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Balancing Act: Monetary Policy Responses to Natural Disasters

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Balancing Act: Monetary Policy Responses to Natural Disasters*†

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Abstract

Natural disasters pose complex challenges for monetary policy in resource-rich small open economies. Using an open-economy dynamic stochastic general equilibrium model calibrated to Canada, we embed stochastic disaster shocks affecting capital, productivity, and the commodity sector. Drawing on detailed historical data, we quantify disaster-specific transmission channels and show that most disasters act as supply shocks, reducing output and modestly raising inflation. The magnitude and persistence of these effects depend on disaster type, sectoral exposure, and spillovers through global trade and terms-of-trade channels. The framework provides a forward-looking assessment of climate-related risks and their implications for monetary policy.

JEL codes: E52, Q54, F41, E12, E31, C68.

Keywords: Natural disasters; Climate shocks; Monetary policy trade-offs; DSGE model; Terms-of-trade effects.

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1 Introduction

The rising frequency and severity of natural disasters underscore the urgency of understanding the macroeconomic consequences of physical climate risks. Events such as hurricanes, floods, and wildfires can destroy capital, disrupt production and supply chains, both domestically and globally, with significant implications for economic growth, inflation, and monetary policy. Beyond their immediate humanitarian and fiscal costs, many of these events can reduce output while simultaneously exerting upward pressure on prices. These shocks create the potential for an inflation–output trade-off as monetary policy faces a difficult balancing act: stabilizing inflation may require tighter policy in the face of elevated inflation, but doing so risks deepening output losses. Conversely, supporting growth through accommodative policy could exacerbate inflationary pressures, especially in the face of supply constraints. These trade-offs are potentially more acute for small open economies that are deeply integrated into global trade networks, where disaster shocks can also transmit through external demand and terms-of-trade effects.

This paper embeds natural disasters into an open-economy medium-scale dynamic stochastic general equilibrium (DSGE) model calibrated to the Canadian economy. Canada is of particular interest as a resource-rich small open economy with significant exposure to climate-related disasters, both due to its geography and its reliance on natural resources. Historical events such as the 1998 Ice Storm, the 2013 Alberta floods, the 2016 Fort McMurray wildfires, and the prolonged 1988 drought, rank among the costliest in Canadian history, underscoring the potential for severe macroeconomic disruptions. Moreover, Canada's deep integration into global trade and energy markets could influence the transmission of such shocks through external demand and terms-of-trade channels, which can either amplify or offset their domestic impact. For example, the 1988 drought caused commodity prices to rise. This increase partly offset revenue losses for Canadian farmers, who faced lower crop yields and higher shipping costs because of low river flows. Building on these historical episodes, we design several disaster scenarios and extrapolate observed trends of increasing frequency and severity of disasters to assess their macroeconomic effects and the potential monetary policy trade-offs they create.

Empirical evidence points to adverse effects of extreme weather events and natural disasters on near-term economic activity (see Botzen et al., 2019 and NGFS, 2024 for reviews of the literature). However, while output costs have received substantial attention, the inflationary consequences are less well understood. Whether a given disaster is inflationary depends on its type, scope, and regional context. For Canada, Duprey and Fernandes (2025) find that floods are inflationary with higher shelter costs as the key transmission channel. Similarly, winter storms tend to increase inflation primarily through an increase in energy-related costs.[1] Food inflation constitutes another prominent transmission channel, as shown by Parker (2018), who links storms and floods to higher food prices, and by Faccia et al. (2021), who find that extreme heat raises food inflation. These findings highlight that climate-related disasters may pose non-trivial trade-offs for monetary policy, particularly when shocks are supply-driven and inflationary.

DSGE models allow for a forward-looking analysis and a broader assessment of monetary policy trade-offs by modeling a variety of possible monetary policy responses to structural shocks arising due to natural disasters. Early work, such as Keen and Pakko (2011), shows that disaster shocks (hurricanes) in closed-economy New Keynesian models behave like negative supply shocks that lower output, raise inflation, and generate monetary policy trade-offs. Hashimoto and Sudo (2024) extend this approach to floods in Japan, incorporating both supply-side capital depreciation and demand-side balance-sheet channels, and find relatively small GDP effects compared to standard macro shocks. Open-economy contributions, including Gallic and Vermandel (2020), highlight trade and real-exchange-rate transmission through weather-dependent agricultural sectors. More recent work embeds rare-disaster risk, as in Cantelmo et al. (2024) and Cantelmo et al. (2023), allowing agents to internalize the probability of extreme events and emphasizing non-linearities and precautionary behavior; their results suggest that inflation-anchoring monetary policy delivers higher welfare in disaster-prone economies than strict exchange-rate or output stabilization frameworks.

This paper makes three main contributions. First, we shed light on the implications of physical risk on a resource-rich small open economy. To assess these impacts, we explicitly allow natural disasters to affect the commodity sector disproportionately, in addition to capital destruction and broader productivity losses. These features are critical for understanding the macroeconomic consequences of disasters that disrupt commodity production, such as the 2016 Fort McMurray wildfire, which temporarily halted oil production locally but with large aggregate consequences. We also extend the analysis beyond domestic shocks by considering how foreign disasters, such as

[1] Duprey and Fernandes (2025) further show that during periods of provincial economic contraction, summer storms (and to a lesser extent wildfires) tend to reduce CPI inflation excluding food and energy, largely because shelter costs decline. One possible explanation is outward migration, which could depress housing demand in the affected province.

Hurricanes Katrina and Rita in the United States, can affect the Canadian economy through trade and terms-of-trade channels, particularly in commodities.

Second, our approach provides a comprehensive assessment of the macroeconomic impacts of different types of natural disasters within a single-country setting. In the model, disasters can propagate through multiple channels, including capital destruction, reduced general labour and land productivity, decreased productivity and price changes in the commodity sector, and government support payments. Using detailed historical information on each disaster—covering its economic and capital impacts, the most affected sectors, and the nature of government assistance—we calibrate the activation and relative strength of these transmission channels for each disaster scenario. To construct this dataset, we draw from a wide range of sources including official government records, insurance estimates, academic studies, reports, media coverage, and other archival material.

Third, we use the model to quantify the potential monetary policy trade-offs arising from natural disasters. In particular, we evaluate how disasters may generate conflicting objectives for monetary policy by simulating the model under alternative policy rules that span the extremes of strictly stabilizing inflation versus strictly stabilizing the output gap. This exercise is motivated by Del Negro et al. (2023) who assess monetary policy trade-offs in the context of decarbonization policies.

Our key findings are as follows: the 1998 ice storm and the longer-lasting droughts inflict significant output losses while the other domestic disasters had a relatively smaller impact. In all domestic disaster scenarios inflation rises mildly under the historical monetary policy rule. The external disaster (Hurricanes Katrina and Rita in 2005) has a net positive impact on the Canadian economy. While the disruption to US oil and gas production raises global commodity prices, it also temporarily reduces Canadian output. However, the resulting improvement in Canada's terms of trade more than offsets this initial decline, leading to a net expansion as higher export revenues boost income. In all disaster scenarios, except the US hurricanes, the historical monetary policy rule implies cutting the policy rate right after the disaster. Looking-through the immediate economic impact, in terms of policy response, can decrease the cost on inflation and have a stabilizing effect (decreasing the volatility in investment, consumption or commodity prices) in most disaster scenarios.

All natural disasters considered, other than the US hurricanes scenario, present the central bank with a trade-off between stabilizing output or inflation. We find that the largest trade-offs are associated with the costliest disasters—–those that damaged infrastructures or significantly disrupted the commodity sector. For instance, in the case of the 1998 ice storm, if the central bank had focused on stabilizing output and closing the output gap, CPI inflation (y/y) could have been about 0.15 percentage points higher on average over the two-year period following the disaster. Conversely, if the central bank had aimed to stabilize inflation, this would have resulted in a drag on output, with the output gap averaging about -0.21 percent over the same period. Droughts, which are longer-lasting, create larger trade-offs. In the case of the 1988 US/Canada drought, inflation could have averaged about 0.22 percentage points above target over a two-year period if the central bank had focused on stabilizing output.

The trade-off might shift as climate-related disasters are expected to increase both in severity and frequency. To illustrate the potential impact on the trade-off, we consider three hypothetical situations. First, we combine disasters in which floods, wildfires, and hailstorms all occur in the same quarter, as was the case in Canada in the third quarter of 2024.[2] The second and third hypothetical scenarios use projected trends in insurance losses and the frequency of disasters to design scenarios that represent increased severity or frequency of natural disasters, respectively. Potential disaster combinations, increased frequency and severity, could worsen the output-inflation trade-off for central banks. For example, having a combination of disasters occurring in two consecutive quarters (increased frequency) could nearly double the average impact on inflation over a two-year period.

Finally, we rely on stochastic simulations conducted over a 10,000-year horizon to assess long-run volatility trade-offs. We use arrival probabilities for each type of disaster—wildfires, droughts, floods, and winter and summer storms—derived from incidence data from the past 40 years. When the simulations respond to average-sized disasters observed over the last decade, the resulting volatility trade-off is minimal. However, when the costliest disasters are assumed to become the norm, the volatility trade-off increases substantially, making the economy significantly more difficult to stabilize.

It is important to note that there is a high degree of uncertainty regarding the cost, severity, and frequency of future disasters. This depends on factors such as the location of the disaster; for example, repeated and more frequent ice storms would lead to more severe trade-offs in densely

[2] We calibrate the combinations of disaster shocks to match the insurance payouts in 2024Q3, the costliest quarter for insurance payouts in the Canadian history.

populated areas. Additionally, longer-lasting droughts combined with other disasters could result in more severe trade-offs.

This paper is organized as follows. Section 2 summarizes seven disaster scenarios and the historical information on their economic impacts. Section 3 presents the DSGE model and discusses how each disaster scenario is calibrated. Section 4 conducts impulse response analysis and Section 5 quantifies the output-inflation trade-off for the disaster scenarios, combinations thereof, and their increased frequency and severity. Section 6 presents stochastic simulations and Section 7 concludes.

2 Historical Disaster Scenarios

This section presents seven disaster scenarios that were among the costliest in Canadian history. They include five domestic disasters, one regional disaster that impacted both the USA and Canada, and one external disaster that had a major impact on the Canadian economy. Table 1 summarizes information about impacts of these disasters on economic activity in Canada. This information was collected from a variety of sources with the goal of capturing key target moments that could be used to calibrate our model of the Canadian economy. Appendix A provides additional details about the data sources and calibration target moments.

None of the data sources used for calibration provide a complete picture of the economic costs of these disasters. To address this gap, we surveyed a combination of official records from the Canadian Disaster Database (CDD), Statistics Canada reports, the insurance payout estimates published by the Insurance Bureau of Canada (IBC), reports from various public and private agencies and organizations, academic studies, and supplementary information from news articles and Wikipedia pages devoted to each disaster. There is considerable uncertainty about the quality and reliability of many estimates, particularly for output losses due to foregone income and unrealized sales. Even for relatively straightforward financial flows, such as insurance payouts, inconsistencies between sources were common. To manage these discrepancies, we applied the following preference order: official estimates from the Canadian Disaster Database or Statistics Canada were prioritized, followed by insurance payout data from the Insurance Bureau of Canada, then agency reports and academic studies. News articles and Wikipedia were least preferred, but they often provided valuable context on timelines and the sectors most affected.

Four of the domestic disasters were the costliest weather-related events representing four main types of disasters (wildfires, floods, storms, and winter storms) that tend to be relatively short in duration but potentially highly destructive. These types of disasters often inflict acute physical damage to structures and other types of tangible capital assets. The 2001-2002 Western Canada and the 1988 US/Canada droughts are examples of longer-lasting disasters that have a more gradual detrimental effect on economic output and productivity, primarily in the agricultural sector.

The external disaster that had the greatest economic impact on Canada was the double hit of the hurricanes Katrina and Rita that battered in a quick succession the energy extracting and processing facilities in Texas, Louisiana and the Gulf of Mexico. Most of economic impacts on Canada were transmitted via energy price adjustments and crude oil processing delays.

Admittedly, these estimates do not capture all economic costs from weather-related disasters. Some of the costs, like casualties and household disutility burdens, are hard to value and measure reliably. GDP losses are measurable in theory, but difficult to assess in the absence of detailed empirical surveys and/or case-specific structural models. Other costs, like insurance payouts and disaster assistance funds are easier to find, but even they likely understate the true economic costs which they are supposed to approximate. Thus, the case studies presented in this section should be taken more as stylized representations of each type of weather-related disaster, and less as precise measurements of economic costs from these events.

3 Simulation Model

This paper aims to understand and quantify monetary policy tradeoffs arising from increasingly frequent and severe weather-related disasters. This makes it important to consider the impact of climate disasters in a model that has been found useful for monetary policy analysis. Typically such models should be rich enough in terms of their structure, transmission channels, and relevant frictions so that they are capable of matching, both qualitatively and quantitatively, the impact of various shocks on the economy. We rely on a medium-scale open-economy DSGE model, Baby-ToTEM, one of the Bank of Canada's policy analysis models (see Lepetyuk et al., 2020).

Baby-ToTEM (further BToTEM) has multiple production sectors, including the commodity sector, which makes it well-suited to analyze the impacts of natural disasters in Canada. As detailed in Lepetyuk et al. (2020), despite its smaller size, BToTEM is capable of closely matching key impulse responses from much more elaborate Bank of Canada projection models, ToTEM and

Table 1: Economic impacts of climate-related disasters on Canada

Disaster Event	**Physical Capital Impact**	**GDP Impact**	**Government Assistance**	**Most Impacted Sectors**
QC/ON Ice Storm (1998 Q1)	\$3.7 billion (1.6% of 1997Q4 GDP)	\$2.6 billion (1.13% of 1997Q4 GDP)	\$0.9 billion (0.39% of 1997Q4 GDP)	Utilities, Agriculture, Retail
AB Floods (2013 Q2)	\$1.7 billion (0.36% of 2013Q1 GDP)	\$0.55 billion (0.12% of 2013Q1 GDP), with 60% in energy sector	\$1.016 billion federal, \$0.937 billion provincial (0.42% of 2013Q1 GDP)	Oil and gas services, General services
Fort McMurray Wildfire (2016 Q2)	\$3.6 billion (0.72% of 2016Q1 GDP)	\$0.4% of 2016Q1 GDP	\$1.484 billion (0.30% of 2016Q1 GDP)	Oil and gas production, Housing
AB storm (2024 Q3)	\$3.25 billion (0.36% of 2024Q2 GDP)	—	—	Structures, Vehicles
AB/SK Drought (2001–02)	—	\$5.8 billion (2.01% of 2001Q2 GDP)	\$3.0 billion (1.04% of 2001Q2 GDP)	Agriculture and related industries
Regional (US/CA) Drought (1988)	—	\$3.06 billion (2.00% of 1988Q1 GDP)	\$0.75 billion (0.49% of 1988Q1 GDP)	Agricultural prices and output
US Hurricanes (2005 Q3)	—	2.8% jump in exports, 3/4 of which is due to higher commodity prices	—	Oil and Gas processing, commodity prices

Notes: All dollar values are reported in current Canadian dollars for the respective year of the disaster. GDP percentages are calculated relative to the GDP of the quarter preceding the disaster event. Dashes (—) indicate data not available or not applicable.

LENS. BToTEM has multiple sources of nominal and real rigidities; rule-of-thumb and optimizing price and wage setters; commodity and non-commodity exports; an input-output production structure relying on imported inputs, commodity inputs, and manufactured intermediate inputs; as well as multiple domestic and external shocks transmitted via various channels, including international trade and exchange rate channels. Monetary policy in the model follows an interest rate rule responding to fluctuations in core inflation and output gaps, smoothed by attaching some weight to the first lag of the policy rate. We kept BToTEM equations and many of its structural parameters as in Lepetyuk et al. (2020).

Several structural parameters affecting steady state calculations were re-calibrated to align the model more closely with consumption-to-output, investment-to-output, exports-to-output and other similar basic ratios (Table 4 in the Appendix D). Additionally, the parameters that affect the dynamics but not the steady state were also re-calibrated to match second moments of inflation, de-trended output and output gap in the data. Our calibrated parameter values are broadly in line with conventional estimates in the DSGE modeling literature. Tables 5 and 6 in the Appendix D provide the full list of parameter values in our model.

In the model, disasters can propagate through multiple channels, including capital destruction, reduced general labour and land productivity, decreased productivity and price changes in the commodity sector, and government support payments. We introduce natural disaster j into the model (with $j = \{i, f, w, h, d, d_{US/CAN}, h_{US}\}$ standing for "ice storm," "flood," "wildfire" "hail," "drought," "US/CAN drought," and "US hurricanes," respectively) as follows:

- **Capital destruction:** The physical capital destruction shocks have a direct impact on the capital stock surviving into the next period:

$$K_t = [(1 - \delta)K_{t-1} + I_t] \times e^{-\Sigma_j \lambda_j^K I_j^K} \tag{1}$$

  where I_j^K indicator functions take on values of 1 or 0 depending on whether this particular disaster happens in period t, and all λ_j^K are non-negative values calibrated to match scenario-specific capital destruction targets from Table 1. For most of our impulse response analysis cases in the following section, we activate only one of these disasters at a time. We will however also model composite disasters in which several elements of I_j^K could be equal to one in the same period, or in consecutive periods, depending on the hypothetical scenario.

- **General labour and land productivity:** Aggregate output losses are introduced as purely transitory (i.e., zero-persistence) shocks reducing both the labour-augmenting productivity, and land-augmenting productivity by the same proportional amount. All of the labour input in the model enters the CES production function of the "intermediate-goods" producing sector:

$$Z_t = \left[\delta^L (A_t e^{(-\Sigma_j \lambda_j^A I_j^A)} L_t)^{\frac{(\sigma-1)}{\sigma}} + \delta^K (u_t \times K_{t-1})^{\frac{(\sigma-1)}{\sigma}} + \delta^{COM} COM_t^{\frac{(\sigma-1)}{\sigma}} + \delta^M M_t^{\frac{(\sigma-1)}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \quad (2)$$

where I_j^A indicator functions take on values of 1 or 0 depending on whether this particular disaster happens in period t; and where all λ_j^A are non-negative values calibrated to hit scenario-specific GDP impact targets from Table 1. Z_t is the output of intermediate goods; A_t is the labour-augmenting productivity; L_t is the aggregate labour input; COM_t is the amount of commodities used as inputs; and M_t is the amount of imported goods used in production of intermediate goods. The $\delta^K, \delta^L, \delta^{COM}$, and δ^M parameters of the CES production function are calibrated to be consistent with target data moments for the respective income or spending shares (Table 4 in the Appendix D). The value of the CES elasticity of substitution $\sigma = 0.5$ was taken from Lepetyuk et al. (2020). Note that the entire capital stock K_{t-1} carried forward from the previous period is employed in production of intermediate goods, but its utilization rate u_t is an endogenous choice variable in BToTEM. In contrast to regular productivity shocks, the disaster-induced productivity drops are not persistent, unless the disaster itself lasts for several periods, as is the case for our AB/SK 2001-2002 drought episode.

- **Commodity-sector productivity**: All of the land, a fixed-supply factor denoted by F, is used in the commodity-producing sector. The labour-augmenting productivity A_t also serves as the land-augmenting productivity entering the Cobb-Douglas production function of the commodity-producing sector:

$$COM_t^{Output} = \left[Z_t^{COM}\right]^s \left[A_t e^{(-\Sigma_j \lambda_j^A I_j^A)} F e^{(-\Sigma_j \lambda_j^F I_j^F)}\right]^{1-s} \quad (3)$$

This production function is disturbed by two types of disaster shocks, first the general productivity reducing shocks $(-\Sigma_j \lambda_j^A I_j^A)$ that are common to labour and land; and second, the transitory land supply reducing shocks $(-\Sigma_j \lambda_j^F I_j^F)$ which are specific to the commodity sector. The parameter $s = 0.8$ in the production function is the share of intermediate-good inputs used in production of commodities.[3] The intensities of the commodity sector specific shock were determined by scenario-specific calibrated values of λ_j^F. The disaster-induced land productivity drops affecting the commodity sector are assumed to be purely transitory, unless the disaster itself lasts for several periods, as is the case for both of our drought scenarios.

- **Commodity prices**: In the 1988 regional drought and 2005 US hurricanes scenarios, we introduced temporary external commodity price shocks that raised domestic commodity prices at the same time as domestic commodity output dropped due to direct drought effects on Canadian agricultural sector or because of shut downs of US refining facilities processing Canadian oil. These effects were captured by the following equation

$$p_t^{COM} = S_t \times p_t^{COM_f} \times e^{\Sigma_j \lambda_j^{COM} I_j^{COM}}. \tag{4}$$

  Here I_j^{COM} indicator functions take on values of 1 or 0 depending on whether this particular disaster happens in period t; and where all λ_j^{COM} are non-negative values calibrated to match scenario-specific commodity price increase targets. The prices p_t^{COM} and $p_t^{COM_f}$ are domestic and external commodity prices in period t, correspondingly. The external commodity prices are assumed to be purely exogenous for Canada. The variable S_t denotes the nominal exchange rate which is determined endogenously via an uncovered interest rate parity condition modified to raise its persistence, as discussed on Lepetyuk et al. (2020).

- **Government support**: Government emergency assistance spending is the final channel through which disasters affect the economy. For simplicity, this government spending is assumed to be lump-sum financed and enters the model as one of the aggregate expenditure items, along with consumption, investment and net exports. For each disaster scenario we distribute the total calibrated amount of government assistance spending over one or more periods, depending on how long the disaster itself or the recovery efforts lasted. See the last column of Table 2 and Appendix A for additional details.

The calibration of climate disaster shocks in BToTEM is one of the main contributions of this paper. As mentioned earlier, we use the target moments in Table 1 to calibrate the relative strength of various channels through which representative disaster shocks impact economic activity

[3]Note that no capital inputs are used for production of commodities, which means the intermediate-goods share effectively represents both the capital share and the share of intermediate inputs.

simulated in our model. Once the measured dollar loss or spending amounts from a specific disaster are normalized by GDP values (in the quarter just preceding the disaster), they can be compared meaningfully to output-normalized losses in a macroeconomic model subjected to a set of disaster-replicating shocks. By examining the sectors most affected and the specific characteristics of each disaster, we identify which transmission channels should be activated in the model to best capture the historical events. With the exception of the 2024 Alberta hailstorm, all of our disaster scenarios involve composite shocks that disrupt the model through two or more channels simultaneously. In the case of droughts and US hurricanes the capital destruction channel is not activated since no significant physical capital damages were reported in Canada for these events. Table 2 summarizes the active channels for all seven historical disaster cases.[4]

4 Impulse response analysis

This section presents changes in key macroeconomic variables in response to shocks calibrated to match our historical disasters summarized in Tables 1 and 2. Three sets of impulse responses are shown in each chart below. One set (blue curves) assumes an immediate response of policy interest rates, following a Taylor-type feedback rule with smoothing,

$$R_t = \rho R_{t-1} + (1-\rho)\left[\bar{R} + \beta_\pi(\pi_t^{core} - \bar{\pi}) + \beta_Y(\log(Y_t) - \log(Y_t^{pot})\right] + \epsilon_t^R. \tag{5}$$

The nominal interest rate R_t in equation (5) responds to fluctuations in the core inflation gap relative to inflation target, but looks through changes in commodity prices.

The second set of impulse response functions (red curves) assumes a delayed interest rate response. This delay captures a more extreme version of policy "look-through" which we model by holding the interest rate unchanged during the periods of disaster (starting in period 1), and for one or two additional periods (quarters) immediately after the disaster seizes to exert its direct impact on the economy.[5] The third set of impulse responses (yellow curves) takes a more subtle approach to modeling temporary policy adjustments aimed at smoothing sharp interest rate fluctuations induced by transitory changes in inflation. In this set of simulations, interest rate policy deviates from the benchmark Taylor rule by responding only to output gap fluctuations and not

[4] Appendix A provides additional details.

[5] The shortest delay that avoids an initial drop in interest rates was chosen in all scenarios.

Table 2: Active impact channels across disaster scenarios

Disaster Event	**Capital Destruction**	**General Labour/Land Productivity**	**Commodity-Sector Productivity**	**Government Spending**
QC/ON Ice Storm (1998 Q1)	✓	✓	—	✓ (100% in Q1)
AB Floods (2013 Q2)	✓	✓	✓	✓ (50% in Q2, 50% in Q3)
Fort McMurray Wildfire (2016 Q2)	✓	—	✓	✓ (50% in Q2, 40% in Q3, 10% in Q4)
AB storm (2024 Q3)	✓	—	—	—
AB/SK Drought (2001–02)	—	✓	✓	✓ (20% in each quarter, 2001Q3–2002Q3)
Regional (US/CA) Drought (1988)	—	—	✓ (coupled with external price increase)	✓ (50% in Q2, 50% in Q3)
US Hurricanes (2005 Q3)	—	—	✓ (coupled with external price increase)	—

Notes: ✓ indicates an active impact channel; — indicates channel not applicable or inactive. The strength of each channel was calibrated to match the relative magnitudes in Table 1, normalized by GDP. Government spending percentages indicate the temporal distribution of disaster assistance across quarters.

to inflation fluctuations.[6] Thus, the interest rate policy leans temporarily toward a more dovish stance softening the detrimental impact of disasters on economic activity and looking through their immediate impacts on inflation.

4.1 Scenario 1: 1998 winter storm in Quebec and Ontario

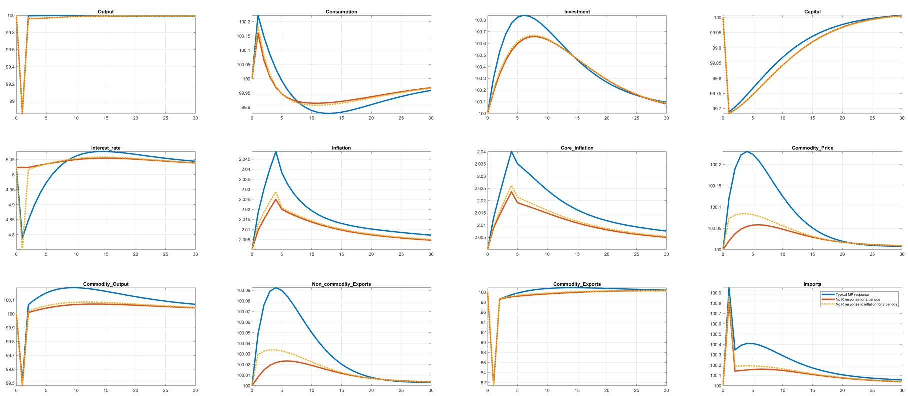


Figure 1: Impulse response for the 1998 Ice Storm in QC and ON

The output and commodity output drops are sharp and short-lasting, as the Ice Storm inflicted a relatively brief but severe disruption on the Canadian economy, hitting some of the most densely populated areas of Quebec and Ontario. The inflation response is small but more persistent. The initial rise in consumption is in response to the initial drop of real interest rates, as households optimize intertemporally. Muting the initial reaction of policy rates has a stabilizing impact, particularly on the commodity prices and on the non-commodity exports. The absence of a reaction to inflation, lasting for two quarters, has a similar impact on most variables as the policy holding the interest rates fixed for two periods, despite a sharp 25 basis points fall in the interest rate itself.

[6]For ease of comparison, the length of such policy adjustment was kept identical to the number of periods interest rates were held unchanged under the policy delay scenarios.

4.2 Scenario 2: 2013 South Alberta Floods

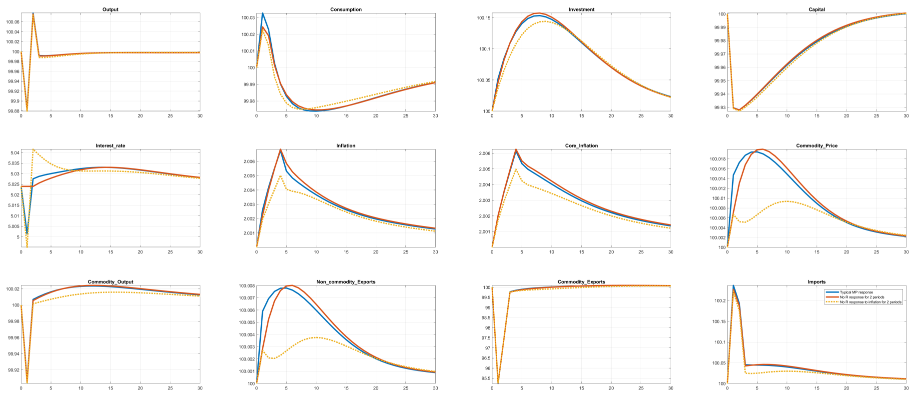


Figure 2: Impulse response for the 2013 AB floods

In response to the 2013 Alberta flood, output drops sharply on impact (followed by a partial rebound) and inflation rises modestly and more persistently. In contrast to Scenario 1, the delayed monetary policy response does not make a big difference for the volatility of the other key variables. Looking through inflation fluctuation for the first two periods leads to slightly lower inflation and lower volatility in commodity prices and non-commodity exports, but otherwise does not have a big differential impact.

4.3 Scenario 3: 2016 Fort McMurray wildfire

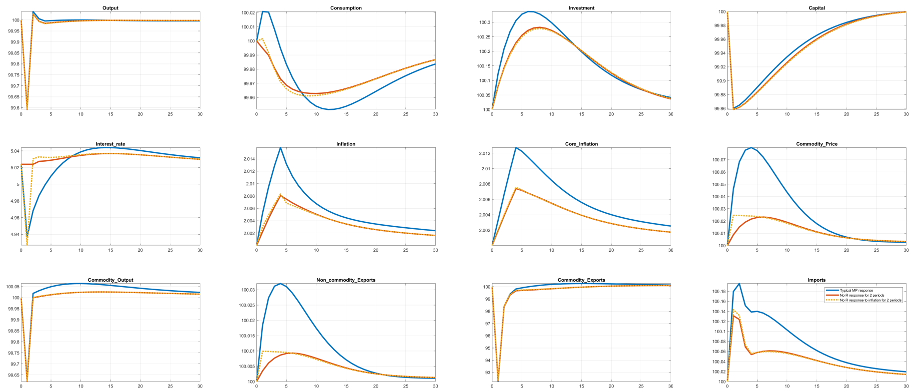


Figure 3: Impulse response for the 2016 Fort McMurray wildfire

The increase in commodity prices after the disaster reflects a temporary productivity reduction in the commodity sector, capturing the effects of wildfire induced disruptions in the oil producing cites around Fort McMurray.[7] A similar rise in non-commodity exports suggests that temporary terms-of-trade adjustments also played some role. Just like in the ice storm scenario, holding the interest rate unchanged for two quarters allows monetary policy to reduce volatility primarily in the commodity prices and non-commodity exports. Looking through inflation for two periods after the shock has a similar stabilizing impact on most variables except the interest rate itself.

[7] Notably, West Canada Select oil price (WCS) nearly doubled between May 2nd and June 1st of 2016, which are the second and the last day of emergency evacuations from the Fort McMurray area.

4.4 Scenario 4: 2024 Calgary hailstorm

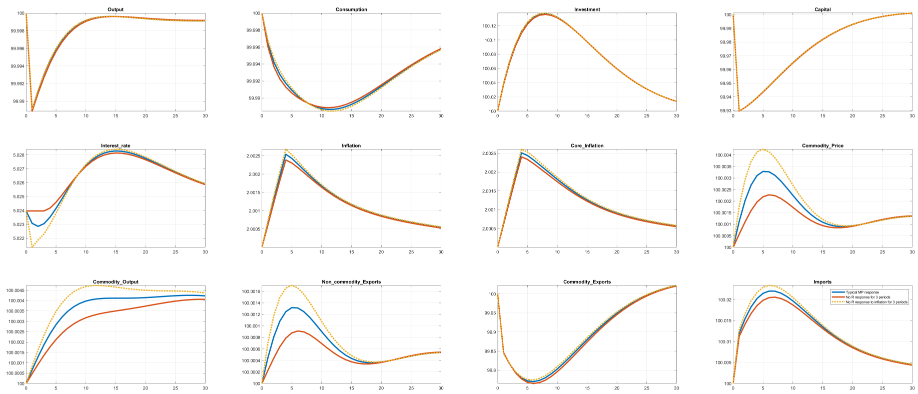


Figure 4: Impulse response for the 2024 AB hailstorm

This disaster had a relatively small impact on most macroeconomic variables, likely because the impact was highly localized both in terms of its duration and geography. Physical damages to vehicles, residential structures, and non-residential structures resulted in substantial insurance payouts and repairs, but did not inflict much additional economic costs. The policy response delay has some stabilizing effects, but not as big as in the other cases discussed above. In contrast, looking through the initial inflation increase adds to volatility of most variables, but only marginally so.

4.5 Scenario 5: 2001-2002 Western Canada drought

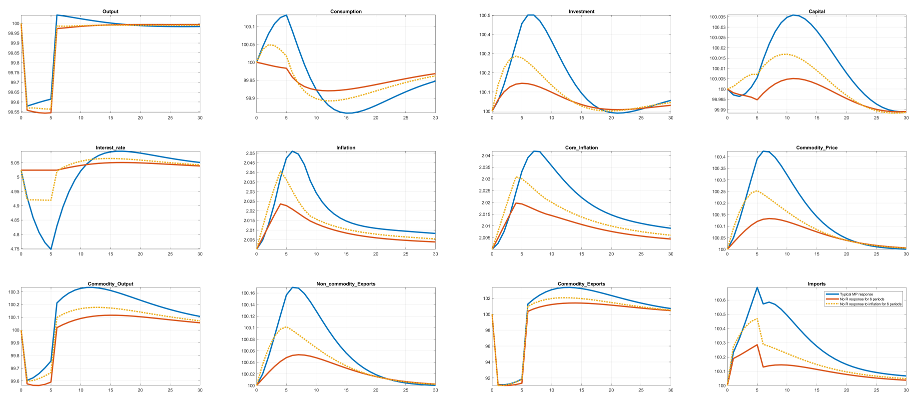


Figure 5: Impulse response for the 2001-2002 West Canada drought

This disaster shock, modeled to last for five periods in line with the reported duration of this drought, has its main impact falling on commodities, but the non-commodity output also falls due to endogenous spillover effects. Aggregate output falls while inflation rises in response to this sector-specific supply shock. A delayed policy response or a temporary policy insensitivity to inflation may be less well suited to a long-lasting shock, but for completeness, the red curves show a simulation in which the interest rate is held at its steady-state level in periods 1 through 6, while the yellow curves illustrate the effects of an inflation look-through lasting the same length.[8] As before, both of these monetary policy responses help dampen fluctuations in most macroeconomic variables.

[8] The drought related shocks are assumed to last for five quarters from 2001Q3 to 2002Q3. Adding one more period of policy inaction after the shock eliminates brief interest rate reversals.

4.6 Scenario 6: 1988 drought in the United States and Canada

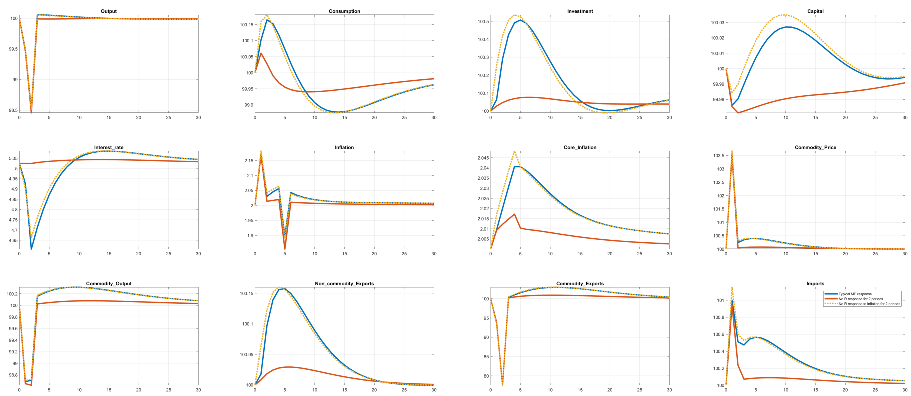


Figure 6: Impulse response for the 1988 drought in the United States and Canada

This disaster had a large effect on the North American agricultural prices. Crop prices rose significantly because of lower yields across North American farmlands, and due to temporary shutdowns of river-based transportation networks. The sharp increase in prices, peaking at the end of the second quarter of 1988, alleviated to some extent the financial impact of agricultural output losses in Canada. In accordance with these observations, we model this disaster as a combination of an increase in external commodity prices and a two-period reduction in commodity sector productivity. Aggregate output and commodity output fall in response to this sector-specific shock, while inflation rises. The delayed policy response, modeled by holding the policy rate constant in periods 1 and 2, has a stabilizing effect on many variables with temporary increases in investment, consumption, core inflation and non-commodity exports noticeably moderated. The interest rate response looking through inflation for two quarters is associated with a sharper spike in core inflation, but otherwise has a similar profile to that of the monetary policy response based on the Taylor rule.

4.7 Scenario 7: 2005 US hurricanes

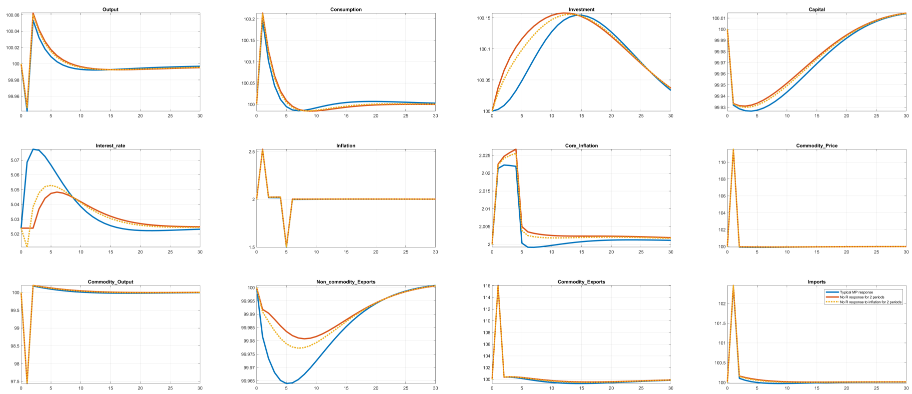


Figure 7: Impulse response for the 2005 US hurricanes

The Hurricanes Katrina and Rita in 2005 generated a contractionary supply shock for the Canadian commodity sector, as production was disrupted, but simultaneously triggered a rise in global oil and gas prices due to severe damage to US extraction capacity. As a result, Canada experienced an improvement in its terms of trade, which offset the initial decline in output and led to a subsequent expansion driven by higher export revenues. Consistent with this mechanism, aggregate output initially falls while inflation rises, followed by a rebound in activity as the positive income effects of stronger commodity prices materialize. The policy response delay and the temporary tolerance to inflation pressures, both lasting for two periods, reduce oscillations in non-commodity exports but do not have a big impact on other variables.

4.8 Summary of Impulse Responses

The results show that, with the exception of the 1998 ice storm and the prolonged 1988 drought, most domestic disasters produce relatively small and short-lived macroeconomic effects. This is consistent with their localized scope and brief duration. However, an increase in the frequency or severity of such events would raise expected output losses and macroeconomic volatility, creating an additional source of risk for economic activity. Although the inflationary impact of all domestic disasters remains modest—typically only a few basis points—inflation displays greater persistence than output. An important exception is the 1988 regional drought and the US hurricane scenario, where both output and inflation increase at similar speeds due to transitory commodity price effects.

In nearly all disaster cases, the benchmark monetary policy rule prescribes an immediate policy rate cut, followed by a gradual increase above the neutral rate. Investment rises persistently after every domestic disaster; however, in the US–Canada drought, the initial investment response depends on whether monetary policy reacts immediately or with delay. A look-through approach, where the central bank temporarily delays its overall response or its response to inflation, stabilizes selected macroeconomic variables in most scenarios. However, such a strategy may become less appropriate if disasters occur more frequently or persist for longer periods, as prolonged or repeated periods of a muted policy reaction to inflation could undermine central bank credibility and risk de-anchoring inflation expectations.

All five domestic disasters, as well as the US–Canada drought, generate a clear trade-off for monetary policy, as they lead to modest increases in inflation while simultaneously reducing output. By contrast, the US hurricane scenario does not present a similar trade-off, as positive terms-of-trade effects largely offset the initial decline in output. However, this outcome could be sensitive to the nature of the disruption: a more severe shock to US refining capacity could restrict export channels and amplify negative spillovers to Canada.

5 Characterizing Monetary Policy Trade-offs

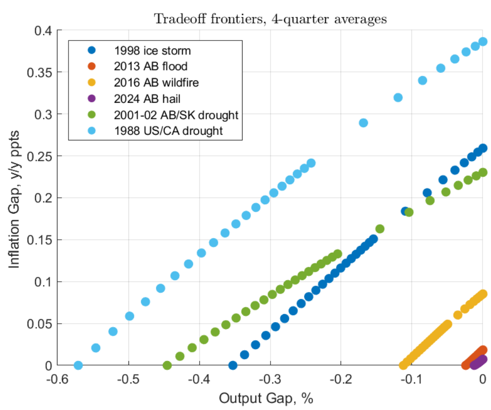
A fruitful way to gain insights about inflation-output trade-offs is to vary the degree to which the interest rate responds to fluctuations in output and inflation. In case of our domestic disaster shocks, inflation and output tend to move in the opposite direction, at least in the short run. In such cases, central banks must accept either higher inflation or weaker output than normally desired. In this section, we quantify such trade-offs across the natural disaster scenarios discussed above. These trade-offs may shift as climate-related disasters are expected to increase both in severity and frequency. To illustrate the potential impact on the trade-off, we also consider hypothetical situations based on combined disasters, their increased frequency or severity.

5.1 Inflation-Output Trade-offs Across Disaster Scenarios

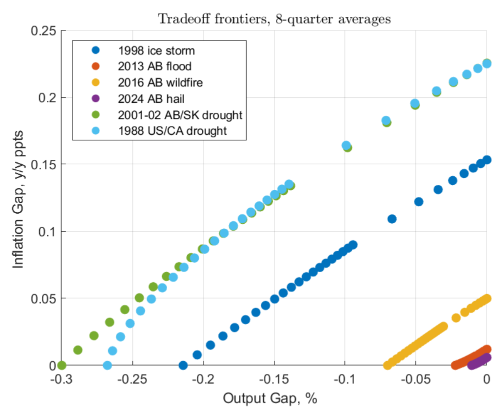
We can quantify such trade-offs by varying the monetary policy rule and plotting the implied policy frontier. We follow Del Negro et al. (2023) and replace the calibrated Taylor rule in BToTEM (equation 5), with a simpler version, which focuses directly on the policy tradeoff between inflation and output gaps, relative to their respective target levels:

$$\alpha(\pi_t - \overline{\pi}) + (1-\alpha)\left[\log(Y_t) - \log(Y_t^{pot})\right] = 0 \tag{6}$$

For a given value of $\alpha \in [0,1]$, this policy rule implies specific relative weights on inflation and output gaps. The degree to which the implied policy rate changes in response to shocks, depends on α. The higher is α, the more (less) aggressively monetary policy reacts to inflation (output) gap fluctuations. Figure 8 shows the policy trade-off frontiers for a range of possible α values (zero to one) for five domestic disasters plus the US-Canada drought. These are all the scenarios that imply a clear trade-off, based on their impulse response functions discussed in the previous section. The vertical (horizontal) axis on Figure 8 indicates the inflation (output) gap, averaged over four (periods 1 to 4) or eight (periods 1 to 8) quarters following the disaster.



(a) Averaged over four quarters



(b) Averaged over eight quarters.

Figure 8: Policy tradeoff frontiers over different averaging horizons. Inflation gap units are year-on-year percentage points, while output gap is measured in percents.

Naturally, the higher is the α weight on inflation, the closer is the inflation gap to zero. When $\alpha = 1$, the inflation gap is zero, while the output gap is at its maximum value. The largest trade-offs are associated with the costliest disasters—those that damaged infrastructures or significantly disrupted the commodity sector. For instance, in the case of the 1998 ice storm (blue dots), if the central bank focused on stabilizing output and closing the output gap ($\alpha = 0$), CPI inflation (y/y) could be about 0.26 percentage points higher on average over the one-year period following the disaster. In contrast, if the central bank exclusively stabilized inflation ($\alpha = 1$), this would result in a drag on output, with the output gap averaging about -0.35 percent during the same period. The trade-offs for the longer-lasting droughts are larger. In the case of the 1988 US/Canada drought (light blue dots), inflation could average about 0.39 percentage points above target over a one-year period if the central bank focused on stabilizing output. There are smaller trade-offs in the case of the 2013 Alberta flood or the 2024 hail as the frontier stays relatively close to the origin. The trade-offs are generally smaller over the two-year period as the effects on output and inflation generally peak within a few quarters following the disasters (see Panel b of Figure 8).

5.2 Inflation-Output Trade-offs Across Hypothetical Disaster Situations

The trade-off may shift as climate-related disasters are expected to increase both in severity and frequency. To illustrate the potential impact on the trade-off, we consider three hypothetical situations:

1. **Combined disasters.** The 2023 Alberta flood, the 2016 Fort McMurray wildfire, and the 2024 Alberta hailstorm are modeled as occurring in the same quarter, with their magnitudes scaled to match the insurance payouts recorded in 2024Q3. We focus on this combined scenario because, according to the Insurance Bureau of Canada (IBC 2024), 2024Q3 was one of the costliest quarters for disaster-related insurance claims, with all three types of summertime disasters, floods, wildfires and a hailstorm, happening within this quarter. In July and August alone, insured losses reached approximately 7.9 billion dollars.[9]

2. **Increased severity.** We normalize annual IBC estimates of insured losses from severe weather by nominal GDP over 1983–2024 and project these values to 2040 (see Appendix

[9] In the model, the shocks from each of these disasters are stacked together as if they happened simultaneously. The wildfire and flood shocks were multiplied by 0.62 to scale them smaller. We calibrate this scaling parameter by making the immediate (period 1) destruction of capital to be consistent with the $7.9 billion insurance payouts, normalized by quarterly GDP in 2024Q2. We did not scale down the magnitude of the 2024 AB hail shock because this disaster did actually happen in 2024Q3.

B, Figure 13).[10] To scale our combination scenario shocks, we adopt the more conservative quadratic trend projection, which implies that disaster-related losses nearly double relative to 2024 levels by 2040.[11] This hypothetical scenario can be thought of as a quarter as extreme as 2024Q3 occurring in 2040, but with all calibrated shocks from the "2024Q3 flood + hail + wildfire" scenario scaled up by a factor of two.

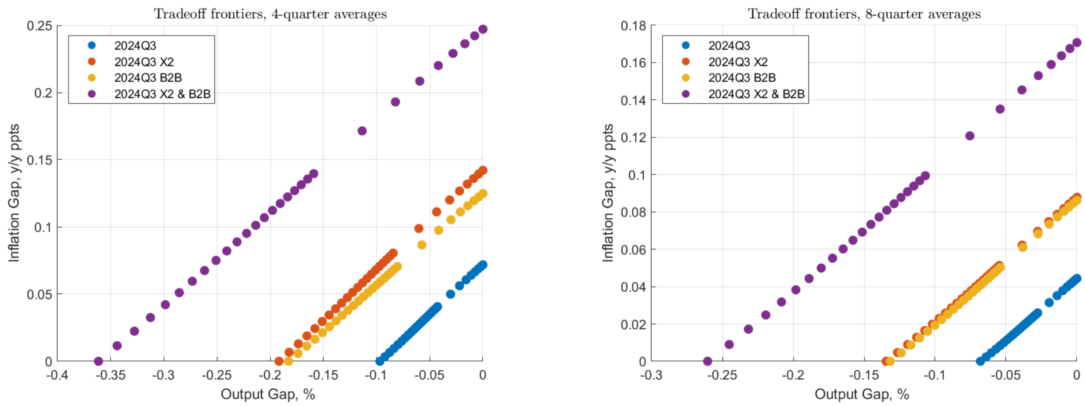
3. **Increased Frequency.** The same IBC data also allow us to project the future frequency of severe-weather events. The exponential trend implies that disaster frequency could more than double by 2040, whereas the better-fitting quadratic trend suggests a more moderate 30 percent increase (see Figure 14 in Appendix B). In our impulse response framework, higher frequency can be modeled by adding additional disasters in consecutive periods, reflecting the growing likelihood that for example, hotter, drier springs and summers will produce back-to-back quarters of multiple severe events similar to those observed in 2024Q3.

Figure 9 shows the trade-off frontiers for the hypothetical scenarios based on four-quarter and eight-quarter averages. The combination of disasters ("2024Q3 flood, hail, and wildfire combined," blue dots) illustrates that simultaneously occurring disasters can worsen the trade-off for monetary policy since the frontier shifts outwards if compared to the 2024 hail scenario alone, for example.[12]

[10] See the Insurance Bureau of Canada 2023 Facts Book (IBC 2023), as well as more recent estimates for 2023 and 2024

[11] An exponential trend would project losses to increase by roughly 2.8 times over the same period. Unlike the exponential specification, the quadratic trend does not impose a constant growth rate and therefore allows for the possibility that technological adaptation or structural change may gradually moderate growth in relative losses, even as they continue to rise relative to GDP.

[12] Appendix C shows the impulse responses for the combined disasters scenario.



(a) Averaged over four quarters

(b) Averaged over eight quarters.

Figure 9: Policy tradeoff frontiers over different averaging horizons. Inflation gap units are year-on-year percentage points, while output gap is measured in percents. 2024Q3 (flood + hail + wildfire) shock is projected to 2040 magnitude (X2), plus back-to-back disaster quarters (B2B).

Turning to the hypothetical scenario with double the shock strength, the policy tradeoff (orange dots on Figure 9) is much less favourable than the original tradeoff frontier implied by the calibrated 2024Q3 shock magnitudes (blue dots). For example, if the central bank were to fully stabilize inflation, the output gap loss would be about twice as large as in the case of the combined disaster scenario.[13] The yellow-dotted line shows the policy frontier for the scenario with two back-to-back quarters of combined disasters calibrated to losses in 2024Q3. This frontier is very similar to the previously discussed scenario in which 2024Q3 shocks are doubled in size consistent with the projected 2040 magnitudes (orange dots). The hypothetical back-to-back disaster situation roughly doubles the inflation-output trade-off faced by the central bank.

Moreover, the purple-dotted policy frontier in Figure 9 presents an additional hypothetical scenario in which the 2024Q3-type combination of disasters happen in two consecutive quarters (periods 1 and 2) and their destructive strength is amplified nearly two-fold, consistent with our 2040 magnitude projection from the quadratic trend model. This hypothetical disaster-shock scenario shifts the frontier further outwards implying a much less desirable trade-off. Finally, as in Section 5.1, we observe that the trade-offs are larger based on four-quarter averages, reflecting the fact that the macroeconomic effects of these hypothetical disaster scenarios generally peak within a few

[13] This roughly one-to-one relationship with the severity of disaster shocks and the trade-off reflects that our model is linear in shock size.

quarters.

Impulse response functions provide a useful analysis of short-run policy tradeoffs immediately after disasters. With more frequent disasters, it might be more appropriate for policy makers to focus on longer-term tradeoffs between volatility of inflation and output. The next section combines historical data on Canadian disasters, and our calibrated disaster scenarios, to analyze such volatility tradeoffs.

6 Stochastic Simulations

To characterize volatility trade-offs, we start by aggregating over 1980-2019, monthly frequency, provincial-level data from Duprey et al. (2024) to construct quarter-specific incidence frequencies for four types of acute sudden disasters in Canada: wildfires, floods, storms, and winter storms (Table 3).[14] Dividing each cell of this table by the number of provinces and the number of years (10 provinces times 40 years), we obtain approximate arrival probability rates for each type of disaster for each quarter of the year.

Table 3: Quarterly Disaster Incidence Numbers by Type

Quarter	**Wildfire**	**Flood**	**Storm**	**Winter Storm**
Q1	2	39	14	57
Q2	43	112	35	14
Q3	68	59	111	0
Q4	7	32	46	20

Notes: Disaster incidence numbers aggregated to quarterly frequency. Data source: Duprey et al. (2024). Numbers represent the count of province-specific disaster events occurring in each quarter by disaster type.

It is harder to pinpoint the exact timing and duration of periods when droughts affect economic activity. According to the Canadian Disaster Database, there were 15 droughts in Canada between 1980 and 2019, with most of them affecting primarily the Prairie provinces. For some of the droughts, the Canadian Disaster Database states their start and end dates which we use to infer the relevant quarters of their economic impacts. Most drought entries only have the year of their occurrence. For such cases with uncertain timing within the year, we assume that the droughts were impacting the economy in the second and third quarter of the respective year, as this is the most likely period when agricultural prices and sales would be reflecting the current precipitation

[14] This is based on Table 1 in Duprey et al. (2024).

and harvest yield conditions. This time allocation procedure results in 2 droughts active during quarter 1, one drought in quarter 4, and 14 droughts in quarters 2 and 3. These incidence rates allow us to infer the implied average arrival probabilities of droughts.

With these arrival probabilities available, we construct a much longer stochastic simulation in which quarter-specific arrival probabilities are similar to those from the 1980-2019 period, but each wildfire looks like the Fort McMurray wildfire, each flood looks like the 2013 Calgary flood, each storm looks like the 2024 hailstorm in Calgary, each winter storm looks like the 1998 Ice Storm, and every drought is like the 2001-2002 West Canada drought in terms of their relative strength configurations across the various impact channels.

Considering that each of these representative disasters was the costliest weather-related disaster in Canada over the last 40 years, we scale their overall magnitude down to avoid a significant overstatement of the volatility trade-offs implied by such stochastic simulation scenarios. With that objective in mind, we applied a uniform scaling factor calibrated to match the average IBC reported annual insurance payouts over the last ten years (2015-2024), normalized by their respective annual GDP numbers (0.46% of annual GDP on average). Specifically, the scaling factor of 0.0283 aligned the average loss of physical capital in the stochastic simulation (with only the disaster shocks present) with this target moment. This scaling factor suggests that our historical disaster cases had a nearly 35 times stronger destructive impact on physical capital than average-sized disasters over the last decade.

The long run volatility tradeoff from a stochastic simulation, with only the (average-sized) disaster shocks included (left panel of Figure 10), suggests a relatively modest volatility tradeoff which pales in size relative to the amount of volatility implied by other business cycle shocks. The right panel of Figure 10 compares the volatility frontiers with and without all the other (six) calibrated business cycle shocks added to the stochastic simulation scenario with 40,000 periods (i.e. 10,000 years).[15] The magnitudes of the business cycle shocks are calibrated to match the volatility and persistence of inflation and output gap measures for the 1995Q1-2019Q4 period, which excludes the pandemic period and also the period before the Inflation Targeting framework with the current 2 percent inflation target was fully established in Canada. The magnitude differences shown on

[15]Exogenous business cycle shocks were modeled as normally distributed innovations to AR(1) processes governing stochastic distributions of: 1) labour productivity shocks; 2) consumption demand shocks; 3) external commodity price shocks; 4) foreign demand shocks for Canadian exports; 5) foreign risk-free interest rate shocks; and 6) markup shocks in the intermediate-goods sector.

the right panel of Figure 10 suggest that the average-sized disasters of the last decade did not alter in a significant way the volatility frontier implied by the other business cycle shocks buffeting the Canadian economy on a regular basis.[16]

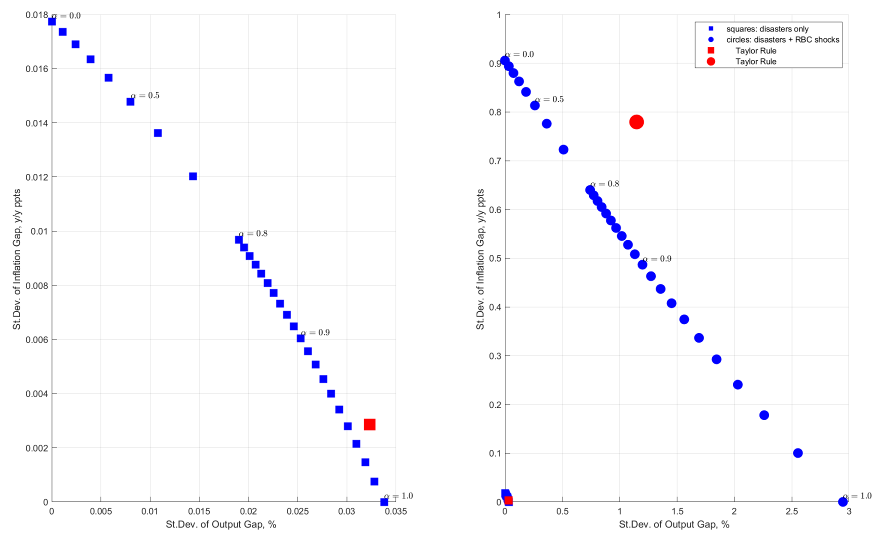


Figure 10: Volatility tradeoffs with only disaster shocks (left) and with all shocks (right).

Could that conclusion change in the future? We can use our year-2040 projections of disaster shock magnitudes and arrival probabilities to assess whether larger and more frequent disasters are likely to aggravate future policy tradeoffs. The left panel of Figure 11 shows four tradeoff frontiers implied by: a) the benchmark disasters calibration (blue dots); b) the calibration with disaster arrival probabilities scaled up by a factor of 1.3 (yellow dots), consistent with our projections with the quadratic trend (see Figure 14 in the Appendix) ; c) the calibration with disaster magnitudes (nearly) doubled (orange dots), consistent with our projections with the quadratic trend (see Figure 13 in the Appendix); and finally, d) an even worse scenario (purple dots) with both the arrival probabilities and the magnitudes of disasters scaled up in accordance with our quadratic trend projections.

[16]The red square and red circle on Figure 10 indicate volatility combinations implied by the historical Taylor rule, with and without other business cycle shocks, correspondingly. Their location to the right of the respective volatility frontiers, suggest that the calibrated historical interest rate rules contribute additional volatility relative to simpler rules balancing the output and inflation volatility.

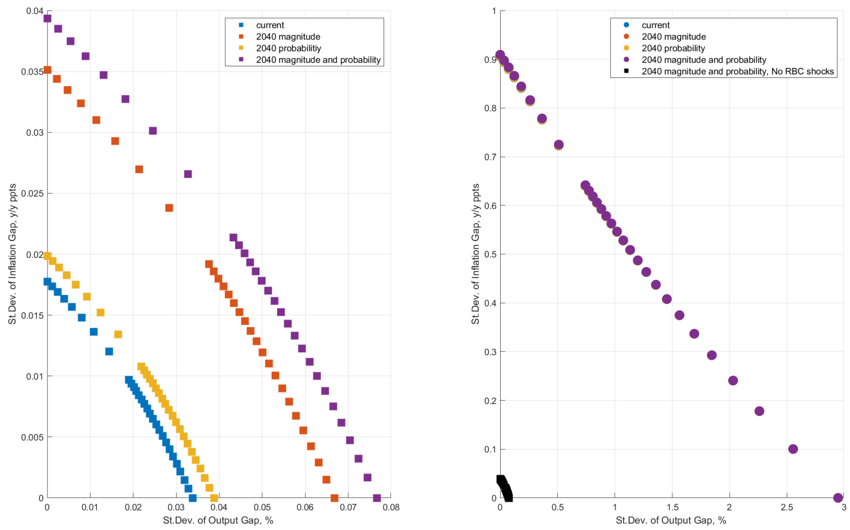


Figure 11: Volatility tradeoffs with only disaster shocks (left) and with all shocks (right). The disaster magnitudes and arrival probabilities are projected to 2040 using the quadratic trend model. Note: the chart on the right panel has several curves which are nearly identical and fully covered by the purple-dots curve.

Despite a significant outward shift of these projected 2040 policy tradeoffs from disasters, the right panel of Figure 11 suggests that the overall volatility tradeoff (purple dots) would not be materially changed by 2040, relative to the frontier associated with all business cycle shocks.[17] So far, taken at their face value, our simulation results do not suggest that climate related disasters are likely to significantly alter the volatility trade off between inflation and economic activity stabilization within the next 10 to 15 years.

As a final experiment, we also compare our 2040 projections with the hypothetical scenario in which the historical disasters we calibrated become the norm. Thus, for this experiment we retain the full strength of our calibrated scenarios in a stochastic simulation instead of scaling them down to match the average insurance payouts over the last ten years.

[17] For easy comparison, the right chart also shows the right-most volatility frontier from the left panel (in black squares).

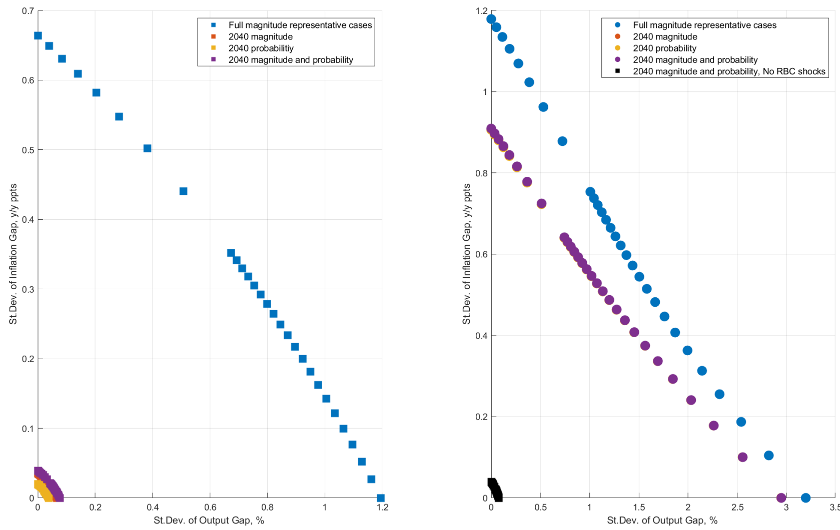


Figure 12: Volatility tradeoffs with only disaster shocks (left) and with all shocks (right). Note: blue-dotted curves highlights the policy tradeoff from a hypothetical scenario in which our calibrated representative disasters become the norm.

The blue-dotted curves on Figure 12 show just how destructive the representative disasters were relative to the average sized disasters over the last 10 years, even if the latter are projected to their 2040 forecasted magnitudes. This opens the door to the possibility that strong non-linearities associated with climate tipping points might create an upside risk to our benchmark results, with severe impacts for economic volatility.

7 Conclusion

This paper develops an open-economy DSGE framework calibrated to the Canadian economy to study how natural disasters affect output, inflation, and monetary policy trade-offs. The results highlight that disasters generally act as adverse supply shocks, simultaneously reducing output and exerting mild upward pressure on inflation. The magnitude of these effects depends on the duration and scope of the event, with the 1998 Ice Storm and prolonged droughts generating the largest impacts. In contrast, foreign disasters that improve Canada's terms of trade, such as US hurricanes that disrupt the energy supply, can temporarily boost both output and inflation. The findings suggest that the macroeconomic consequences of natural disasters are heterogeneous and highly context-specific.

From a monetary policy perspective, our analysis underscores that natural disasters can create short-term trade-offs between stabilizing inflation and supporting output, particularly when shocks are supply-driven and persistent. A "look-through" approach—delaying an immediate policy reaction—can mitigate volatility in some cases but may be less effective in a world where disasters become more frequent or prolonged. As the severity and recurrence of physical climate risks rise, monetary policy may face more complex stabilization challenges, requiring greater attention to the nature of shocks, their transmission channels, and the interactions between fiscal and monetary responses. Future work should further integrate these risks into modeling frameworks, including through nonlinear modeling and welfare-based evaluations of alternative policy rules.

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A Additional details about disaster events

A.1 Scenario 1: 1998 winter storm in QC and ON

The economic costs of this disaster were relatively well documented. One of the most detailed early accounts of the event timeline and costs is given by Lecomte, et al. (1998) The acute phase of the ice storm with widespread electric power outages and hazardous icy roads lasted for about two weeks between January 5 and January 18. During this period, approximately 2.6 million people (19 per cent of all Canadian employees) were prevented from traveling to work.[18] The economic costs of the 1998 Ice storm can be broken down into three main parts:

- 3.7 billion was estimated to be in the form of physical capital destruction. This estimate consists of 1.7 billion CAD in insurance payments and about 2 billion CAD in damages to power generation lines and the agricultural sector of Canada (mostly dairy, forestry, and maple

[18] See Soulard et al. (1998).

syrup production).[19] The (current-dollar, seasonally adjusted, annualized) GDP in 1997Q4 (i.e., the quarter just preceding the disaster) was $923.98 billion CAD. Thus, the physical capital loss was about $100(3.7 \times 4/924.0) = 1.60$ percent of the quarterly rate GDP. In our simulation, we calibrate the immediate (i.e. period 1) impact of disaster on physical capital to match the same ratio relative to model-implied steady-state level of quarterly GDP.

- Further, the 1998 Ice storm generated an estimated $2.6 billion of output losses in Canada. These output losses estimated by the Conference Board of Canada (as per indirect reference in Lecomte et al. 1998) include $1.6 billion of direct output losses due to electricity outages (e.g. work interruptions and inventory spoilage) as well as $1 billion in "lost income" due to unrealized retail sales.[20] $2.6 billion in 1998 is $100(2.6 \times 4/924.0) = 1.13$ percent of the same 1997Q4 GDP benchmark. In our simulation, we calibrate a period 1 shock to labour- (and land-) augmenting productivity so that the immediate fall in output (during the disaster period) matches the same ratio relative to model-implied steady-state level of GDP. Note that these productivity shocks impacted both the intermediate good sector and the commodity sector, consistent with the fact that many businesses from various industries experienced electricity shutoffs and employee absences.

- The Canadian Disaster Database reports $0.9 billion of assistance payments split between the federal government agencies, the provincial governments, and the NGO payments. This amount is equivalent to $100(0.9 \times 4/924.0) = 0.39$ percent of the same 1997Q4 GDP benchmark. In our simulation, we increase the government spending during the disaster period by the same amount, when expressed as a fraction of steady-state level of quarterly GDP. Since most of the recovery efforts were completed by February 6, 1998 (timeline in Lecomte, et al. 1998), we concentrate all of the government spending in the period of the disaster.

- None of the cross-border trade effects were mentioned in any of the available sources on the 1998 Ice storm. The only exception is that a small amount of Canadian milk had to be

[19]The Canadian Disaster Database reports $1.712 billion of insurance payments and $2.018 billion in additional municipal costs. The estimate of municipal costs is consistent with $2 billion of damages to power lines reported in Campbell (2025). With regard to insurance payouts, IBC (2023) estimates a smaller total of $1.384 billion. In case of discrepancies like this, we stick with the official loss estimates, when available.

[20]The same Conference Board of Canada report was mentioned in Soulard et al. (1998) stating: "According to The Conference Board of Canada, the Ice storm resulted in a short-term loss of $1.6 billion for Canada's economic output, of which $1.4 billion originated in Quebec and $200 million in Ontario". Unfortunately, we could not locate the original Conference Board of Canada report to confirm the basis for the $1 billion in lost sales estimate.

processed in the United States. For this reason, we chose not to activate any trade-related channels of our model in response to this disaster.

A.2 Scenario 2: 2013 South Alberta floods

The economic costs of the 2013 South Alberta Floods are broken down into the same three main categories:

- 1.7 billion was estimated to be in the form of physical capital destruction, approximated by total insurance payments.[21] The (current-dollar, seasonally adjusted, annualized) GDP in 2013Q1 (i.e., in the quarter preceding the disaster quarter) was \$1,876.8 billion CAD. Thus, the physical capital loss was about $100(1.7 \times 4/1876.8) = 0.36$ percent of the quarterly rate GDP. In our simulation, we calibrate the immediate impact of disaster on physical capital to match the same ratio relative to model-implied steady-state level of quarterly GDP.

- Further, 2013 South Alberta Floods generated an estimated \$0.55 billion of output losses (primarily due to lost labour income). This is equivalent to $100(0.550 \times 4/1876.8) = 0.1172$ percent of the same 2013Q1 GDP benchmark. Notably, 60 percent of these estimated output losses was attributed to the oil producing sector (see the Government of Alberta 2013 report). We matched both the overall GDP loss and the relative decline in the output of commodities by calibrating separate disaster shocks to the labour-augmenting and land-augmenting productivity factors, with the latter one affecting primarily the commodity-producing sector.

- The federal government contributed \$1.016 billion in terms of DFAA payments, while the government of Alberta spent \$937 million.[22] These two amounts are equivalent to $100(1.016 + 0.937)4/1876.8 = 0.42$ as a percent of model implied steady-state level of quarterly GDP. Since, much of government recovery efforts likely fell into both Q2 and Q3 of 2013, we split the government assistance equally between the disaster period (period 1) and the next subsequent period (period 2) in our impulse response simulation.

[21] The Canadian Disaster Database reports \$1.7 billion of insurance payments, 1 billion of Federal DFFA payments, and \$550 million of GDP losses. Once again, IBC (2023) reports a smaller total for insurance payouts of \$1.6 billion.

[22] The City of Calgary 2013 report provides additional details regarding provincial and municipal recovery costs. It lists \$409 million of damages to city infrastructure, \$55 million emergency response, \$323 million of recovery costs, and \$150 million in flood mitigation and resilience projects.

A.3 Scenario 3: 2016 Fort McMurray wildfire

The Canadian Disaster Database lists \$3.6 billion in insurance payouts and \$468.7 million of DFAA government assistance payments for this severe wildfire event.[23] Additionally, Statistics Canada report estimates -0.4% impact of this event on the real national GDP in the second quarter of 2016. This output impact was concentrated primarily on commodities as 14.6% of the national workforce employed in the oil and gas extraction industry worked in the Fort McMurray area. The output of Crude Oil and Refined energy products fell by 7 and 16.4 percent, respectively, in the second quarter of 2016. Finally, the Financial Post 2017 article states that the provincial government spent \$647 million on disaster assistance and recovery costs, and \$369 million on firefighting. Taking these estimates into consideration, we employ the following calibration strategy:

- \$3.6 billion of insurance payouts will serve as an approximation of the physical capital destruction. The (current dollar, seasonally adjusted, annualized) GDP in 2016Q1 (that is, in the quarter preceding the disaster) was \$1,998.42 billion CAD. Thus, the physical capital loss was about $100(3.6 \times 4/1998.4) = 0.72$ percent of the quarterly rate GDP. In our simulation, we calibrate the immediate impact of disaster on physical capital to match the same ratio relative to the model-implied steady-state level of quarterly GDP.

- Further, 0.4% of real GDP loss reported by Statistics Canada will be induced by a temporary reduction in productivity exclusive to the commodity-producing sector. Specifically, we calibrate a one-period shock to Land-augmenting productivity so that the immediate fall in GDP during the disaster period matches the same ratio of 0.4 percent, relative to model-implied steady-state level of GDP.

- \$468.7 million of DFAA payments, plus \$647 million on provincial assistance and \$369 million on firefighting costs, constitute about $100((0.468 + 0.647 + 0.369) \times 4/1998.4) = 0.3$ percent of the same 2016Q1 GDP benchmark. Since some evacuated people could not return home till 2016 Q4,[24] we decided to split this government spending between Q2 (50%), Q3 (40%) and Q4 (10%). Correspondingly, in our simulation, we distribute the total government spending in the same proportions between the disaster period (period 1), and two subsequent periods (periods 2 and 3).

[23] The Insurance Bureau of Canada gives a slightly higher total for the insurance payouts equal to \$3.75 billion. Here again we resolved this discrepancy by resorting to the official CDD estimate.

[24] The Government of Alberta relief funding was ended only on October 31, 2016.

A.4 Scenario 4: 2024 Calgary hailstorm

According to CatIQ estimates (see Allen 2025), the estimated insurance compensations for the damages to physical structures and vehicles amounted to \$3.25 billion.[25] No other significant losses were reported for this disaster. The most affected segment of the economy is the household sector. It seems reasonable to assume that a one-time shock destroying some part of the capital stock best approximates the economic impact of such disaster in bToTEM. The (current-dollar, seasonally adjusted, annualized) GDP in 2024Q2 (i.e., in the quarter preceding the disaster quarter) was \$3,055.3 billion CAD. Thus, the physical capital loss was about $100(3.25 \times 4/3055.3) = 0.43$ percent of the quarterly rate GDP. In our simulation, we calibrate the immediate impact of disaster on physical capital to match the same ratio relative to model-implied steady-state level of quarterly GDP.

A.5 Scenario 5: 2001-2002 Western Canada drought

Wheaton et al. (2008) provides one of the most comprehensive accounts of economic costs to Canada from this drought. This disaster had a big impact on the Canadian economy, but the economic losses accumulated gradually, as the low precipitation period was lasting for much longer than expected, until the heavier rains resumed in the Fall of 2002. Main impact was on crop raising and animal farming industries across Canada, particularly in Alberta and Saskatchewan, but also on other related industries due to lower sales and lost income opportunities. Various government agencies provided assistance via crop insurance, income support measures, and tax deferrals. For modeling purposes, these economic costs may be grouped into the following three categories:

- \$3.6 Billion was estimated to be in the form of agricultural output losses. The (current-dollar, seasonally-adjusted, annualized) quarterly GDP in the 2001Q2 (the last quarter before agricultural output losses started materializing) was \$1,152.9 billion. This means that the equivalent commodity output loss in the model should be $100(3.6 \times 4/1152.9) = 1.249$ as a percentage of model-implied steady-state level of GDP. This GDP loss accumulated gradually over the approximate period between the third quarter of 2001 and the third quarter of

[25] The recent post from the Insurance Bureau of Canada gives a slightly lower estimate of \$3 billion, but cites CatIQ as the main source of their payouts estimates. Wilhelm (2025) provides additional details about this event confirming \$3.25 billion as the latest estimate of insurance payouts.

2002.[26] To capture this impact in bToTEM, we calibrated a uniform reduction in the Land-augmenting productivity over five periods (periods 1 through 5, corresponding to 2001Q3-2002Q3) so that the price-adjusted value of output in the commodity-producing sector falls by the same percentage (1.249 % relative to model-implied steady-state level of GDP) when cumulated over the first five periods after the disaster.

- Further, $2.2 Billion was estimated to be lost due to unrealized sales and lost labour incomes, spillovers from the agricultural sector to the broader economy. The model counterpart of this additional GDP loss can be matched to be equivalent to $100(2.2\times4/1152.9) = 0.7633$ as a percentage of model-implied steady-state quarterly level of GDP. We calibrated a small uniform reduction in the labour-augmenting productivity over five periods (periods 1 through 5, corresponding to 2001Q3-2002Q3) so that the model-implied output loss in the non-commodity sector (cumulated over the first five periods after the disaster) matches the same ratio (0.7633 % relative to model-implied steady-state level of GDP).

- As stated in the same source, Wheaton et al. (2008), the government crop insurance payouts were about $3 billion dollars in total. We assume that this amount of government assistance was spread equally among five quarters 2001Q3-2002Q3. Thus, we split the model-consistent amount of lump-sum financed government spending, equivalent to $3 billion dollars, equally between the period of the disaster (period 1) and the next four periods after that (periods 2-5).

A.6 Scenario 6: 1988 drought in USA and Canada

Although the 1988 drought was one of the costliest droughts in North America in the post-war period, its main impact fell on the US agricultural sector. The direct economic impact in Canada included lost agricultural output, primarily in the crop raising areas of Saskatchewan. According to the Canadian Disaster Database, the overall amount of economic losses in Canada is estimated at $4.1 billion of 2000 dollars. The government-run crop insurance program paid more than $750 million to compensate affected farmers (Wilson 2001). The big part of the total impact of this disaster on the Canadian economy stemmed from commodity price adjustments induced by the

[26] This time frame is roughly consistent with the Canadian Disaster Database records indicating June 1, 2001 and October 1, 2002 as the start and end dates of this disaster.

much more severe impact of the drought on the United States. The North American agricultural prices (mostly for crops) rose sharply in the second quarter of 1988, with the Bank of Canada commodity price index (BCPI) for agricultural components peaking in June 1988 at 20.4% above its level at the end of the previous quarter (relative to March 1988). Taking into account that the 1998 BCPI weight of agricultural prices was approximately 17.4%, we can estimate that the total increase in commodity prices in response to this drought was about $0.174 \times 20.4 = 3.55\%$. The commodity price increase offset to some extent revenue losses of Canadian farmers suffering lower crop yields and more expensive shipping rates due to lower than usual river flow levels. The Canadian Disaster Database gives approximate dates for the start and end date of this event, January 1 1988 to December 1988. Considering that the agricultural prices spiked in June 1998, we assume that the main impacts of this shock were realized in the second and third quarter of 1988, which are the quarters covering the typical harvesting season in North America. For modeling purposes, these economic costs may be grouped into the following three categories:

- The overall amount of economic losses in Canada, estimated at $4.1 billion of 2000 dollars. We need to adjust this number to the 1988 dollars amount. The annual CPI index numbers for 1988 and 2000 are 71.2 and 95.4, respectively (Statistics Canada table 18-10-0005-01). Thus, the equivalent amount in 1988 dollars is $4.1 \times 71.2/95.4 = 3.06$ billion dollars. According to Statistics Canada Table: 36-10-0104-01, the current dollar GDP in the first quarter of 1988 (the last quarter before agricultural output losses started materializing) was $610.9 billion at the annualized rate. This means that the equivalent output loss in the model should be $100(3.06 \times 4/610.9) = 2.0$ as a percentage of model-implied steady-state level of GDP. This GDP loss accumulated over the approximate period including the second and third quarter of 1988, and likely included mostly agricultural output losses. To capture this impact in bToTEM, we calibrated a uniform reduction in the Land-augmenting productivity over two periods (periods 1 and 2, corresponding to 1988Q2-1988Q3) so that the price-adjusted value of output in the commodity-producing sector falls by the same percentage (2.0% relative to model-implied steady-state level of GDP) when cumulated over the first two periods after the disaster.

- Further, $750 million dollars of government assistance is assumed to be split equally between quarters 2 and 3 of 1988. The model counterpart of this fiscal expense can be matched to be equivalent to $100(0.75 \times 4/610.9) = 0.49$ as a percentage of model-implied steady-state quarterly level of GDP.

- Finally, we assume a one-period shock to external commodity prices, which makes the domestic commodity prices to increase by 3.55%, consistent with our estimates from BCPI data.

A.7 Scenario 7: 2005 US hurricanes

The hurricanes Katrina (August 23-31) and Rita (September 18-26) had a significant impact on oil and gas producing regions of the US. Some petroleum refining operations were suspended temporarily, while many gas and oil extraction facilities were severely damaged. According to the November 10, 2005 Canadian international merchandise trade report from Statistics Canada:

> "Exports jumped 2.8% to a record $39.8 billion [...] Hurricanes Katrina and Rita sent natural gas prices soaring, resulting in a big gain in the value of natural gas exports going south of the border. In fact, about three-quarters of September's 2.8% increase in exports was due to higher natural gas prices. [...] This price jump was the result of a shock to the North American market as hurricanes Katrina and Rita compromised natural gas production along the Gulf Coast. [...] Despite gains in the rest of the sector, exports of crude petroleum fell to $2.8 billion."

In line with the description above, the impact of this disaster could be modeled as a combination of an external commodity price increase[27], coupled with an adverse productivity shock in the commodity sector. The temporary productivity fall in the commodity sector would capture the aforementioned decline in crude oil exports from Canada to the United States due to oil processing disruptions. The relative size of price and productivity shocks could be calibrated to make the increase in commodity prices to account for three-fourth of the 2.8% jump in overall Canadian exports.

[27] The Bank of Canada Commodity Price index (BCPI) peaked during the first week of October 2005, rising 30.7% over the third quarter of 2005. Most of the increase was due to a 52.9% rise rise in energy commodity prices, while non-energy commodity prices rose by a much more modest 2.6%.

B Projected trends in severity and frequency of natural disasters

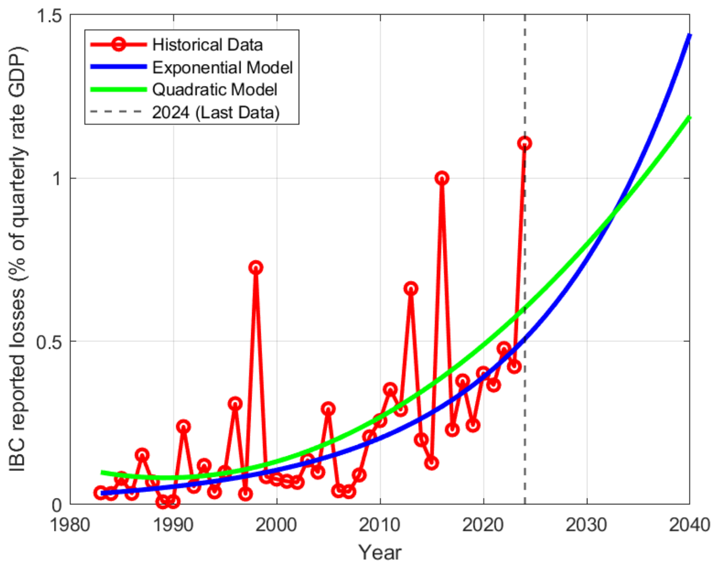

Figure 13: Exponential and quadratic trend projections of IBC reported losses from weather-related disasters.

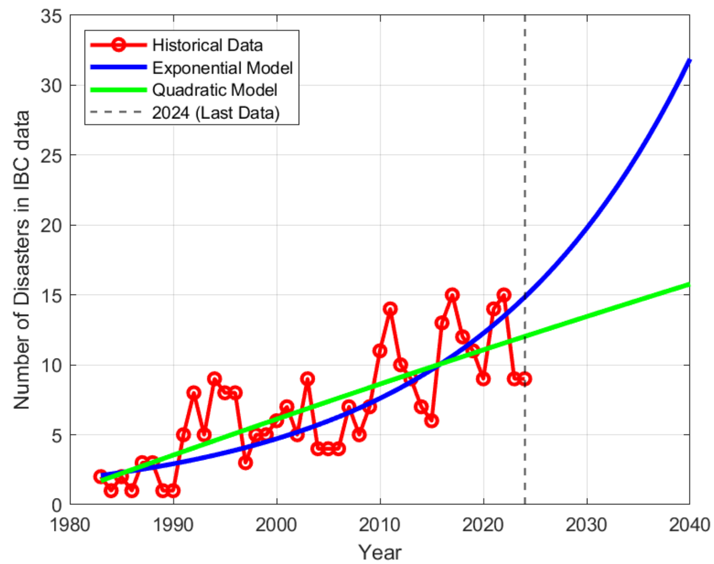

Figure 14: Exponential and quadratic trend projections of the number of IBC reported disaster events per year.

C Impulse responses for the 2024Q3 combination disasters

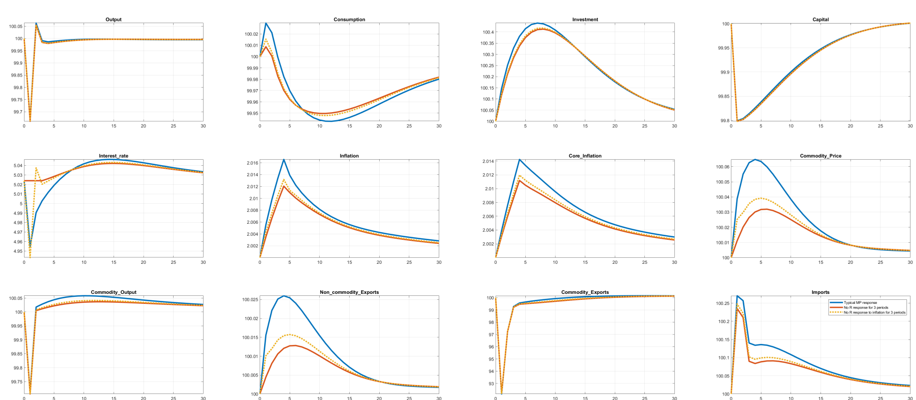

Figure 15: Impulse responses to combination of three domestic disasters: flood + wildfire + hail

D Calibration of the structural parameter values

Table 4: Calibration targets

Target	**Value**
Wage bill to GDP ($\frac{wL}{Y}$)	0.5392
Value of Capital to GDP ($\frac{qK}{Y}$)	5.1478
Value of Investment to GDP ($\frac{p^i I}{Y}$)	0.1644
Consumption to GDP ($\frac{C}{Y}$)	0.5568
Value of Imports to GDP ($\frac{p^m M}{Y}$)	0.3505
Value of non-commodity Exports to GDP ($\frac{p^{nc} X^{nc}}{Y}$)	0.2199
Value of (net) Commodity Exports to GDP ($\frac{p^{com} X^{com}}{Y}$)	0.0468
Value of Domestic Commodity Usage to GDP ($\frac{p^{com} COM^d}{Y}$)	0.1715

Table 5: Structural parameter values

Parameter	Symbol	Value
Rates		
– real interest rate	$\bar{r}$	1.008
– discount factor	$\bar{\beta}$	0.992
– inflation target	$\bar{\pi}$	1.005
– nominal interest rate	$\bar{R}$	1.013
Output production		
– CES elasticity of substitution	σ	0.5
– CES labor share parameter	δ_l	0.122
– CES capital share parameter	δ_k	0.256
– CES commodity share parameter	δ_{com}	0.069
– CES import share parameter	δ_m	0.024
– investment adjustment cost	χ_i	8.207
– fixed depreciation rate	d_0	0.005
– variable depreciation rate	$\bar{d}$	0.027
– depreciation semielasticity	ρ	2.125
– real investment price	ι_i	1.270
– real noncommodity export price	ι_x	1.143
– labor productivity	$\bar{A}$	100
Price setting parameters for consumption		
– probability of indexation	θ	0.837
– RT indexation to past inflation	γ	0.506
– RT share	ω	0.542
– elasticity of substitution of consumption goods	ε	11
– Leontief technology parameter	s_m	0.6
Price setting parameters for imports		
– probability of indexation	θ_m	0.350
– RT indexation to past inflation	γ_m	0.552
– RT share	ω_m	0.203
– elasticity of substitution of imports	ε_m	11
Price setting parameters for wages		
– probability of indexation	θ_w	0.488
– RT indexation to past inflation	γ_w	0.422
– RT share	ω_w	0.530
– elasticity of substitution of labor service	ε_w	5
Household utility		
– consumption habit	ξ	0.6
– consumption elasticity of substitution	μ	0.877
– wage elasticity of labor supply	η	0.070
Monetary policy		
– interest rate persistence parameter	ρ_r	0.850
– interest rate response to inflation gap	ρ_π	4.650
– interest rate response to output gap	ρ_y	0.4
Other		
– capital premium	κ^k	0.017
– exchange rate persistence parameter	κ	0.504
– foreign commodity price	$\bar{p}^{comf}$	1.659
– foreign import price	$\bar{p}^{mf}$	1.049
– risk premium response to debt	ς	0.008
– export scale factor	γ^f	20.695
– foreign demand elasticity	ϕ	0.401
– elasticity in commodity production	s_z	0.8
– share of other components of output	υ_z	0.747
– share of other components of GDP	υ_y	0.363
– adjustment cost in commodity production	χ_{com}	16
– land	F	0.186
– persistence of potential GDP	φ_z	0.748

Table 6: Calibrated parameters for AR(1) shock processes

Parameter	Symbol	Value
Shock persistence		
– persistence of markup shock	φ_{mu}	0.818
– persistence of productivity shock	φ_{a}	0.916
– persistence of consumption demand shock	φ_{c}	0.000
– persistence of foreign demand shock	φ_{Zf}	0.900
– persistence of foreign commodity price shock	φ_{comf}	0.945
– persistence of foreign interest rate shock	φ_{rf}	0.665
Shock volatility		
– standard deviation of markup shock	σ_{mu}	0.0011
– standard deviation of productivity shock	σ_{a}	0.0239
– standard deviation of consumption demand shock	σ_{c}	0.0079
– standard deviation of foreign demand shock	σ_{Zf}	0.0076
– standard deviation of foreign commodity price shock	σ_{comf}	0.0034
– standard deviation of foreign interest rate shock	σ_{rf}	0.0333

Note: final good markup and foreign demand shocks were added, while interest rate and foreign output shocks were removed relative to Lepetyuk et al. (2020) version.