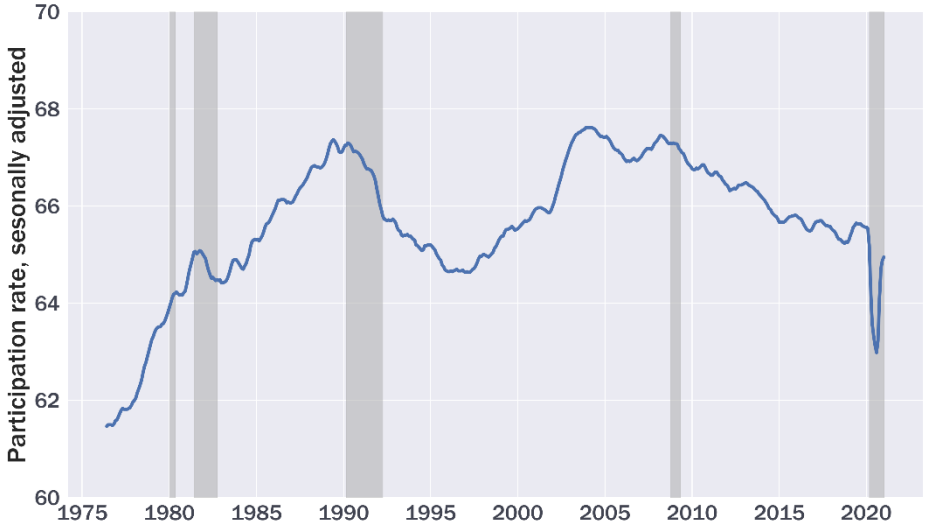
Motivated by the incidence of downturns where the participation gap is a primary driver of the employment gap, Erceg and Levin (2014) build a New Keynesian model that features endogenous labour force participation as well as adjustment costs of moving between market and home production. It differs from a standard RANK framework in two important ways. First, while less severe recessions result in only small changes in labour supply (with the employment gap mostly driven by a rise in unemployment), prolonged recessions may eventually result in a significant decline in labour force participation. The model captures this

because adjustment costs imply that workers are unwilling to move out of the labour force during mild recessions when unemployment spells are short-lived. Second, the model's Phillips curve includes both the unemployment gap and labour force participation gap. More specifically, a wide participation gap implies that workers in the labour force do not bargain up wages as much as they would in normal times. In this case, inflation would be further depressed during recessions that resemble the global financial crisis, where the participation gap remained high even after the unemployment gap closed.

Erceg and Levin (2014) find that during recessions characterized by a persistently high participation gap, full employment (i.e., closing the employment gap) can occur only when the participation gap closes quickly. They find that achieving this objective requires monetary policy to allow the unemployment rate to undershoot its natural rate in order to fully offset the negative participation gap. Given that the unemployment rate remains below trend, the Philips curve implies an accompanying overshoot of inflation until the participation gap closes. Once again, this suggests that overshooting inflation during recessions may be beneficial for a particular group of households that are severely affected by recessions: workers who are out of the labour force.

The same persistent declines in labour force participation that motivate Erceg and Levin's findings can be observed in Canada during large downturns, as shown in **Chart 3**. While the length of observation remains limited, the Canadian labour market during the pandemic also shows signs of delayed recovery along the participation margin. **Chart 4** plots the E-P ratio and labour force participation rate in Canada, which remains well below pre-pandemic levels three quarters after the onset of the crisis. The slow recovery of employment is especially evident for young workers, whose E-P ratio and participation rate remain below their levels from the previous year by 10 percent and 3 percent, respectively.

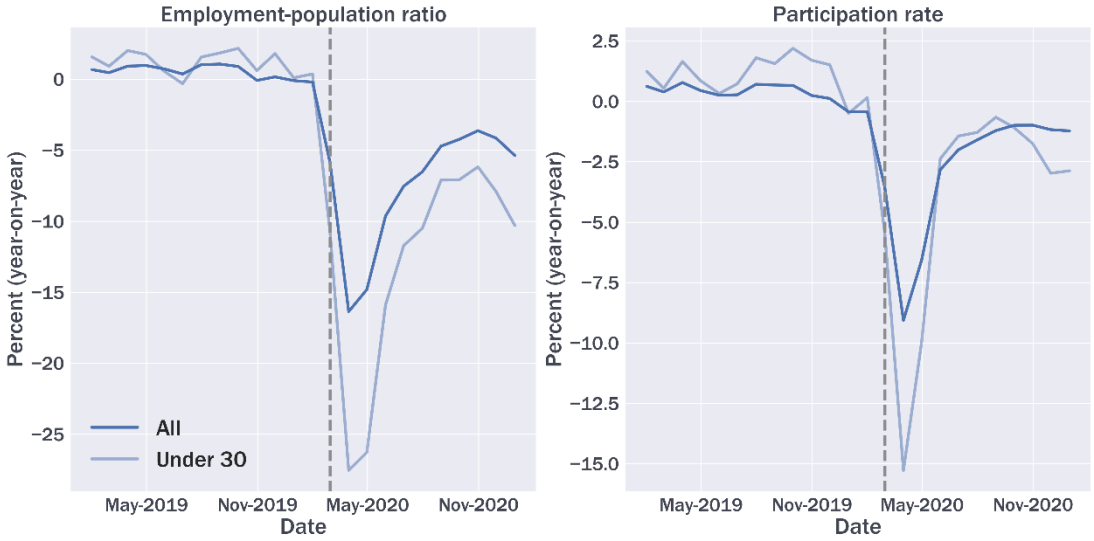
Chart 3: Labour force participation over the business cycle in Canada



Note: This chart plots the six-month moving average of the labour force participation rate. Shaded periods indicate recessions.

Source: Statistics Canada Labour Force Survey

Chart 4: Employment-population ratio and participation rate



Note: The left panel plots the year-over-year change in the employment-population ratio for the entire sample and for respondents under age 30. The right panel plots the labour force participation rate for the same two samples.

Source: Statistics Canada Labour Force Survey

Long-term unemployment

Central banks with a dual mandate use monetary policy to achieve both price stability and full employment. The ability of monetary policy to simultaneously achieve both objectives is predicated on the so-called divine coincidence: that a strong positive correlation between inflation and employment implies that stabilizing prices is the same as stabilizing output. However, some studies (Gordon 2013; Watson 2014) argue that the effect of the long-term unemployed on wages and prices is weaker than that of the short-term unemployed. The reasoning behind this is that the long-term unemployed are more likely to become detached from the labour market because employers assume that their skills have depreciated or have become obsolete and so perceive them as less-desirable candidates.

Rudebusch and Williams (2016) argue that if short-term unemployment is the more appropriate measure of slack in the Philips curve, then this introduces a wedge between the measure of slack relevant for characterizing inflation and the measure relevant for characterizing full employment (encompassing both long- and short-term unemployed). This wedge introduces trade-offs in the conduct of monetary policy because closing the employment gap is no longer equivalent to closing the inflation gap. This trade-off or wedge is most severe during periods when high unemployment is also characterized by a prevalence of lengthy unemployment spells among the jobless. For example, during the global financial crisis, the rise in short-term unemployment was not as pronounced as the rise in long-term unemployment. The short-term unemployment rate had recovered by 2013, while long-term unemployment remained elevated.

Similar patterns that give rise to this wedge are beginning to emerge in Canada as a result of the recession induced by COVID-19. The left panel of **Chart 5** shows a dramatic rise in the share of long-term unemployed among unemployed workers in Canada. Meanwhile, the right panel shows a recovery of the short-term unemployment rate that is in sharp contrast with an increasing long-term unemployment rate. A large long-term unemployment gap would imply that achieving full employment may thus come at the expense of exceeding inflation targets, especially when small (or even negative) short-term unemployment gaps exert upward pressure on prices.

Rudebusch and Williams (2016) use a simple model that features three key macroeconomic relationships:

- short-term unemployment share and a measure of the business cycle
- inflation and both short- and long-term unemployment
- a conventional investment-savings curve that relates unemployment with the nominal short-term interest rate

After estimating these relationships, Rudebusch and Williams (2016) find that the share of short-term unemployed has become more cyclical over time. They also find that the share of long-term unemployed indeed has little power in explaining inflation once the short-term unemployment share is accounted for. Key to their findings is the fact that the global financial crisis saw a widening gap between the short- and long-term unemployment gaps, which historically have tracked each other closely. This allowed the empirical exercise to identify the differential predictive power of short- and long-term unemployment on prices.

To illustrate the implications of these findings on monetary policy, Rudebusch and Williams (2016) use the estimated equations to solve for the path of interest rates that minimizes a standard loss function. Using actual US data from 2013 as initial conditions, they compare the optimal path between a model that distinguishes between short- and long-term unemployment and a model that does not. Given that this period is characterized by a large deviation between the short-term unemployment gap and the long-term unemployment gap (i.e., the unemployment gap is mostly driven by the long-term unemployment gap), the wedge in the dual mandate is large. As a result, they find that optimal policy for the model with short- and long-term unemployment prescribes that inflation exceed 2 percent for some time to reduce the aggregate unemployment gap. Overall, these findings suggest that overshooting inflation may have benefits that accrue toward a vulnerable group of households that experience long unemployment spells.

Using Canadian data, we implement the same stylized exercise as in Rudebusch and Williams (2016). We find that the optimal policy implied by the model that distinguishes between short- and long-term unemployment prescribes an overshoot of inflation for several quarters, as shown in **Chart 6** (the **Appendix** outlines our methodology). In addition, aggregate unemployment returns to its steady state much earlier relative to a standard model that

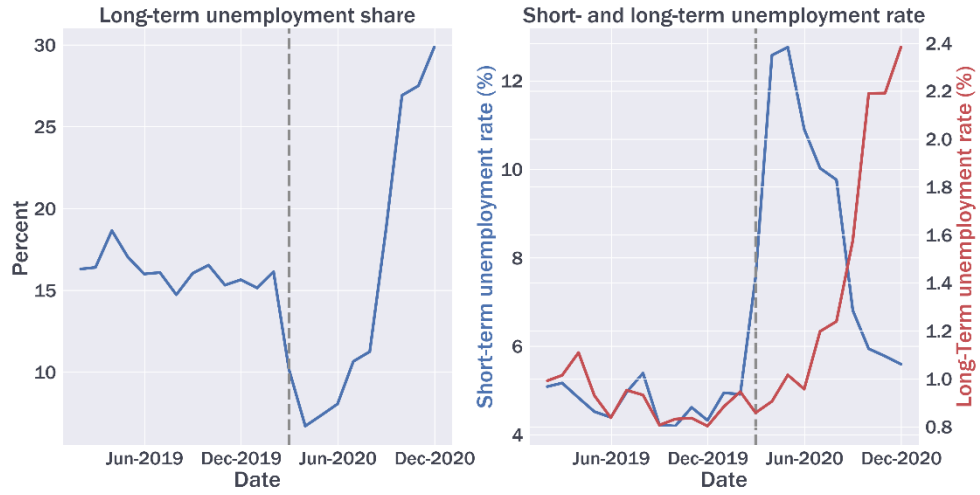
considers only the aggregate unemployment rate. The substantial gap between the optimal paths for inflation implied by the two models reflects this latter result. In particular, the moment inflation from the short-term unemployment model hits the target (before overshooting), the standard model admits a level of inflation that is still below 1 percent. The implied path of inflation in the standard model also takes longer to converge back to target.

We note that the magnitude of overshoot is consistent with that found by Rudebusch and Williams (2016). This implies that even with US data around the global financial crisis, the implied overshoot in this framework is small relative to the initial drop in inflation. This likely reflects the fact that we, like Rudebusch and Williams, use a stylized linear model, which makes it difficult to interpret the size of the overshoot. Instead, the common result is that the pace and manner by which inflation returns to target is markedly different. In the short-term unemployment / long-term unemployment (STU-LTU) model, inflation rises quickly and increases above 2 percent before returning to target. In the standard model, it converges slowly and from below.[3]

We emphasize that this exercise should be viewed as simply *illustrative* of the merits of overshooting. It is not a guide to actual policy given the simple structure of the model, which abstracts from behavioural responses of economic agents and other factors that might influence macroeconomic aggregates. Importantly, the benefits on an overshoot rely critically on central bank credibility; clarity on policy parameters such as duration, magnitude and state-contingency; and the central bank's ability to shift agents' inflation expectations. Furthermore, the model does not account for financial stability issues that might arise with keeping interest rates low for an extended period. An interesting question this analysis raises is the potential challenge that a central bank may face in using one instrument to stabilize two measures of unemployment with different dynamics. Along a related dimension, Woodford (2020) finds that after a pandemic-like shock with disproportionate effects across sectors, monetary policy can support a recovery in output, but its composition may not necessarily be optimal. In particular, monetary policy cannot ensure that the gains among the sectors will be realized by those that are the most financially constrained, suggesting a role for more targeted fiscal policy to improve welfare.

[3] This gap in convergence between the standard and STU-LTU models is robust to a wider range of parameters.

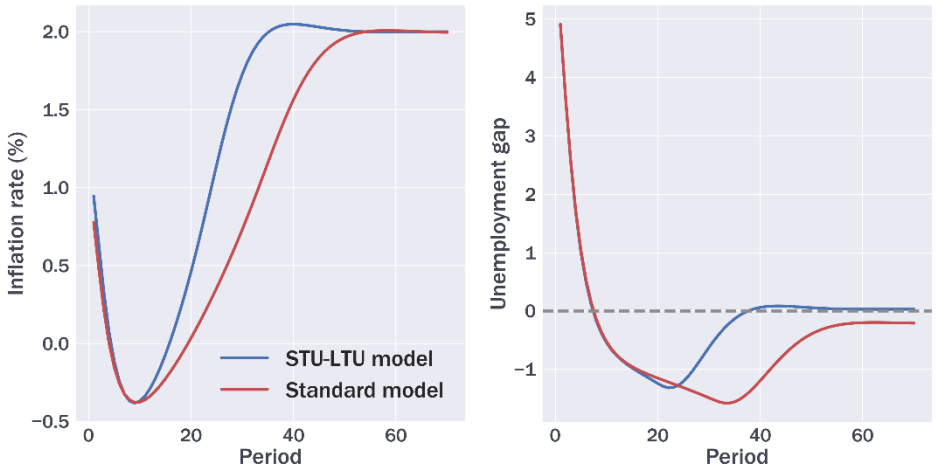
Chart 5: Long-term unemployment



Note: The left panel plots the fraction of unemployed workers who have been jobless for at least six months. The right panel plots the short- and long-term unemployment rates. Workers are classified as long-term unemployed if they report being unemployed for at least six months.

Source: Statistics Canada Labour Force Survey

Chart 6. Simulation exercise following Rudebusch and Williams (2016)



Note: This chart plots the paths of inflation and the unemployment gap implied by the optimal path of monetary policy under the model that distinguishes between short- and long-term unemployment (STU-LTU model) and a model that does not (standard model). Simulation periods are quarterly.

Source: Model simulations

Conclusion

We review how different segments of the population may benefit from an inflation overshoot of its target after a period at the ELB.

Implementing such a policy entails a number of challenges. First, the overshoot of inflation implicit in the Bank's forward guidance during the COVID-19 pandemic could represent a tension with the Bank's official inflation objective, which emphasizes the 2 percent midpoint of the 1 to 3 percent inflation-control range. Second, measures of inflation expectations remain well anchored at the target, so additional communication to move expectations higher may be required. One potential way to move inflation expectations from the 2 percent target is to provide greater emphasis around the Bank's 1 to 3 percent inflation-control range. Indeed, Chung et al. (2020) examine the implications of using a range of inflation indifference to guide monetary policy in the US Federal Reserve Board's model.

One notable result from Chung et al.'s (2020) work is the potential for inflation expectations to move within the range. Bianchi, Melosi and Rottner (2020) argue that an asymmetric monetary policy rule where the central bank responds less aggressively to an inflation overshoot improves welfare and reduces the risk of a deflationary spiral after an ELB episode. Moreover, the asymmetric approach does not entail any history dependence and can be implemented with an asymmetric target range. As such, further work looking at the inflation-control range may be a fruitful line of monetary policy research. Finally, to attain the policy's potential benefits, the central bank must be able to credibly commit to an inflation overshoot and elicit an increase in inflation expectations.

We note that the preceding analysis abstracts from several factors that should be considered when evaluating the merits of overshooting inflation. For example, overshooting may have additional benefits through increased investment, capital deepening and firm dynamism. However, it could also introduce potential risks to financial stability due to prolonged periods of low borrowing costs—a factor that can be incorporated in models that evaluate overshooting. We also abstract from the effects of fiscal policy that could have important interactions with monetary policies, especially at the ELB (see, for example, Christiano, Eichenbaum and Rebelo 2011).

Again, we emphasize that the results from our highly stylized model regarding the potential benefits of overshooting inflation are strictly qualitative. We leave the important questions on the magnitude and duration of an inflation overshoot to future research with richer, quantitative macroeconomic models. Finally, it is important to distinguish short-lived periods of *tolerating* an overshoot of the inflation target during recoveries from more fundamental changes to the Bank's monetary policy framework that may feature deliberately *engineering* an overshoot. Indeed, frameworks such as average-inflation targeting, price-level targeting and those with some form of history dependence will induce a purposeful over- or undershoot of the inflation target as part of the approach to monetary policy. An examination of these frameworks is at the core of the Bank of Canada's ongoing efforts to evaluate alternative monetary policy frameworks for the 2021 renewal of the inflation-control target agreement with the federal government.

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Appendix

As an illustrative exercise, we closely follow the empirical methodology of Rudebusch and Williams (2016) to calculate the path of optimal monetary policy. This procedure involves two main steps. First, we estimate three key relationships:

- short-term unemployment share and the business cycle
- inflation and both short- and long-term unemployment
- a conventional investment-savings curve that relates unemployment with the nominal short-term interest rate

Second, we use the estimated equations to solve for the optimal path of interest rates that minimizes a loss function (described below).

First stage

Equation 1

The first equation relates the short-term unemployment share θ with a resource gap measure that is taken to be the unemployment gap $ugap$. The following specification allows us to capture both cyclical and secular changes:

$$\theta_t = \mu_0 + \delta_0 \times ugap_{t-1} + \mu_1 \times TIME + \delta_1 \times ugap_{t-1} \times TIME + \rho \times \theta_{t-1} + \epsilon_t$$

We use the Labour Force Survey to compute the share of short-term unemployed relative to total unemployment. The trend unemployment rate (TUR) used to calculate the unemployment gap is based on the structural factors wage Phillips curve measure described in Brouillette et al. (2019). We estimate Equation 1 using time series spanning from 1981Q1 to 2019Q4.

Equation 2

The second equation is an expectations-augmented Phillips curve:

$$\pi_t = \alpha + \beta_1 \times \pi_{t-1} + \beta_2 \times \pi_{t-2} + \beta_3 \times \pi lr_{t-1} + \kappa \times sgap_{t-1} + \eta_t,$$

where π is the inflation rate, πlr is a measure of long-run inflation expectations and $sgap$ is the short-term unemployment gap. This equation does not include the long-term unemployment gap because Rudebusch and Williams (2016) find that it does not materially affect inflation. To compute the short-term unemployment gap, we require a series for trend short-term unemployment. We obtain this by multiplying the trend short-term unemployment share (fitted linear trend on θ) with our selected TUR measure.

We use CPI-common as our measure of inflation π and a survey-based measure of long-run inflation expectations provided by the Conference Board of Canada as our measure of long-run inflation expectations, πlr. We estimate Equation 2 using time series spanning from 1990Q1 to 2019Q4.

Equation 3

The third equation establishes a relationship between the unemployment gap and interest rates:

$$ugap_t = \gamma_0 + \gamma_1 \times ugap_{t-1} + \gamma_2 \times ugap_{t-2} + \gamma_3 \times (i_{t-1} - \pi_{t-1} + i_{t-2} - \pi_{t-2}) + \zeta_t$$

We estimate Equation 3 using time series spanning from 1990Q1 to 2007Q4.[4]

Second stage

The resulting estimated equations are:

$$\theta_t = 29.16 - 1.98 \times ugap_{t-1} + 0.643 \times \theta_{t-1} + \epsilon_t$$

$$\pi_t = -0.00608 + 1.35 \times \pi_{t-1} - 0.375 \times \pi_{t-2} + 0.0291 \times \pi lr_{t-1} - 0.0814 \times sgap_{t-1} + \eta_t$$

$$ugap_t = -0.184 + 1.136 \times ugap_{t-1} - 0.276 \times ugap_{t-2} + 0.0748 \times (i_{t-1} - \pi_{t-1} + i_{t-2} - \pi_{t-2}) + \zeta_t$$

We use the Nelder-Mead optimization algorithm to find a path of interest rates $\{i_t\}_{t=0,\cdots,T}$ that minimizes the same loss function as in Rudebusch and Williams (2016):

$$L_t = \sum_{j=0}^{\infty} \{\beta^j ({\tilde{\pi}_{t+j}}^2 + \lambda {\tilde{u}_{t+j}}^2 + \psi (i_{t+j} - i_{t+j-1})^2\},$$

where discount factor β is set to 0.98, the relative weight on the unemployment gap λ is set to 0.1 and the penalty on interest changes ψ is set to 0.5. Finally, we set the target inflation rate to 2 percent.

[4] As in Rudebusch and Williams (2016), we estimate Equation (3) only with data until before the global financial crisis to avoid periods when short-term interest rates were at or close to the effective lower bound.