Has Exchange Rate Pass-Through Really Declined? Evidence from Canada*

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Abstract

Several empirical studies suggest that exchange rate pass-through has declined in recent years among industrialized countries. Results for Canada also indicate that import and consumer prices have become less responsive to exchange rate movements in the 1990s. These findings are based on reduced-form regressions that are typically motivated by partial-equilibrium models of pricing. This paper uses instead a structural, general-equilibrium approach to test the premise that exchange rate pass-through has decreased in Canada. Our approach consists in estimating a dynamic stochastic general-equilibrium model for Canada over two sub-samples, which cover the periods before and after the adoption of inflation targeting by the Bank of Canada. We then use impulse-response analysis to assess the stability of exchange rate pass-through across the two sub-samples. Our results indicate that pass-through to Canadian import prices has been rather stable, while pass-through to Canadian consumer prices has declined in recent years. Counterfactual experiments reveal that the change in monetary policy regime is largely responsible for this decline.

JEL classification: F3, F4
Key words: Exchange rate pass-through, General equilibrium, Maximum-likelihood estimation.

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1. Introduction

The extent to which exchange rate movements are *passed-through* to domestic prices is a central issue in international finance and a much-debated question among policy-makers. Indeed, a large body of theoretical research shows that the degree of exchange rate pass-through has stark implications for the conduct of monetary policy (e.g., Smets and Wouters 2002, Corsetti and Pesenti 2002, Adolfson 2002, Sutherland 2002, and Monacelli 2003), the choice of exchange rate regime (Engel 2002; Devereux and Engel 2003), and the international transmission of shocks (see Betts and Devereux 2001). A parallel empirical literature has therefore developed to try to accurately measure exchange rate pass-through and to assess its stability across time.

Recent studies in this literature, including those by Campa and Goldberg (2002), Gagnon and Ihrig (2004), and Bailliu and Fujii (2004), suggest that exchange rate pass-through has declined in recent years in industrialized countries. Results for Canada also indicate that import and consumer prices have become less responsive to exchange rate movements in the 1990s (e.g., Kichian 2001). The methodology adopted in this literature consists in estimating a reduced-form equation where the rate of inflation depends on current and lagged changes in the nominal exchange rate and other control variables suggested by economic theory.[1] The coefficients associated with changes in the exchange rate are then interpreted as pass-through coefficients. This methodology has two important drawbacks. First, the derivation of pass-through equations is typically based on a partial-equilibrium setting where exchange rate movements are treated as an exogenous process. Such a framework obscures the channels through which the exchange rate is affected by other economic variables.[2] More importantly, however, the endogeneity of the exchange rate may, if not dealt with appropriately, lead to biased estimates and therefore incorrect inference about the degree of pass-through. Second, the reduced-form approach adopted in this literature provides very little insight about the way in which, and the extent to which, the degree of exchange rate pass-through depends on the nature of the shocks impinging on the economy. In addition to these methodological shortcomings, existing results for Canada are subject to another important caveat. As emphasized by Bailliu and Bouakez (2004), a number of Canadian import prices are constructed merely by multiplying the foreign-currency price by the nom-

[1] These control variables typically capture changes in the unit cost of exporting firms as well as changes in the level of economic activity in the importing country.

[2] For instance, Betts and Devereux (2000) show that the extent of local currency pricing limits the degree of exchange rate pass-through and in the same time amplifies nominal and real exchange rate volatility.

inal exchange rate, thereby implying that pass-through is complete for those prices and that, consequently, empirical estimates of pass-through for Canada are likely to be biased upward.

In this paper, we use a structural general-equilibrium approach to test the premise that exchange rate pass-through has declined in Canada. That is, we estimate a fully-fledged dynamic general-equilibrium model for Canada over two sub-samples, and, using impulse-response analysis, we investigate whether the implied pass-through has decreased from one sub-sample to the other. Our methodology has several advantages. First, and most importantly, it avoids the endogeneity issue described above, as it takes into account the fact that prices and the nominal exchange rate are simultaneously determined. Second, because our model is structural, the analysis can be made conditional on the shocks. Third, our general-equilibrium perspective allows us to estimate the degree of pass-through to import prices without using data on import prices: the structural parameters that affect the behaviour of import prices can be identified indirectly, via the interaction of those prices with remaining economic variables.

The two sub-samples considered in this study correspond to the episodes before and after the adoption by the Bank of Canada of an inflation-targeting regime. This choice is motivated by the so-called Taylor hypothesis (Taylor 2000), which attributes the observed decline in exchange rate pass-through in industrialized countries to the shift by those countries towards a low-inflation environment, mainly through the adoption of inflation targeting. Hence, as a by-product, this paper will assess whether or not this hypothesis is valid.

The model developed in this paper belongs to the new open-economy macroeconomic literature.[3] It embeds monopolistic competition and price stickiness into a dynamic general–equilibrium setting. As in Ireland (2003), monetary policy is described by a general interest-rate rule that nests two particular cases. The first case corresponds to a purely exogenous money-supply process. In the second case, the monetary authority varies the nominal interest rate in response to movements in inflation, output, and money growth. These two regimes describe reasonably well the conduct of monetary policy in Canada before and after the adoption of inflation targeting.[4] The model parameters are estimated by the maximum-

[3]See Bowman and Doyle (2003) for a recent survey of this literature.

[4]It is important to emphasize that the model setup is not specific to the Canadian case. The main features of the model, including the mechanisms that give rise to incomplete pass-through, are fairly standard in the new open-economy macroeconomic literature. As for the change in the conduct of monetary policy, this is also not specific to Canada. Since 1990, several countries have officially adopted inflation targeting (e.g.,

likelihood method using Canadian data on the real exchange rate, the nominal interest rate, inflation, consumption and output.

Our analysis distinguishes between import and consumer prices and between conditional and aggregate exchange rate pass-through. Conditional pass-through is computed as the ratio of the impulse responses of the price level and the nominal exchange rate to a given shock. Aggregate pass-through, on the other hand, is expressed as weighted sum of conditional pass-through coefficients, where the weights reflect the relative contribution of the different shocks in explaining nominal exchange rate variability. Because both measures are conditional on the horizon, the model can be used to study exchange rate pass-through both in the short and long run.

Our results indicate that conditional pass-through to Canadian import prices is essentially unchanged across the two sub-samples, regardless of the underlying shock. In contrast, there is a significant decline in pass-through to consumer prices conditional on technology and, to a lesser extent, foreign output shocks. On aggregate, we find that exchange rate pass-through has remained fairly stable at the import-price level, but that it has declined at the consumer price level from about 12 per cent to roughly zero in the short run. We also perform counterfactual experiments to investigate which factors might have contributed to this decline in pass-through to consumer prices. We focus on three potential factors that have been identified in the earlier literature: the persistence of the shocks, the degree of price rigidity, and the monetary policy regime. Our results show that the shift by the Bank of Canada towards an inflation-targeting regime is largely responsible for the lower degree of pass-through to consumer prices, thus lending support to the Taylor hypothesis.

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 describes the estimation methodology and discusses the results. Section 4 performs counterfactual experiments. Section 5 concludes.

2. The Model

The model is one of a small open economy similar to those developed by Kollmann (2001), Bergin (2003), and Ambler, Dib, and Rebei (2003). The economy has a final-good sector

New Zealand, the United Kingdom, Sweden, Australia, Israel, the Czech Republic, Poland, Brazil, Chile, Israel, and more recently the members of the European Central Bank). Many other countries are widely believed to have implicitly adopted an inflation-targeting regime without formally announcing it. Therefore, our approach to test for a potential decline in pass-through and for the extent to which it is related to monetary policy can be applied to other small open economies that experienced a shift in the conduct of monetary policy.

and an intermediate-good sector. The final good, which serves consumption and investment purposes, is produced by perfectly competitive firms that use domestic and foreign intermediate goods as inputs. There is a continuum of differentiated domestic intermediate goods indexed by $i \in [0,1]$. They are produced by monopolistically competitive firms that use domestic labour and capital as inputs. Domestic intermediate goods are also exported to the rest of the world. Export prices are denominated in foreign currency. Foreign intermediate goods are imported by monopolistically competitive importers at the world price. These goods are then sold to final-good producers at domestic-currency prices. Prices set by monopolistic firms are costly to change, and are thus sticky. Price stickiness in import and export prices causes the law of one price to fail, and leads to movements in the real exchange rate. It also implies that exchange rate pass-through is incomplete in the short run.

Throughout this paper, variables that originate in the rest of the world are denoted by an asterisk, and variables that do not have a time subscript refer to steady-state values.

2.1 Households

The representative household maximizes its lifetime utility given by

$$U_0 = E_0 \sum_{t=0}^{\infty} \beta^t u\left(c_t, m_t, h_t\right), \tag{1}$$

where β is the subjective discount factor ($0 < \beta < 1$), u is the instantaneous utility function, c_t is consumption, m_t denotes real money balances held at the end of period t, and h_t denotes hours worked by the household.[5] The instantaneous utility function is assumed to be

$$u(\cdot) = \frac{\gamma}{\gamma-1} \log\left(c_t^{\frac{\gamma-1}{\gamma}} + \chi_t^{\frac{1}{\gamma}} m_t^{\frac{\gamma-1}{\gamma}}\right) + \eta \log\left(1-h_t\right), \tag{2}$$

where $m_t = M_t/P_t$, with M_t being the nominal money stock and P_t the price of the final good; γ and η are positive parameters. The term χ_t is a shock to money demand. It follows the first-order autoregressive process given by

$$\log(\chi_t) = (1-\rho_\chi)\log(\chi) + \rho_\chi \log(\chi_{t-1}) + \epsilon_{\chi t}, \tag{3}$$

where ρ_χ is strictly bounded between -1 and 1, and the innovation $\epsilon_{\chi t}$ is a normally distributed, serially uncorrelated shock with zero mean and standard deviation σ_χ.

[5]In each period, the household's total endowment of time is normalized to unity.

The representative household enters period t with M_{t-1} units of domestic money, B^*_{t-1} foreign-currency non-state-contingent bonds, and a stock of capital, k_t. In period t, the household receives a lump-sum transfer, T_t, from the government and dividends, D_t, from monopolistic firms. It also receives total factor payments of $W_t h_t + Q_t k_t$ from selling labour and renting capital to domestic intermediate-good producers, where W_t and Q_t denote the nominal wage and rental rates, respectively. The household's income in period t is allocated to consumption, investment, money holdings, and the purchase of nominal bonds. Buying foreign bonds entails paying a risk premium, κ_t, which implies departures from uncovered interest parity. For convenience, we assume that the risk premium depends on the ratio of net foreign assets to domestic output[6]

$$\log(\kappa_t) = \omega \left[\exp\left(\frac{e_t B^*_t}{P_t y_t} \right) - 1 \right], \tag{4}$$

where ω is a positive parameter and e_t is the nominal exchange rate defined as the number of units of domestic currency needed to purchase one unit of foreign currency. The variables P_t and y_t will be formally defined in section 2.2. Investment, i_t, increases the household's stock of capital according to

$$k_{t+1} = (1 - \delta) k_t + i_t, \tag{5}$$

where $\delta \in (0, 1)$ is the depreciation rate of capital. Investment is subject to quadratic adjustment costs

$$\frac{\psi_k}{2} \left(\frac{i_t}{k_t} - \delta \right)^2 k_t$$

where $\psi_k \geq 0$. The household's budget constraint is given by:

$$\begin{aligned} & P_t(c_t + i_t) + M_t + \frac{e_t B^*_t}{\kappa_t R^*_t} \\ & \qquad \leq W_t h_t + Q_t k_t + M_{t-1} + e_t B^*_{t-1} + D_t + T_t - \frac{\psi_k}{2} \left(\frac{i_t}{k_t} - \delta \right)^2 P_t k_t, \end{aligned} \tag{6}$$

where $D_t \equiv D^d_t + D^m_t$, with D^d_t being dividends received from domestic intermediate-good producers and D^m_t those received from importers of foreign intermediate goods. R^*_t denotes the gross nominal world interest rate, which evolves according to the following stochastic process:

$$\log(R^*_t) = (1 - \rho_{R^*}) \log(R^*) + \rho_{R^*} \log(R^*_{t-1}) + \epsilon_{R^* t}, \tag{7}$$

[6] Without risk premium, the model would have a unit root because the bond holdings process would follow a random walk. The risk premium also ensures that the model has a unique steady state.

where ρ_{R^*} is strictly bounded between -1 and 1 and the innovation ϵ_{R^*t} is a normally distributed, serially uncorrelated shock with zero mean and standard deviation σ_{R^*}.

The representative household chooses c_t, h_t, M_t, B_t^*, and k_{t+1} to maximize its lifetime utility subject to its budget constraint (6), the capital accumulation equation (5), the definition of the risk premium (4), and a no-ponzi-game condition on its holdings of assets. The household's first-order conditions are

$$\lambda_t = c_t^{-\frac{1}{\gamma}} \left(c_t^{\frac{\gamma-1}{\gamma}} + \chi_t^{\frac{1}{\gamma}} m_t^{\frac{\gamma-1}{\gamma}} \right)^{-1}, \tag{8}$$

$$w_t = \frac{\eta (1-h_t)^{-1}}{\lambda_t}, \tag{9}$$

$$\lambda_t = \beta E_t \left(\frac{\lambda_{t+1}}{\pi_{t+1}} \right) + \chi_t^{\frac{1}{\gamma}} m_t^{-\frac{1}{\gamma}} \left(c_t^{\frac{\gamma-1}{\gamma}} + \chi_t^{\frac{1}{\gamma}} m_t^{\frac{\gamma-1}{\gamma}} \right)^{-1}, \tag{10}$$

$$\lambda_t = \beta \kappa_t R_t^* E_t \left(\frac{\lambda_{t+1}}{\pi_{t+1}} \frac{e_{t+1}}{e_t} \right), \tag{11}$$

$$\lambda_t = \frac{\beta E_t \{ \lambda_{t+1} [1 + q_{t+1} - \delta + \psi(\frac{i_{t+1}}{k_{t+1}} - \delta) + \frac{\psi}{2}(\frac{i_{t+1}}{k_{t+1}} - \delta)^2] \}}{1 + \psi(\frac{i_t}{k_t} - \delta)}, \tag{12}$$

where λ_t is the Lagrange multiplier associated with the budget constraint expressed in real terms; $w_t \equiv W_t/P_t$ is the real wage; $q_t \equiv Q_t/P_t$ is the real rental rate; and $\pi_t \equiv P_t/P_{t-1}$ is the gross inflation rate between $t-1$ and t.

2.2 Firms

2.2.1 Final-good producers

Firms in the final-good sector are perfectly competitive. They combine domestic and imported intermediate goods to produce a single homogenous good using the following constant elasticity of substitution (CES) technology:

$$y_t = \left[\phi^{\frac{1}{\nu}} (y_t^d)^{\frac{\nu-1}{\nu}} + (1-\phi)^{\frac{1}{\nu}} (y_t^m)^{\frac{\nu-1}{\nu}} \right]^{\frac{\nu}{\nu-1}}, \tag{13}$$

where $y_t^d \equiv \left(\int_0^1 y_t^d(i)^{(\theta-1)/\theta} di \right)^{\theta/(\theta-1)}$ and $y_t^m \equiv \left(\int_0^1 y_t^m(i)^{(\vartheta-1)/\vartheta} di \right)^{\vartheta/(\vartheta-1)}$ are composite indexes of domestic and imported intermediate goods, respectively; θ (ϑ) > 1 is the elasticity of substitution between domestic (foreign) intermediate goods; $\phi > 0$ is the weight of the domestic composite good; and $\nu > 0$ is the elasticity of substitution between domestic and imported intermediate goods. Define $P_t^d \equiv \left(\int_0^1 P_t^d(i)^{1-\theta} di \right)^{1/(1-\theta)}$ and $P_t^m \equiv \left(\int_0^1 P_t^m(i)^{1-\vartheta} di \right)^{1/(1-\vartheta)}$ as the price indexes associated with the aggregators

y_t^d and y_t^m. Then, demands for individual domestic and imported intermediate goods are, respectively, given by

$$y_t^d(i) = \left(\frac{P_t^d(i)}{P_t^d}\right)^{-\theta} y_t^d, \qquad i \in (0,1),$$

and

$$y_t^m(i) = \left(\frac{P_t^m(i)}{P_t^m}\right)^{-\vartheta} y_t^m, \qquad i \in (0,1). \tag{14}$$

The representative final-good producer solves

$$\max_{\{y_t^d, y_t^m\}} P_t y_t - P_t^d y_t^d - P_t^m y_t^m, \tag{15}$$

where y_t is given by (13). Profit maximization implies

$$y_t^d = \phi \left(\frac{P_t^d}{P_t}\right)^{-\nu} y_t, \tag{16}$$

and

$$y_t^m = (1-\phi)\left(\frac{P_t^m}{P_t}\right)^{-\nu} y_t. \tag{17}$$

The zero-profit condition implies that the price of the final good, P_t, is given by

$$P_t = \left[\phi (P_t^d)^{1-\nu} + (1-\phi)\,(P_t^m)^{1-\nu}\right]^{\frac{1}{1-\nu}}. \tag{18}$$

2.2.2 Domestic intermediate-good producers

Domestic intermediate-good producers have identical Cobb-Douglas production functions given by

$$z_t(i) \equiv y_t^d(i) + y_t^x(i) = A_t k_t(i)^{\alpha} h_t(i)^{1-\alpha}, \tag{19}$$

where $\alpha \in (0,1)$; $k_t(i)$ and $h_t(i)$ are capital and labour inputs used by firm i; and A_t is an aggregate technology shock that follows the stochastic process

$$\log(A_t) = (1-\rho_A)\log(A) + \rho_A \log(A_{t-1}) + \epsilon_{At}, \tag{20}$$

where ρ_A is strictly bounded between -1 and 1 and the innovation ϵ_{At} is a normally distributed, serially uncorrelated shock with zero mean and standard deviation σ_A.

Domestic intermediate-good producers are monopolistically competitive, and are thus price setters. They segment markets by setting different prices for different destinations.

That is, firm i chooses a domestic-currency price $P_t^d(i)$ for its sales in the domestic market and a foreign-currency price $P_t^x(i)$ for its exports. Changing prices entails quadratic adjustment à la Rotemberg (1982):[7]

$$\frac{\psi_j}{2}\left(\frac{P_t^j(i)}{\pi^j P_{t-1}^j(i)}-1\right)^2,$$

where $j = d, x$; $\psi_j \geq 0$; and π^j is the steady-state value of $\pi_t^j \equiv P_t^j/P_{t-1}^j$. Firm i solves the following dynamic problem:

$$\max_{\{h_t(i),k_t(i),P_t^d(i),P_t^x(i)\}} E_t \sum_{s=0}^{\infty} \beta^s \left(\frac{\lambda_{t+s}}{\lambda_t}\right) \frac{D_{t+s}^d(i)}{P_{t+s}}, \tag{21}$$

where

$$\begin{aligned} D_t^d(i) \equiv\ & P_t^d(i)y_t^d(i) + e_t P_t^x(i) y_t^x(i) - W_t h_t(i) - Q_t k_t(i) \\ & -\frac{\psi_d}{2}\left(\frac{P_t^d(i)}{\pi^d P_{t-1}^d(i)}-1\right)^2 P_t^d(i)y_t^d(i) - \frac{\psi_x}{2}\left(\frac{P_t^x(i)}{\pi^x P_{t-1}^x(i)}-1\right)^2 e_t P_t^x(i) y_t^x(i). \end{aligned}$$

It is assumed that the world demand for the domestic intermediate good i is analogous to the domestic demand for that good. That is,

$$y_t^x(i) = \left(\frac{P_t^x(i)}{P_t^x}\right)^{-\theta} y_t^x, \qquad i \in (0,1), \tag{22}$$

where $P_t^x \equiv \left(\int_0^1 P_t^x(i)^{1-\theta} di\right)^{1/(1-\theta)}$, and y_t^x is an aggregate of exported intermediate goods that represents a fraction φ of world demand

$$y_t^x = \varphi \left(\frac{P_t^x}{P_t^*}\right)^{-1} y_t^*. \tag{23}$$

In this equation, P_t^* is the world price and y_t^* is the overall world output, which evolves according to the following stochastic process:

$$\log y_t^* = (1-\rho_{y^*}) \log(y^*) + \rho_{y^*} \log(y_{t-1}^*) + \epsilon_{y^*t}, \tag{24}$$

where ρ_{y^*} is strictly bounded between -1 and 1 and the innovation ϵ_{y^*t} is a normally distributed, serially uncorrelated shock with zero mean and standard deviation σ_{y^*}.

[7] As is well known, the pricing behaviour under the assumption of costly price adjustment is observationally equivalent to that resulting from a Calvo-type price setting (Calvo 1983), where firms are randomly selected to change their prices with a constant probability.

Given the demand functions (16) and (22), the first-order conditions for firm i are

$$w_t = (1-\alpha)\xi_t(i)\frac{z_t(i)}{h_t(i)}, \tag{25}$$

$$q_t = \alpha\xi_t(i)\frac{z_t(i)}{k_t(i)}, \tag{26}$$

$$\begin{aligned} -\theta\frac{\xi_t(i)}{p_t^d(i)} &= (1-\theta)\left[1-\frac{\psi_d}{2}\left(\frac{\pi_t^d(i)}{\pi^d}-1\right)^2\right] \\ &- \psi_d\left[\frac{\pi_t^d(i)}{\pi^d}\left(\frac{\pi_t^d(i)}{\pi^d}-1\right)-\beta E_t\frac{\lambda_{t+1}}{\lambda_t}\frac{\left(\pi_{t+1}^d(i)\right)^2}{\pi_{t+1}\pi^d}\left(\frac{\pi_t^d(i)}{\pi^d}-1\right)\frac{y_{t+1}^d(i)}{y_t^d(i)}\right], \end{aligned} \tag{27}$$

$$\begin{aligned} -\theta\frac{\xi_t(i)}{p_t^x(i)}\frac{1}{s_t} &= (1-\theta)\left[1-\frac{\psi_x}{2}\left(\frac{\pi_t^x(i)}{\pi^x}-1\right)^2\right] \\ &- \psi_d\left[\frac{\pi_t^x(i)}{\pi^x}\left(\frac{\pi_t^x(i)}{\pi^x}-1\right)-\beta E_t\frac{\lambda_{t+1}}{\lambda_t}\frac{s_{t+1}}{s_t}\frac{\left(\pi_{t+1}^x(i)\right)^2}{\pi_{t+1}^*\pi^x}\left(\frac{\pi_t^x(i)}{\pi^x}-1\right)\frac{y_{t+1}^x(i)}{y_t^x(i)}\right], \end{aligned} \tag{28}$$

where $\xi_t(i)$ is the Lagrange multiplier associated with equation (19) and is equal to the real marginal cost of firm i; $p_t^d(i) \equiv P_t^d(i)/P_t$; $p_t^x(i) \equiv P_t^x(i)/P_t^*$, $\pi_t^d(i) \equiv P_t^d(i)/P_{t-1}^d(i)$; $\pi_t^x(i) \equiv P_t^x(i)/P_{t-1}^x(i)$; and $\pi_t^* \equiv P_t^*/P_{t-1}^*$ is the gross inflation rate in the rest of the world, which we normalize to 1.

2.2.3 Importing firms

Foreign intermediate goods are imported by monopolistically competitive firms at the world price, P_t^*. Importing firms then sell those goods in domestic currency to final-good producers. Resale prices, $P_t^m(i)$ are also subject to quadratic adjustment costs:

$$\frac{\psi_m}{2}\left(\frac{P_t^m(i)}{\pi^m P_{t-1}^m(i)}-1\right)^2,$$

where π^m is the steady-state value of $\pi_t^m \equiv P_t^m/P_{t-1}^m$. The importing firm i solves the following problem:

$$\max_{\{P_t^m(i)\}} E_t\sum_{s=0}^{\infty}\beta^s\left(\frac{\lambda_{t+s}}{\lambda_t}\right)\frac{D_{t+s}^m(i)}{P_{t+s}}, \tag{29}$$

where

$$D_t^m(i) = \left(P_t^m(i)-e_tP_t^*\right)y_t^m(i) - \frac{\psi_m}{2}\left(\frac{P_t^m(i)}{\pi^m P_{t-1}^m(i)}-1\right)^2 P_t^m(i)y_t^m(i). \tag{30}$$

The first-order condition for this problem is

$$\vartheta \frac{s_t}{p_t^m(i)} = 1 + (1-\vartheta)\frac{\psi_m}{2}\left(\frac{\pi_t^m(i)}{\pi^m} - 1\right)^2$$
$$-\psi_m \left[\frac{\pi_t^m(i)}{\pi^m}\left(\frac{\pi_t^m(i)}{\pi^m} - 1\right) - \beta E_t \frac{\lambda_{t+1}}{\lambda_t}\frac{\left(\pi_{t+1}^m(i)\right)^2}{\pi_{t+1}\pi^m}\left(\frac{\pi_t^m(i)}{\pi^m} - 1\right)\frac{y_{t+1}^m(i)}{y_t^m(i)}\right] \quad (31)$$

where $p_t^m(i) \equiv P_t^m(i)/P_t$ and $\pi_t^m(i) \equiv P_t^m(i)/P_{t-1}^m(i)$.

2.3 Monetary authority

Following Ireland (2003), we assume that the central bank manages the short-term nominal interest rate according to the following policy rule:

$$\varrho_R \log(R_t/R) = \varrho_\pi \log(\pi_t/\pi) + \varrho_\mu \log(\mu_t/\mu) + \varrho_y \log(y_t/y) + v_t, \quad (32)$$

where R_t is the gross nominal interest rate; $\mu_t \equiv M_t/M_{t-1}$ is the growth rate of nominal money between $t-1$ and t; and v_t is a serially correlated monetary policy shock that evolves according to

$$v_t = \rho_v v_{t-1} + \epsilon_{vt}, \quad (33)$$

where ρ_v is strictly bounded between -1 and 1 and the innovation ϵ_{vt} is a normally distributed, serially uncorrelated shock with zero mean and standard deviation σ_v. The interest rate rule (32) nests two polar cases: by setting $\varrho_R = 1$ and $\varrho_\mu = \varrho_y = 0$, a pure inflation targeting rule is obtained. Alternatively, when $\varrho_R = \varrho_\pi = \varrho_y = 0$ and $\varrho_\mu = -1$, equation (32) collapses to an exogenous money-supply process.

2.4 The government

The government makes lump-sum transfers to households, which are financed by printing additional money in each period. Thus, the government budget constraint is

$$T_t = M_t - M_{t-1}. \quad (34)$$

2.5 Symmetric equilibrium

In a symmetric equilibrium, all intermediate-good producers make identical decisions. That is, $z_t(i) = z_t$, $k_t(i) = k_t$, $h_t(i) = h_t$, $P_t^d(i) = P_t^d$, $P_t^x(i) = P_t^x$, and $P_t^m(i) = P_t^m$ for all $i \in (0,1)$. Hence, a symmetric equilibrium for this economy is a collection of 26 sequences (c_t, m_t, h_t, i_t, k_{t+1}, y_t, y_t^d, y_t^m, y_t^x, z_t, w_t, q_t, ξ_t, λ_t, π_t, π_t^d, π_t^m, π_t^x, R_t, μ_t, s_t, κ_t, b_t^*, p_t^d,

$p_t^m,\ p_t^x)_{t=0}^{\infty}$ satisfying the private agents' first-order conditions, the monetary policy rule, market-clearing conditions, and a balance of payments equation (the model's equations are listed in Appendix A).[8]

3. Estimation

3.1 Estimation methodology and data

To solve the model, we log-linearize its equilibrium conditions around a symmetric steady state where all variables are constant. In particular, we assume that the steady-state domestic gross inflation is equal to 1. Standard techniques are then used to solve the linearized system, which leads to the following state space representation:

$$\mathcal{S}_t = \mathbf{A}\mathcal{S}_{t-1} + \mathbf{B}\epsilon_t, \tag{35}$$

$$\mathcal{H}_t = \mathbf{C}\mathcal{S}_t, \tag{36}$$

where the vector $\mathcal{S}_t$ keeps track of the model's predetermined and exogenous variables, and the vector $\mathcal{H}_t$ includes remaining endogenous variables. We use the Kalman filter to evaluate the likelihood function associated with the state space solution. The structural parameters are estimated by maximizing the likelihood function. Since the model has only five structural shocks, it cannot be estimated using more than five observable variables.[9] The series used in the estimation are the real exchange rate, the nominal interest rate, inflation, consumption, and output.

The model is estimated using Canadian quarterly data covering the period 1973Q2 to 2006Q2. The sample is divided into two sub-samples: 1973Q2 to 1990Q4 and 1991Q1 to 2006Q2. The chosen cutoff date, 1991Q1, represents the official date on which the Bank of Canada formally adopted inflation targeting.[10] In section 5, we check the robustness of our results to alternative sample-splitting dates.

[8] The variable b_t^* denotes B_t^*/P_t^*.

[9] With more than five observable variables, the system becomes stochastically singular and the maximum-likelihood procedure fails. See Ingram, Kocherlakota and Savin (1994).

[10] We also adopted an agnostic, data-based approach to determine the cutoff date, by applying the multiple break test with unknown break dates developed by Bai and Perron (1998), to search for possible shifts in the mean of Canadian inflation. The test procedure endogenously determined that there have been two breaks in the inflation process, one occurring at 1982Q3 and the other at 1991Q1. The former date corresponds to the episode where the Bank of Canada raised interest rates substantially to reduce the high inflation of the late 1970s and early 1980s. Dividing the sample at this date, however, leaves too few observations in the pre-1982 period to obtain reliable estimates.

The series used in the estimation are constructed as follows. The real exchange rate is constructed by multiplying the nominal exchange rate, defined as the price of one U.S. dollar in terms of Canadian dollars, by the ratio of the U.S. consumer price index (CPI) to the Canadian CPI. The nominal interest rate is measured by the 3-month Treasury bill rate. The inflation rate is measured by the change in Canadian CPI. Consumption is measured by real private spending on non-durable goods and services, and output is measured by real gross domestic product (GDP). The consumption and output series are converted to per capita terms by dividing them by the civilian population age 16 and over. To maintain consistency with the theoretical model, we transform all series into percentage deviations from a linear trend.

3.2 Parameter estimates

As is typically the case with the maximum-likelihood estimation of relatively large structural models, it is difficult to obtain sensible estimates for *all* the structural parameters, either because some of them are poorly identifiable or because the mapping from the parameters to the objective function is so highly nonlinear that the optimization algorithm fails to locate the maximum and eventually crashes. To deal with this issue, some parameters need to be calibrated prior to estimation. These parameters will be held constant across the two sub-samples. The estimated parameters are ρ_A, ρ_v, ρ_χ, ρ_{R^*}, ρ_{y^*}, σ_A, σ_v, σ_χ, σ_{R^*}, σ_{y^*}, ψ_d, ψ_x, ψ_m, ϱ_π, ϱ_z, and ϱ_μ. By focusing on this subset of parameters, we are implicitly assuming that a change in the degree of exchange rate pass-through from one sub-sample to the other could arise only from a change in the properties of the shocks, the degree of price rigidity, or the conduct of monetary policy.

The remaining parameters are calibrated as follows. The subjective discount rate, β, is set to 0.99, which implies an annual real interest rate of 4 per cent in the steady state. We calibrate the steady-state world interest rate so that it matches the average U.S. short-term interest rate during the sample period. The parameter ω is chosen to match the average ratio of Canadian foreign debt to domestic absorption of 10 per cent. The weight on leisure in the utility function, η, is calibrated so that the representative household spends about one-third of its total time working in the steady state. The parameter χ is set to 0.25, to match the average ratio of consumption to real balances of 80 per cent. As is standard in the literature, the depreciation rate of physical capital, δ, and the elasticity of output with respect to capital in the intermediate-good sector, α, are chosen to be 0.025 and 0.36, respectively. The weight of the domestic composite good in the final good aggregator, ϕ, is calibrated to 0.64, the value estimated by Ambler, Dib, and Rebei (2004), which implies that imports represent 34 per cent of output in the steady state. We choose the elasticity of substitution between domestic (imported) intermediate goods, θ (ϑ), to be 6, which yields a steady-state markup of 20 per cent, as assumed by Ireland (2001, 2003) and Dib (2003).

Assigning values to the interest elasticity of money demand, γ, the elasticity of substitution between domestic and imported intermediate goods, ν, and the capital adjustment cost parameter, ψ_k, is a more delicate task, mainly because there exists a wide range of estimates in the literature for each of these parameters. We set $\gamma = 0.25$, $\nu = 1.5$, and $\psi_k = 25$. These values are well within the range of estimates reported by earlier empirical studies and/or used in international macroeconomic models. Nonetheless, in section 5, we check the robustness of our results to alternative values for these parameters.

As stated earlier, we assume that in the pre-1991 sub-sample, Canadian monetary policy followed a purely exogenous process for money growth, which implies imposing the restrictions $\varrho_\mu = -1$ and $\varrho_R = \varrho_\pi = \varrho_y = 0$. In the post-1991 period, however, we assume that the Bank of Canada conducted monetary policy by adjusting the nominal interest rate in response to deviations of inflation, output, and money growth from their respective targets. Therefore, we impose $\varrho_R = 1$, while keeping the parameters ϱ_π, ϱ_y, and ϱ_μ unconstrained in this sub-sample.

Estimation results are reported in Table 2.[11] In the pre-1991 period, all shocks, except money demand shocks, are found to be persistent. Money demand shocks and, to a lesser extent, foreign output shocks have relatively large standard deviations. The estimation procedure yields a moderate degree of price rigidity for domestic prices. Export and import prices, on the other hand, are substantially rigid. In the post-1991 period, technology, money demand, and foreign interest rate shocks became slightly more persistent but with smaller standard deviations. In contrast, the variance of the monetary policy shock significantly increased. Estimates of the price adjustment cost parameters indicate that the degree of price rigidity is lower for domestic prices and higher for import prices compared with the pre-1991 period.

[11] During estimation, the estimate of the parameter ψ_x was systematically driven to infinity in both sub-samples. Thus, we chose to constrain this parameter to be less than an arbitrarily large upper limit (the chosen upper limit, 100, implies, when converted to a frequency of price change, that export prices cannot be fixed for more than five quarters on average). Because the estimate of ψ_x hits the boundary, however, regularity conditions are not satisfied and standard errors cannot be computed. For this reason, we set $\psi_x = 100$ in both sub-samples and estimated the remaining parameters conditionally on this value. We treated the parameter ψ_m similarly in the post-1991 sub-sample.

3.3 Exchange rate pass-through

Traditionally, exchange rate pass-through is defined as the percentage variation in the domestic-currency price of imports that results from a 1 per cent change in the nominal exchange rate. A broader definition, also found in the literature, focuses on consumer prices rather than import prices. Existing empirical studies that attempt to estimate the degree of exchange rate pass-through in Canada can be criticized for their methodology and their data. Regarding the methodology, the partial-equilibrium, reduced-form approach generally adopted in these studies overlooks the joint determination of prices and the exchange rate, and takes the latter as an exogenous process. Moreover, this approach is not useful for understanding the way in which, and the extent to which, the degree of exchange rate pass-through depends on the nature of the shocks impinging on the economy. Regarding the data, since a number of import prices are constructed by multiplying the foreign-currency price by the nominal exchange rate, the estimated degree of pass-through reported by earlier studies is likely to be biased upward.

We adopt a completely different strategy to test for a potential decline in the degree of pass-through. In contrast to earlier empirical studies, where exchange rate pass-through is treated as an *unconditional* phenomenon, our analysis is made *conditional* on the structural shocks and on the horizon. More precisely, we define exchange rate pass-through to import prices at horizon j as

$$\mathcal{P}^m_{t+j} = \frac{Cov_{t-1}(\hat{P}^m_{t+j}, \hat{e}_{t+j})}{Var_{t-1}(\hat{e}_{t+j})},$$

where the circumflex denotes percentage deviation from steady state. A analogous expression is used to define exchange rate pass-through to consumer prices. This model-consistent aggregate measure of pass-through can be decomposed into sub-measures that are conditional on the structural shocks. To see this, notice that the variables $\hat{P}^m$ and $\hat{e}$ can be expressed as follows:

$$\hat{P}^m_{t+j} = \kappa^{j+1}\mathcal{S}_{t-1} + \sum_i \sum_{\tau=0}^{j} \varpi_{\tau i}\epsilon_{i,t+j-\tau},$$

and

$$\hat{e}_{t+j} = \zeta^{j+1}\mathcal{S}_{t-1} + \sum_i \sum_{\tau=0}^{j} \varkappa_{\tau i}\epsilon_{i,t+j-\tau},$$

where κ^{j+1} and ζ^{j+1} are row vectors with as many columns as the number of state variables; $\varpi_{\tau i}$ and $\varkappa_{\tau i}$ are scalars; and i is a subscript that runs across the structural shocks. Aggregate pass-through to import prices at horizon j is then given by

$$\begin{aligned}
\mathcal{P}_{t+j}^m &= \frac{\sum_i \sum_{\tau=0}^j \varpi_{\tau i} \varkappa_{\tau i} \sigma_i^2}{\sum_i \sum_{\tau=0}^j \varkappa_{\tau i}^2 \sigma_i^2} \\
&= \sum_i \frac{\sum_{\tau=0}^j \varpi_{\tau i} \varkappa_{\tau i} \sigma_i^2}{\sum_i \sum_{\tau=0}^j \varkappa_{\tau i}^2 \sigma_i^2} \\
&= \sum_i \sum_{\tau=0}^j \frac{\varpi_{\tau i} \varkappa_{\tau i} \sigma_i^2}{\sum_i \sum_{\tau=0}^j \varkappa_{\tau i}^2 \sigma_i^2} \\
&= \sum_i \sum_{\tau=0}^j \frac{\varpi_{\tau i}}{\varkappa_{\tau i}} \frac{\varkappa_{\tau i}^2 \sigma_i^2}{\sum_i \sum_{\tau=0}^j \varkappa_{\tau i}^2 \sigma_i^2}. \qquad (37)
\end{aligned}$$

In this expression, the term $\frac{\varpi_{\tau i}}{\varkappa_{\tau i}}$ is the ratio of the impulse response function of $\hat{P}^m$ to that of $\hat{e}$ at horizon τ following shock i (note that the disturbances ϵ_i are serially uncorrelated). Because this measure is conditional on a particular shock, we refer to it as conditional pass-through. To gain some intuition about the relationship between the aggregate and the conditional measures of pass-through, it is useful to focus on what happens at time t. In this case, the expression in (37) collapses to $\mathcal{P}_t^m = \sum_i \frac{\varpi_{0i}}{\varkappa_{0i}} \frac{\varkappa_{\tau i}^2 \sigma_i^2}{\sum_i \varkappa_{\tau i}^2 \sigma_i^2}$. That is, aggregate pass-through to import prices at time t is equal to the sum of conditional pass-through coefficients ($\frac{\varpi_{0i}}{\varkappa_{0i}}$) weighted by the contribution of each shock to the (conditional) variance of the exchange rate at time t.[12] Therefore, in principle, a change in aggregate pass-through could result either from a different degree of conditional pass-through or from a change in the relative importance of shocks in explaining exchange-rate movements (or from both).

The left column of Figure 1 depicts exchange rate pass-through to import prices before and after 1991Q1. The upper five panels show exchange rate pass-through conditional on each of the structural shocks, while the bottom panel shows aggregate pass-through, constructed according to (37). In both sub-samples, conditional pass-through ranges between 10 and 30 per cent on impact and converges to its long-run level from below, regardless of the nature of the shock.[13] None of the five panels shows a significant difference in the

[12] Note that the weights in the expression of $\mathcal{P}_t^m$ add up to 1, so that aggregate pass-through is a weighted *average* of conditional pass-through coefficients. For subsequent periods, however, aggregate pass-through can be expressed as: $\mathcal{P}_{t+j}^m = \mathcal{P}_{t+j-1}^m + \sum_i \frac{\varpi_{ji}}{\varkappa_{ji}} \frac{\varkappa_{ji}^2 \sigma_i^2}{\sum_i \sum_{\tau=0}^j \varkappa_{\tau i}^2 \sigma_i^2}$. As can be readily seen, the weights in the summation do not add up to 1. In fact, these weights tend towards 0 as the horizon approaches infinity. Consequently, the second sum in the expression above cannot be viewed as a weighted average of conditional pass-through coefficients.

[13] In the pre-1991 period, the response of the nominal exchange rate to a money demand shock changes sign at around six quarters after the shock, thus implying that exchange rate pass-through is infinite at that horizon. For ease of illustration, the plot of exchange rate pass-through in the case of a money demand shock is truncated around that horizon. A similar treatment is applied to pass-through conditional on a foreign interest rate shock in the two sub-periods.

behaviour of conditional pass-through across the two sub-periods, especially in the short run (less than one year). Only in the case of a money demand shock, do we observe a decline in exchange rate pass-through in the post-1991 period, which, however, becomes apparent only several quarters after the shock. The bottom left panel of Figure 1 shows that, at the aggregate level, exchange rate pass-through decreased from 15 to 13 per cent on impact, and from 70 to 64 per cent after 20 quarters. Therefore, there is only a minor change in aggregate pass-through to import prices before and after 1991.

Exchange pass-through to consumer prices is shown in the right column of Figure 1. The top panel shows that conditional pass-through is much lower in the post-1991 when the underlying disturbance is a technology shock. This is also true, albeit to a lesser extent, in the case of a foreign output shock. In contrast, there is a slight increase in pass-through conditional on a monetary policy shock. For the remaining shocks, the results are very similar to those obtained for import prices: there is almost no difference in conditional pass-through before and after 1991, especially in the short run.

At the aggregate level, exchange rate pass-through to consumer prices decreased by roughly 12 percentage points in the short run, reaching zero (on impact) in the post-1991 episode. This result is consistent with earlier findings by Kichian (2001) who estimates a backward-looking Phillips curve with time-varying coefficients, and finds that pass-through to Canadian CPI inflation has dropped from an average value of 20 per cent to essentially zero after the mid-1980s. The bottom right panel of Figure 1 shows that the decline in aggregate pass-through to consumer prices exceeds 21 percentage points after 20 quarters.

In sum, this discussion suggests there has been a significant decline in exchange rate pass-through to Canadian consumer prices in Canada, but that at the import-price level, pass-through has been rather stable.

4. Counterfactual Experiments

The purpose of this section is to investigate which factors might have caused the decline in exchange rate pass-through to Canadian consumer prices. We focus on three potential factors, which have been identified in the literature (see, for example, Devereux and Yetman 2002): the persistence of the shocks, the degree of price rigidity, and the monetary policy regime. The analysis is based on counterfactual experiments that consist in comparing the degree of pass-through across the two sub-samples by varying one factor at a time, while keeping everything else constant. The results are illustrated in Figure 2. Although, in this section, we are primarily interested in pass-through to consumer prices, the figure also shows the results for import prices.

4.1 Persistence of the shocks

In the first experiment, we seek to determine the degree to which exchange rate pass-through to consumer prices would have decreased if the persistence of the shocks had changed across the two sub-samples but everything else remained constant. In particular, we assume that, in the post-1991 period, the monetary authority chose the growth rate of money supply exactly as it did in the pre-1991 period.

In principle, the persistence of the shocks has two distinct effects. On the one hand, it affects the magnitude and the persistence of the price and nominal exchange rate responses. On the other hand, it changes the *relative* size of these two responses. The direction in which conditional pass-through is affected, however, is ambiguous and depends, in a complex way, on many features, including the nature of the shock, the horizon, and the monetary policy regime.

Table 2 shows that technology, money demand, and foreign interest rate shocks became slightly more persistent after 1991 than before that time. On the other hand, there is almost no change in the persistence of monetary policy shocks and a slight decrease in the persistence of foreign output shocks. The upper right panel of Figure 2 shows that exchange rate pass-through conditional on a technology shock decreased very little in the short run as a result of the increase in the persistence of this shock. Pass-through conditional on the four remaining shocks, however, remained virtually unchanged at all horizons. These observations preclude the persistence of the shocks as a potential explanation for the decline in exchange rate pass-through to Canadian consumer prices.

4.2 Price rigidity

In the second experiment, we vary the degree of price rigidity while keeping the persistence of the shocks and the monetary policy rule unchanged. As is well known from the literature on exchange rate determination, the higher the degree of price stickiness, the stronger the nominal exchange rate response to a nominal shock relative to that of the price level. This, in turn, should translate into a lower degree of pass-through in the short run. In general, a similar result holds in the case of real shocks.

As stated earlier, our estimation results indicate that domestic prices became less rigid and import prices more rigid in the post-1991 period. In relative terms, however, the fall in the rigidity of domestic prices is more important than the rise in the rigidity of import prices. Because domestic prices receive a larger weight (than import prices) in the consumption-based price index, one can conclude that consumer prices became less rigid after 1991. As a result, there is an increase in pass-through to consumer prices in the short run, as shown in the right panels of Figure 2. This indicates that price rigidity is not responsible for the observed decline in pass-through to consumer prices in Canada.

4.3 Monetary policy regime

In the final experiment, we investigate the Taylor hypothesis to determine if, and to what extent, the transition of the Canadian economy towards a low-inflation environment, facilitated by the adoption of an inflation-targeting regime, has reduced the degree of exchange rate pass-through to consumer prices, ceteris paribus.[14] For this purpose, we compare the degree of exchange rate pass-through under an exogenous money-supply rule and under inflation targeting.[15] The former regime is obtained by setting $\varrho_\mu = -1$ and $\varrho_R = \varrho_\pi = \varrho_y = 0$, and the latter by setting $\varrho_R = 1$. The remaining parameters are set to their pre-1991 estimates and kept unchanged across the two sub-samples. Thus, the experiment constitutes an appropriate way of assessing whether the change in monetary policy *alone* is responsible for the decline in pass-through to consumer prices.

Figure 2 shows that the shift from an exogenous money-supply process to an inflation-targeting regime largely accounts for the different patterns of exchange rate pass-through to consumer prices before and after 1991. In particular, it explains the important decline in pass-through to consumer prices conditional on technology and foreign output shocks. It is also responsible for the slight increase in pass-through generated by a monetary policy shock. In the case of money demand and foreign interest rate shocks, the change in monetary policy regime does not affect pass-through in the short run, which mirrors the results depicted in Figure 1.

Overall, our results corroborate earlier findings by Choudhri and Hakura (2001), Devereux and Yetman (2002), Gagnon and Ihrig (2004), and Bailliu and Fujii (2004) who find

[14]Taylor (2000) was the first to formally articulate the hypothesis that the low-inflation environment in many industrialized countries has reduced the degree of pass-through to domestic prices. He argued that exchange rate pass-through is primarily a function of the persistence of exchange rate and price shocks, which tend to be reduced in an environment where inflation is low and monetary policy is more credible.

[15]Strictly speaking, the monetary policy regime in the post-1991 period is one in which the monetary authority targets not only inflation but also output and the growth rate of money supply, as suggested by our estimates of ϱ_π, ϱ_y, and ϱ_μ.

strong evidence that exchange rate pass-through tends to be relatively lower in economies with a credible monetary policy and, therefore, stable inflation.

5. Robustness Analysis

This section studies the robustness of the results to a number of perturbations related to the calibrated parameters, the sample-splitting date, and the test of the Taylor hypothesis.

5.1 Alternative calibration

As stated above, some parameters were fixed prior to estimation. Thus, all our empirical results are conditional on the chosen values for these parameters. In what follows, we check the robustness of our findings to alternative values of the interest elasticity of money demand, γ, the elasticity of substitution between domestic and imported goods, ν, and the capital adjustment cost parameter, ψ_k. We reestimate the model by changing one parameter at a time. Compared with our benchmark calibration, we consider a more elastic money demand ($\gamma = 0.35$), a greater degree of substitutability between domestic and foreign intermediate goods ($\nu = 2$), and larger capital adjustment costs ($\psi_k = 100$). Estimation results are reported in columns a through f of Table 3, while the implied measures of pass-through are shown in Figures 3, 4, and 5, respectively.

In all three cases, the estimated values of the parameters are very similar to those reported in Table 2, with the exception of the policy rule parameters ϱ_π, ϱ_y and ϱ_μ, for which we obtain lower estimates (especially for the case where $\gamma = 0.35$). As in the benchmark case, domestic prices became less rigid and import prices more rigid in the post-1991 period. Figures 3, 4, and 5 show very similar patterns of exchange rate pass-through to those depicted in Figure 1. In all three cases, conditional pass-through to import prices remained stable in the short run, regardless of the underlying shock. In contrast, there is a decline in pass-through to consumer prices, conditional on technology and foreign output shocks. On aggregate, pass-through to import prices is roughly the same before and after 1991, whereas pass-through to consumer prices declined after 1991 in all three scenarios.

5.2 Alternative break dates

Although it is widely agreed that the major structural break in Canadian inflation coincided with the adoption of inflation targeting by the Bank of Canada, there is no strong reason to believe that exchange rate pass-through should have changed exactly at the time of the switch. For example, if the new policy were fully anticipated, then it is likely that the private sector's behaviour (and therefore exchange rate pass-through) would change before the official date. Alternatively, if the announced policy were not perfectly credible, the private sector's reaction would come with a lag. To take these two possibilities into account, we consider two alternative break dates: 1990Q3 and 1991Q3.

Columns g through j report estimation results for these two cases. Again, the parameter estimates are very close to those obtained using 1991Q1 as the cutoff date (see Table 2). Figures 6 and 7 show exchange rate pass-through to import and consumer prices before and after each of the alternative sample-splitting dates. These two figures closely resemble Figure 1, showing, in essence, that there is a decline in pass-through to consumer prices, driven by technology and foreign output shocks, but that at the import-price level, pass-through is largely unchanged, at least in the short run.[16]

5.3 Test of the Taylor hypothesis

To test the Taylor hypothesis, we conducted, in section 4.3, a counterfactual exercise where we assumed that monetary policy followed an exogenous money growth process in the pre-1991 period, and a Taylor-type rule in the post-1991 period. In order to check whether the results depend on the *à priori* choice of the monetary policy regime before 1991, we reestimate the model assuming the same Taylor-type monetary policy rule in both subsamples.[17] Estimation results for this case are reported in columns k and l of Table 3.[18] For most parameters, the pre-1991 estimates are similar to those obtained under exogenous money supply (Table 2). The only two exceptions are the autocorrelation coefficient of the money demand shock, ρ_χ, which becomes larger, and the price adjustment cost parameter ψ_d, which becomes smaller under the Taylor-type rule. The estimates of the parameters ϱ_π, ϱ_y, and ϱ_μ indicate that monetary policy was much less aggressive in the pre-1991 period than in the post-1991 period.

Using the new estimates for the pre-1991 period, we repeat the counterfactual experi-

[16] As an additional check, we also divided the sample at 1988Q2, the date on which the then Governor John Crow delivered the Hanson Lecture (18 June 1988), which has been interpreted by many as a strong signal that Canadian monetary policy was moving towards an inflation-targeting regime. The main results were robust to this alternative sample-splitting date. To conserve space, these results are not reported, but are available upon request.

[17] The Taylor-type rule is obtained by setting $\varrho_R = 1$. Therefore, it does not nest the case with exogenous money growth.

[18] Column l simply reproduces the results from Table 2 for the post-1991 period.

ments described in Section 4.[19] The results, shown in Figure 8, indicate that the change in the conduct of monetary policy is clearly the main factor responsible for the decline in pass-through to consumer prices conditional on technology and foreign output shocks, although, in the former case, the decrease is less pronounced than in the upper right panel of Figure 2. These results are again supportive of the Taylor hypothesis.

To summarize, our assessment of the evolution of exchange rate pass-through and the factors that account for it appears to be robust to alternative values of the calibrated parameters, to the choice of the sample-splitting date, and to the use of the same monetary policy rule in both sub-samples.

6. Conclusion

This paper has investigated the conventional view that exchange rate pass-through has recently declined in Canada. Whereas most previous empirical research on pass-through has been carried out within reduced-form settings, our approach is based on a structural general-equilibrium model. This allows us to take into account the endogeneity of the exchange rate, to treat pass-through as a conditional phenomenon, and to avoid the mismeasurement of a number of Canadian import prices. Our results suggest that, by and large, exchange rate pass-through has been stable in Canada at the import price level, but that it has declined in recent years at the consumer price level. Moreover, we find that this decline is largely attributed to the shift of Canadian monetary policy towards an inflation-targeting regime.

Of the several ways in which our analysis can be extended, two in particular seem most natural. First, unlike the current setup where the choice of currency of denomination is exogenous, one could allow this decision to be endogenous, as in Devereux, Engel, and Storgaard (2003). In their model, the extent of local currency pricing reduces the degree of pass-through and magnifies exchange rate volatility. But high exchange rate volatility reduces the incentive for firms to follow local currency pricing (as opposed to producer currency pricing), which in turn increases the degree of pass-through. Thus, in such a framework, not only are pass-through and the exchange jointly determined, they also interact with one another.

Second, one could allow the number of traded varieties to change endogenously over

[19]Results regarding conditional and aggregate pass-through to import and consumer prices are very similar to those shown in Figure 1. In particular, on impact, aggregate pass-through falls from 17 to 15 per cent at the import-price level, and from 12 per cent to zero at the consumer-price level.

time. By abstracting from the issue of endogenous tradability, our model implicitly assumes that there are no changes in the composition of import or consumption bundles over time. For this reason, our model would not be able to detect a decline in pass-through that resulted from a shift in the composition of imports towards sectors that have lower degrees of exchange rate pass-through.

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Appendix A

The model's equations are:

$$
\begin{aligned}
\lambda_t &= c_t^{-\frac{1}{\gamma}}\left(c_t^{\frac{\gamma-1}{\gamma}}+\chi_t^{\frac{1}{\gamma}}m_t^{\frac{\gamma-1}{\gamma}}\right)^{-1}, \\
w_t &= \frac{\eta\,(1-h_t)^{-1}}{\lambda_t}, \\
\lambda_t &= \beta E_t\left(\frac{\lambda_{t+1}}{\pi_{t+1}}\right)+\chi_t^{\frac{1}{\gamma}}m_t^{-\frac{1}{\gamma}}\left(c_t^{\frac{\gamma-1}{\gamma}}+\chi_t^{\frac{1}{\gamma}}m_t^{\frac{\gamma-1}{\gamma}}\right)^{-1}, \\
\lambda_t &= \beta\kappa_t R_t^* E_t\left(\frac{\lambda_{t+1}}{\pi_{t+1}}\frac{s_{t+1}}{s_t}\right), \\
\lambda_t &= \beta R_t E_t\left(\frac{\lambda_{t+1}}{\pi_{t+1}}\right), \\
\lambda_t &= \frac{\beta E_t\{\lambda_{t+1}[1+q_{t+1}-\delta+\psi(\frac{i_{t+1}}{k_{t+1}}-\delta)+\frac{\psi}{2}(\frac{i_{t+1}}{k_{t+1}}-\delta)^2]\}}{1+\psi(\frac{i_{t+1}}{k_{t+1}}-\delta)}, \\
\log(\kappa_t) &= \omega\left[\exp\left(\frac{s_t b_t^*}{y_t}\right)-1\right], \\
k_{t+1} &= (1-\delta)k_t+i_t, \\
y_t &= \left[\phi^{\frac{1}{\nu}}(y_t^d)^{\frac{\nu-1}{\nu}}+(1-\phi)^{\frac{1}{\nu}}(y_t^m)^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}}, \\
y_t &= c_t+i_t, \\
y_t^d &= \phi(p_t^d)^{-\nu}y_t, \\
y_t^m &= \phi\,(p_t^m)^{-\nu}\,y_t, \\
z_t &= y_t^d+y_t^x, \\
z_t &= A_t k_t^{\alpha}h_t^{1-\alpha}, \\
y_t^x &= \varphi\,(p_t^x)^{-1}\,y_t^*, \\
w_t &= (1-\alpha)\xi_t\frac{z_t}{h_t}, \\
q_t &= \alpha\xi_t\frac{z_t}{k_t},
\end{aligned}
$$

$$
\begin{aligned}
-\theta\frac{\xi_t}{p_t^d} &= (1-\theta)\left[1-\frac{\psi_d}{2}\left(\frac{\pi_t^d}{\pi^d}-1\right)^2\right] \\
&\quad -\psi_d\left[\frac{\pi_t^d}{\pi^d}\left(\frac{\pi_t^d}{\pi^d}-1\right)-\beta\frac{\lambda_{t+1}}{\lambda_t}\frac{\left(\pi_{t+1}^d\right)^2}{\pi_{t+1}\pi^d}\left(\frac{\pi_t^d}{\pi^d}-1\right)\frac{y_{t+1}^d}{y_t^d}\right], \\
-\theta\frac{\xi_t}{p_t^x}\frac{1}{s_t} &= (1-\theta)\left[1-\frac{\psi_x}{2}\left(\frac{\pi_t^x}{\pi^x}-1\right)^2\right] \\
&\quad -\psi_d\left[\frac{\pi_t^x}{\pi^x}\left(\frac{\pi_t^x}{\pi^x}-1\right)-\beta E_t\frac{\lambda_{t+1}}{\lambda_t}\frac{s_{t+1}}{s_t}\frac{\left(\pi_{t+1}^x\right)^2}{\pi^x}\left(\frac{\pi_t^x}{\pi^x}-1\right)\frac{y_{t+1}^x}{y_t^x}\right], \\
\vartheta\frac{s_t}{p_t^m} &= 1+(1-\vartheta)\frac{\psi_m}{2}\left(\frac{\pi_t^m}{\pi^m}-1\right)^2 \\
&\quad -\psi_m\left[\frac{\pi_t^m}{\pi^m}\left(\frac{\pi_t^m}{\pi^m}-1\right)-\beta E_t\frac{\lambda_{t+1}}{\lambda_t}\frac{\left(\pi_{t+1}^m\right)^2}{\pi_{t+1}\pi^m}\left(\frac{\pi_t^m}{\pi^m}-1\right)\frac{y_{t+1}^m}{y_t^m}\right], \\
\varrho_R\log(R_t/R) &= \varrho_\pi\log(\pi_t/\pi)+\varrho_\mu\log(\mu_t/\mu)+\varrho_y\log(y_t/y)+\upsilon_t, \\
\frac{b_t^*}{\kappa_t R_t^*} &= \frac{b_{t-1}^*}{\pi_t^*}+p_t^x y_t^x-y_t^m, \\
\mu_t &= \frac{m_t}{m_{t-1}}\pi_t, \\
\pi_t^m &= \frac{p_t^m}{p_{t-1}^m}\pi_t, \\
\pi_t^d &= \frac{p_t^d}{p_{t-1}^d}\pi_t, \\
\pi_t^x &= \frac{p_t^x}{p_{t-1}^x}.
\end{aligned}
$$

Table 1: Values of Calibrated Parameters

Description	Parameter	Value
Structural parameters		
Discount factor	β	0.99
Interest elasticity of money demand	γ	0.25
Risk-premium parameter	ω	-0.05
Weight of domestic composite good in aggregator	ϕ	0.64
Depreciation rate of capital	δ	0.025
Elasticity of output with respect to capital	α	0.36
Elasticity of substitution between domestic intermediate goods	θ	6
Elasticity of substitution between imported intermediate goods	ϑ	6
Elasticity of substitution between domestic and imported goods	ν	1.5
Capital adjustment cost parameter	ψ_k	25
Steady-state values		
Inflation	π	1
Technology shock	A	1
Money-demand shock	χ	0.25
Foreign interest rate shock	R^*	1.008

Table 2: Maximum-Likelihood Estimates

Parameter	Before 1991Q1	After 1991Q1
ρ_A	0.9731 (0.0452)	0.9969 (0.0044)
ρ_v	0.9963 (0.0055)	0.9946 (0.0076)
ρ_χ	0.6389 (0.0497)	0.6967 (0.0504)
ρ_{R^*}	0.9160 (0.0235)	0.9419 (0.0268)
ρ_{y^*}	0.8596 (0.0244)	0.8384 (0.0245)
σ_A	0.0115 (0.0011)	0.0055 (0.0006)
σ_v	0.0008 (0.0001)	0.0026 (0.0016)
σ_χ	0.0808 (0.0077)	0.0438 (0.0046)
σ_{R^*}	0.0064 (0.0011)	0.0059 (0.0012)
σ_{y^*}	0.0333 (0.0033)	0.0435 (0.0050)
ψ_d	22.8402 (1.5879)	5.3510 (1.9892)
ψ_x	100 (−)	100 (−)
ψ_m	92.4000 (10.3208)	100 (−)
ϱ_π	− (−)	3.1427 (1.4798)
ϱ_z	− (−)	−0.2501 (0.1175)
ϱ_μ	−1 (−)	0.8916 (0.2807)

Note: Standard errors (in parentheses) are the square root of the diagonal elements of the inverted Hessian of the (negative) log-likelihood function evaluated at the estimates.

Table 3: Robustness Analysis: Maximum-Likelihood Estimates

	$\gamma = 0.35$		$\nu = 2$		$\psi_k = 100$		1990Q3		1991Q3		Taylor-type rule	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Parameter	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)
ρ_A	0.9756 (0.0459)	0.9976 (0.0034)	0.9886 (0.0190)	0.9969 (0.0044)	0.9480 (0.0369)	0.9965 (0.0049)	0.9441 (0.0474)	0.9983 (0.0025)	0.9833 (0.0295)	0.9959 (0.0058)	0.9774 (0.0111)	0.9969 (0.0044)
ρ_v	0.9964 (0.0056)	0.9944 (0.0078)	0.9962 (0.0057)	0.9945 (0.0077)	0.9954 (0.0070)	0.9936 (0.0090)	0.9955 (0.0067)	0.9955 (0.0065)	0.9968 (0.0048)	0.9918 (0.0116)	0.9541 (0.0185)	0.9946 (0.0076)
ρ_χ	0.6349 (0.0498)	0.7849 (0.0371)	0.6386 (0.0496)	0.7160 (0.0414)	0.6374 (0.0497)	0.6984 (0.0597)	0.6377 (0.0512)	0.7865 (0.1119)	0.6342 (0.0494)	0.6742 (0.0547)	0.9430 (0.0582)	0.6967 (0.0504)
ρ_{R^*}	0.9177 (0.0235)	0.9247 (0.0352)	0.9166 (0.0233)	0.9406 (0.0293)	0.9155 (0.0239)	0.9451 (0.0278)	0.9140 (0.0252)	0.9407 (0.0322)	0.9188 (0.0218)	0.9301 (0.0290)	0.9276 (0.0220)	0.9419 (0.0268)
ρ_{y^*}	0.8597 (0.0244)	0.8289 (0.0253)	0.8684 (0.0234)	0.8436 (0.0243)	0.8649 (0.0232)	0.8393 (0.0234)	0.8466 (0.0262)	0.8379 (0.0230)	0.8687 (0.0234)	0.8397 (0.0241)	0.8534 (0.0248)	0.8384 (0.0245)
σ_A	0.0122 (0.0012)	0.0056 (0.0006)	0.0112 (0.0010)	0.0054 (0.0009)	0.0118 (0.0011)	0.0056 (0.0005)	0.0102 (0.0010)	0.0066 (0.0007)	0.0113 (0.0010)	0.0054 (0.0005)	0.0089 (0.0007)	0.0055 (0.0006)
σ_v	0.0006 (0.0001)	0.0010 (0.0004)	0.0008 (0.0001)	0.0018 (0.0013)	0.0008 (0.0002)	0.0023 (0.0011)	0.0007 (0.0001)	0.0020 (0.0018)	0.0007 (0.0001)	0.0024 (0.0016)	0.0006 (0.0003)	0.0026 (0.0016)
σ_χ	0.1157 (0.0110)	0.0627 (0.0064)	0.0810 (0.0077)	0.0437 (0.0045)	0.0812 (0.0077)	0.0434 (0.0045)	0.0824 (0.0080)	0.0447 (0.0046)	0.0794 (0.0074)	0.0435 (0.0045)	0.0760 (0.0065)	0.0438 (0.0046)
σ_{R^*}	0.0064 (0.0011)	0.0064 (0.0016)	0.0063 (0.0011)	0.0060 (0.0012)	0.0062 (0.0012)	0.0056 (0.0012)	0.0059 (0.0011)	0.0059 (0.0013)	0.0067 (0.0012)	0.0063 (0.0013)	0.0057 (0.0010)	0.0059 (0.0012)
σ_{y^*}	0.0338 (0.0033)	0.0425 (0.0052)	0.0358 (0.0036)	0.0486 (0.0056)	0.0320 (0.0033)	0.0435 (0.0050)	0.0330 (0.0032)	0.0429 (0.0049)	0.0337 (0.0033)	0.0418 (0.0048)	0.0345 (0.0034)	0.0435 (0.0050)
ψ_d	25.4147 (9.8221)	4.8545 (1.6104)	22.4048 (1.3099)	4.6567 (3.5889)	24.1360 (7.0749)	5.7479 (0.6066)	16.5293 (1.2247)	7.5449 (2.0945)	22.9383 (15.8857)	4.9307 (1.0934)	6.3786 (0.5995)	5.3510 (1.9892)
ψ_x	100 (−)	100 (−)	100 (−)	100 (−)	100 (−)	100 (−)	100 (−)	100 (−)	100 (−)	100 (−)	99.9437 (14.5666)	100 (−)
ψ_m	88.5417 (7.2653)	100 (−)	100 (−)	100 (−)	100 (−)	100 (−)	94.3906 (7.4015)	100 (−)	96.4543 (6.8395)	100 (−)	85.5935 (15.6606)	100 (−)
ϱ_π	− (−)	1.7370 (0.3354)	− (−)	2.4018 (1.2232)	− (−)	2.8230 (1.0768)	− (−)	2.3030 (1.4110)	− (−)	2.9720 (1.5344)	0.5271 (0.1194)	3.1427 (1.4798)
ϱ_z	− (−)	−0.1134 (0.0187)	− (−)	−0.1897 (0.0916)	− (−)	−0.2407 (0.0414)	− (−)	−0.2240 (0.2110)	− (−)	−0.2285 (0.0957)	−0.0310 (0.0138)	−0.2501 (0.1175)
ϱ_μ	−1 (−)	0.3535 (0.1536)	−1 (−)	0.7170 (0.2245)	−1 (−)	0.8223 (0.1378)	−1 (−)	0.5453 (0.3875)	−1 (−)	0.8587 (0.2879)	0.4653 (0.0928)	0.8916 (0.2807)

Note: See note below Table 2.

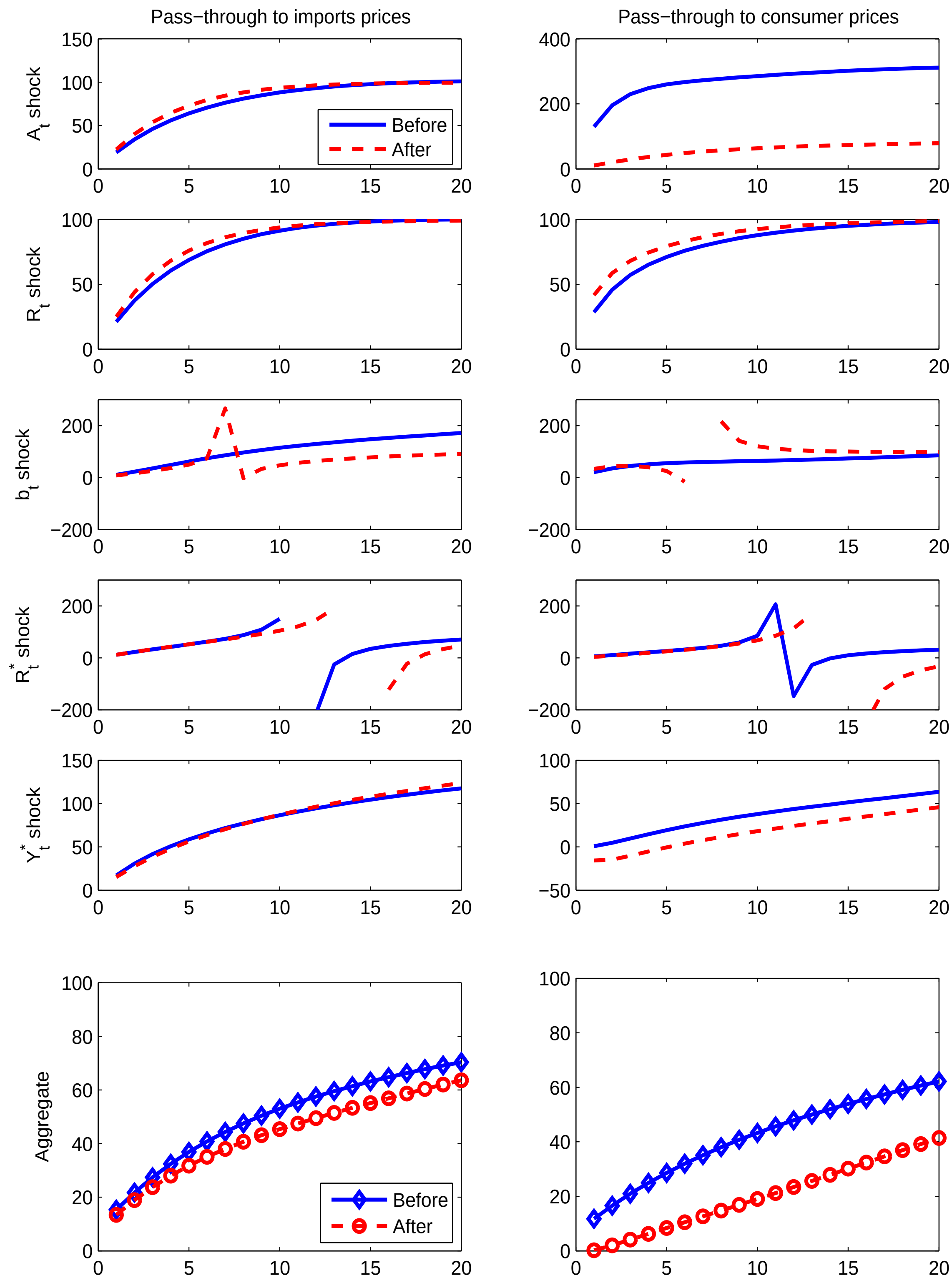

Figure 1: Exchange rate pass-through to import and consumer prices before and after 1991Q1

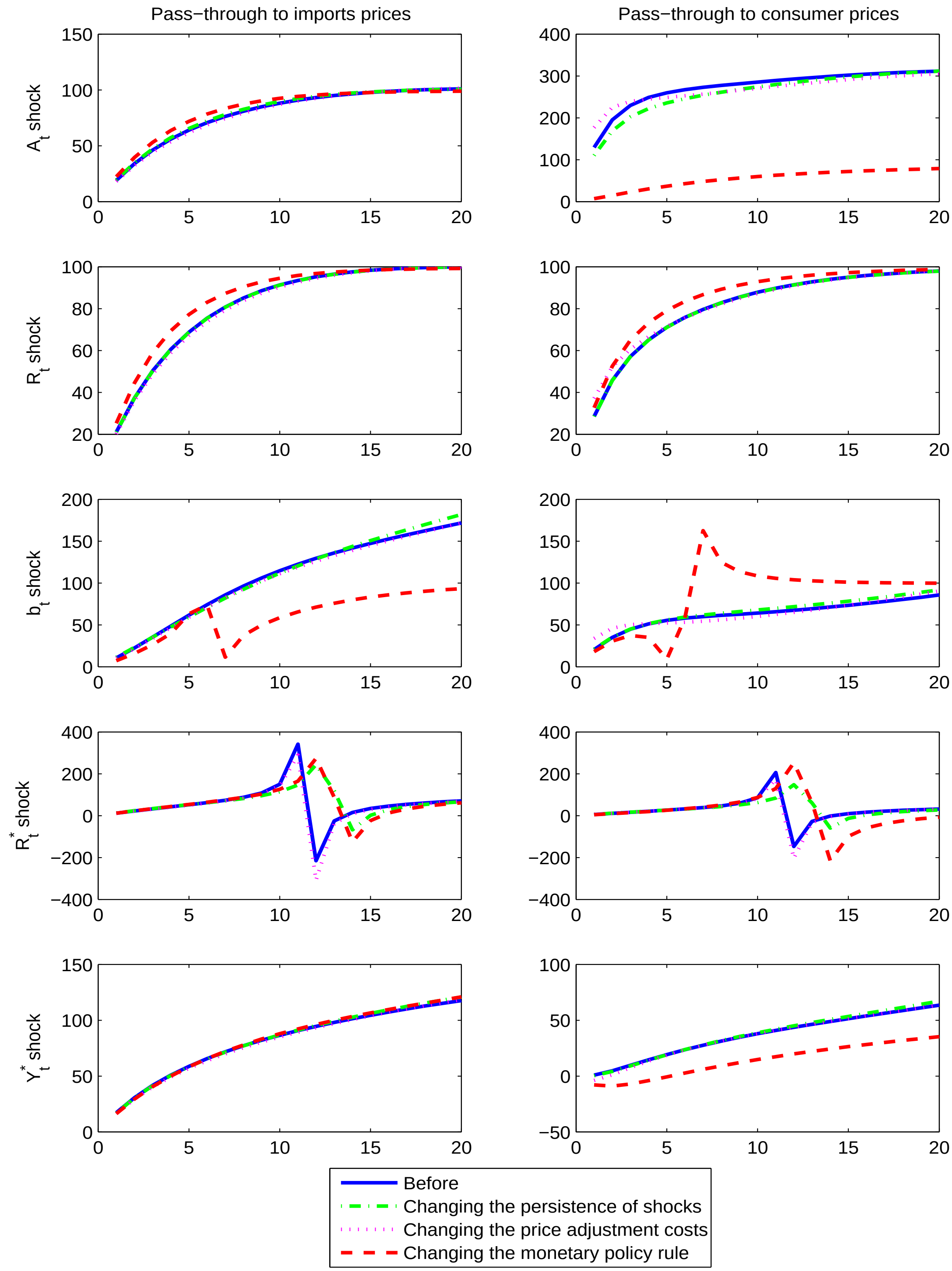

Figure 2: Counterfactual experiments

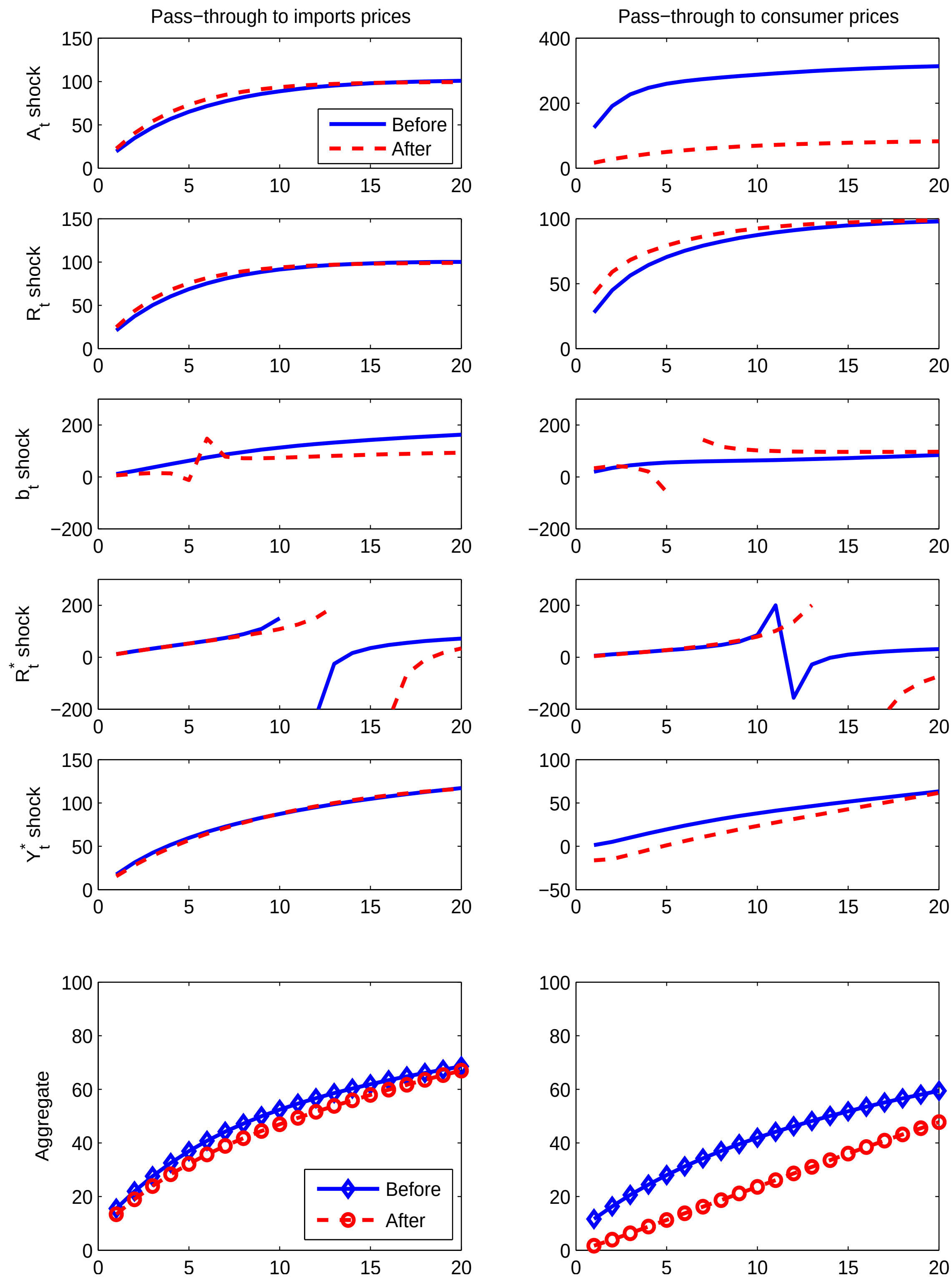

Figure 3: Robustness analysis: $\gamma = 0.35$

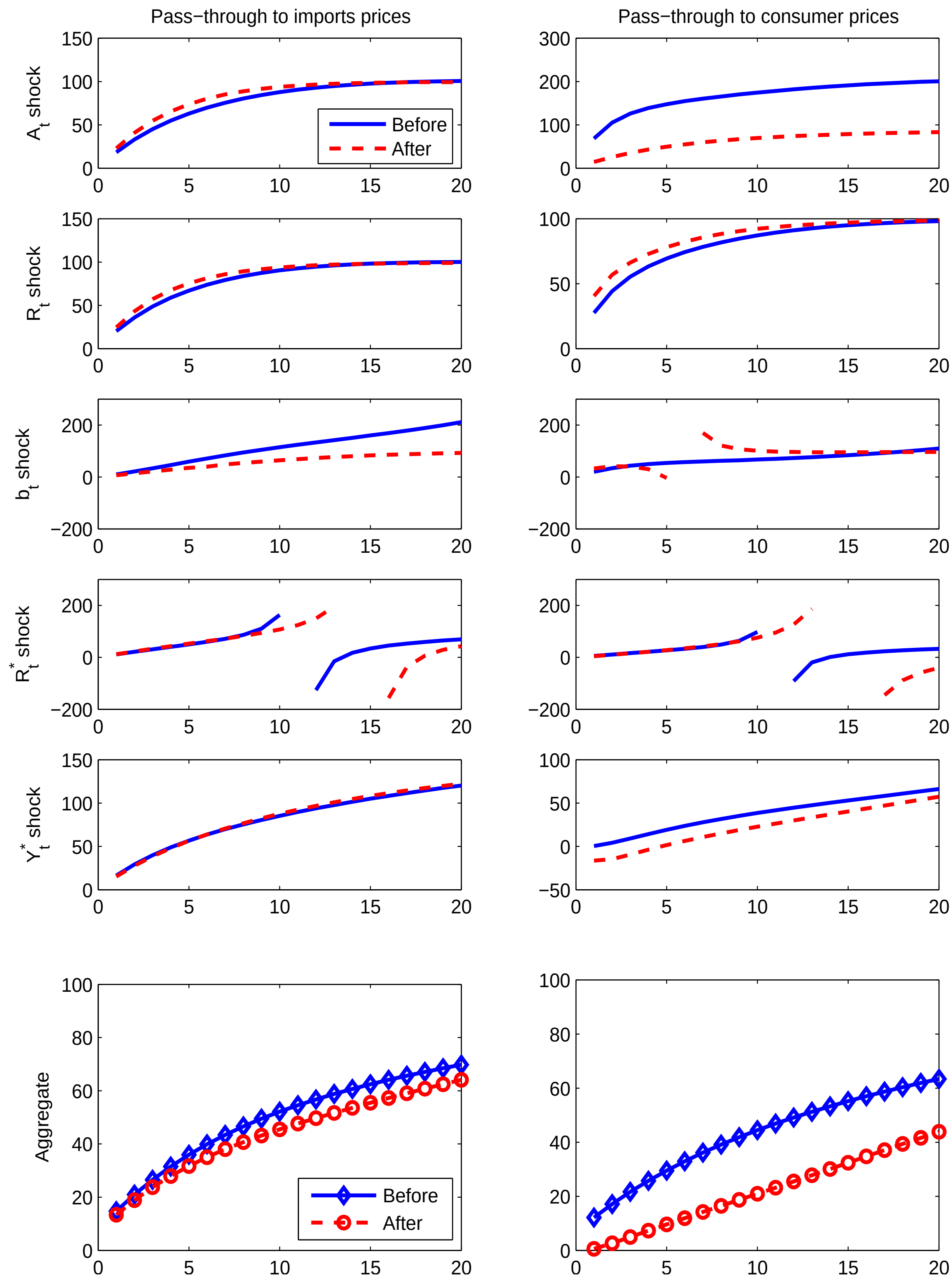

Figure 4: Robustness analysis: $\nu = 2$

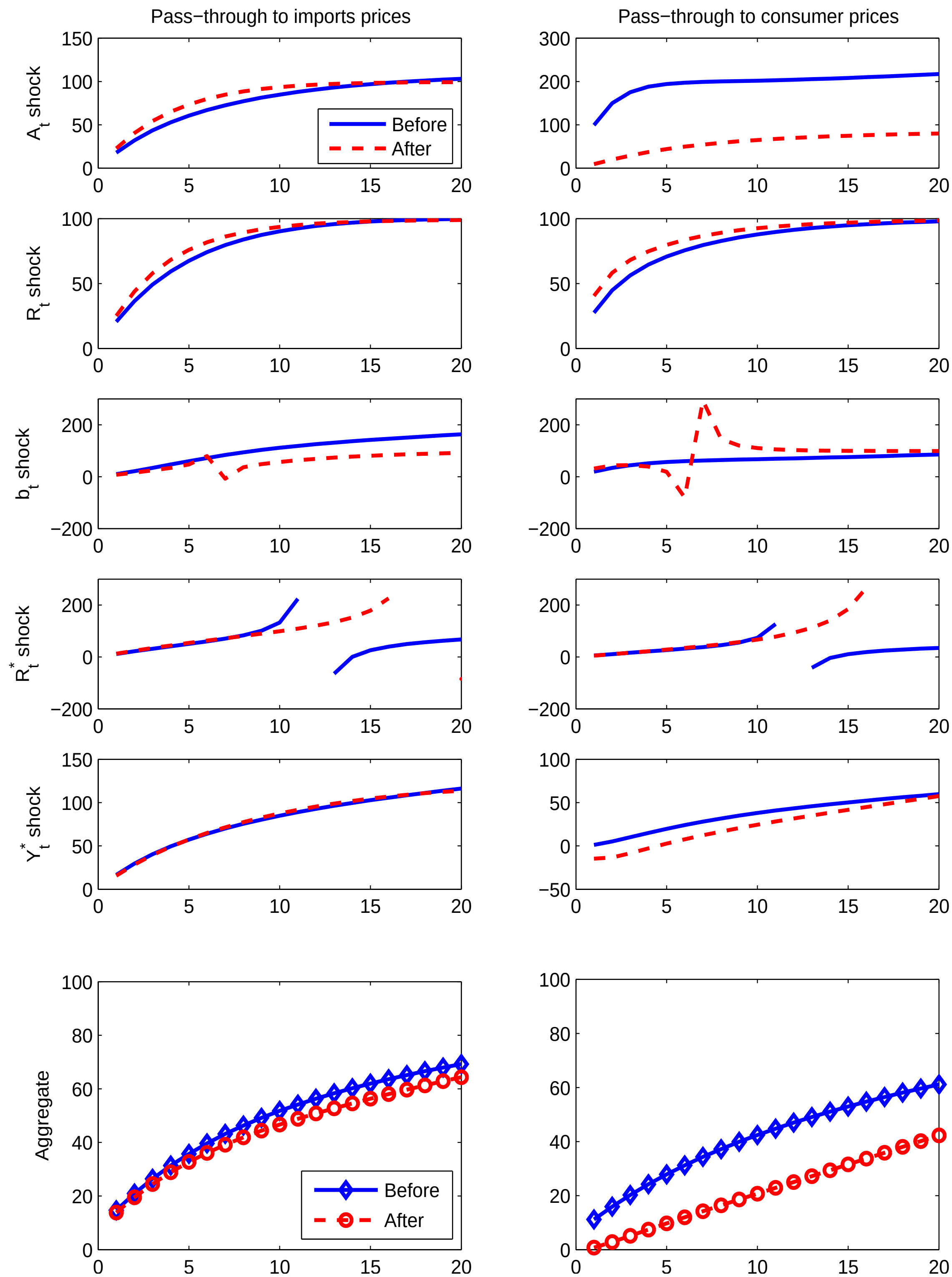

Figure 5: Robustness analysis: $\psi_k = 100$

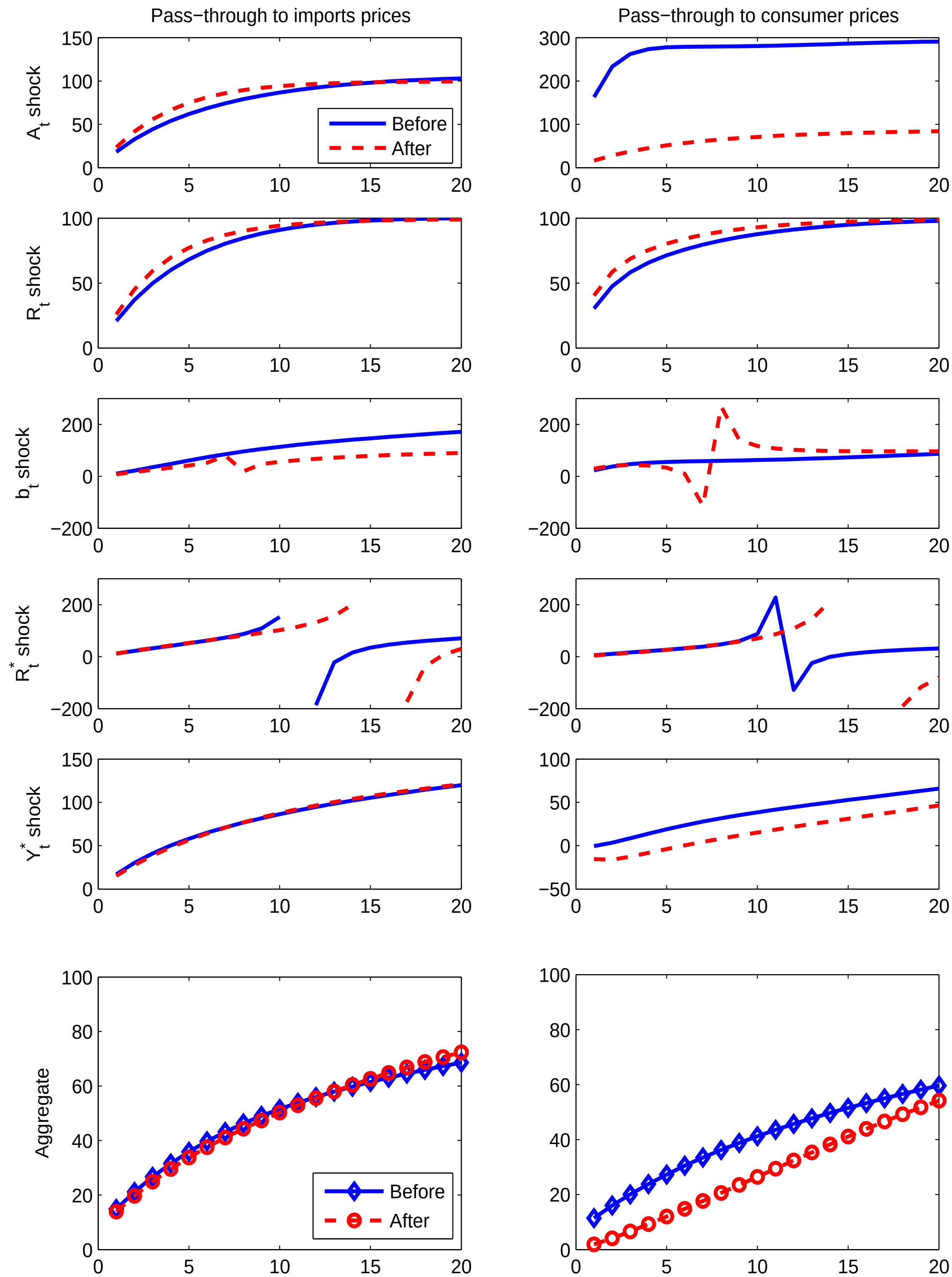

Figure 6: Robustness analysis: Alternative break date (1990Q3)

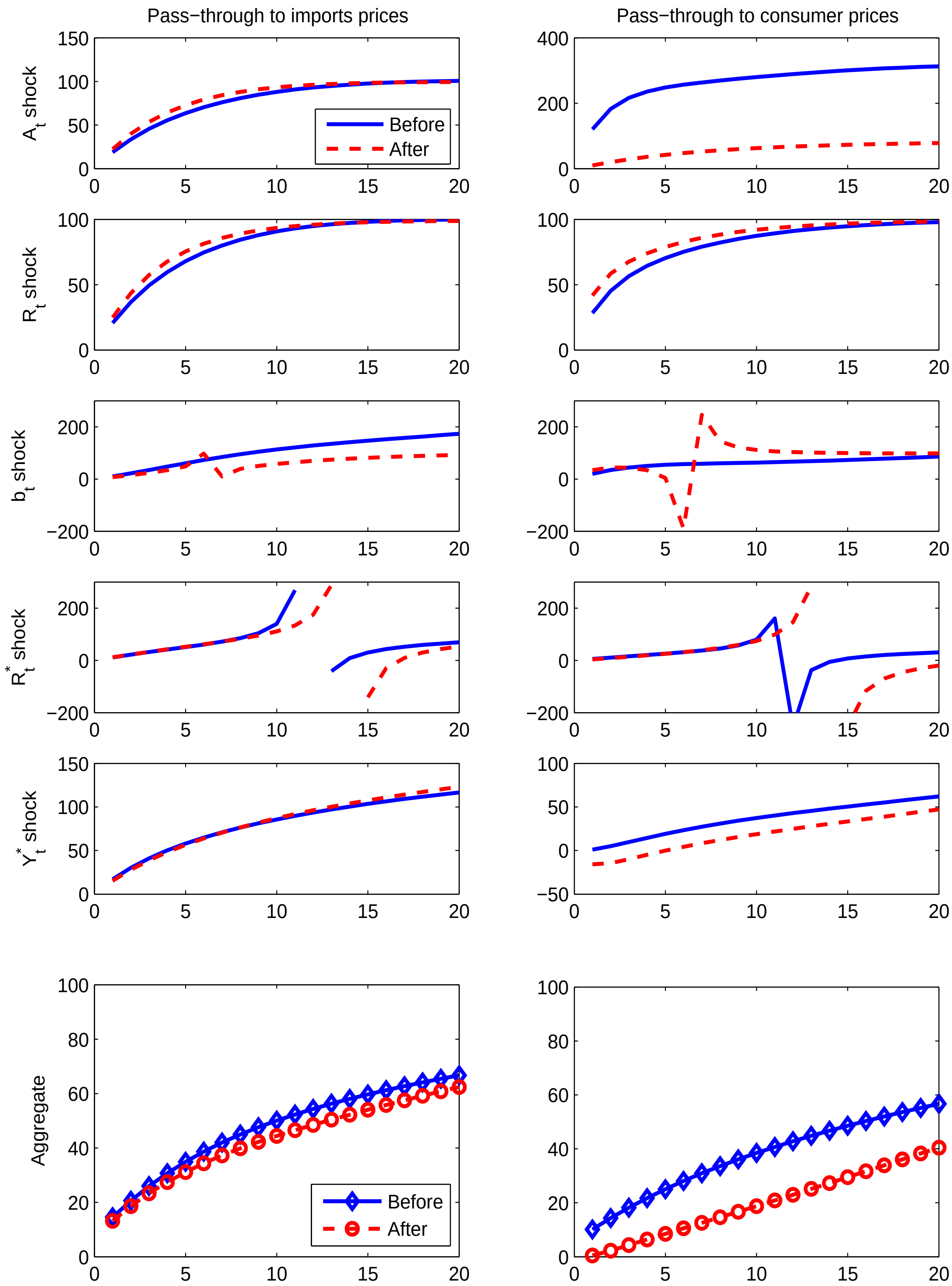

Figure 7: Robustness analysis: Alternative break date (1991Q3)

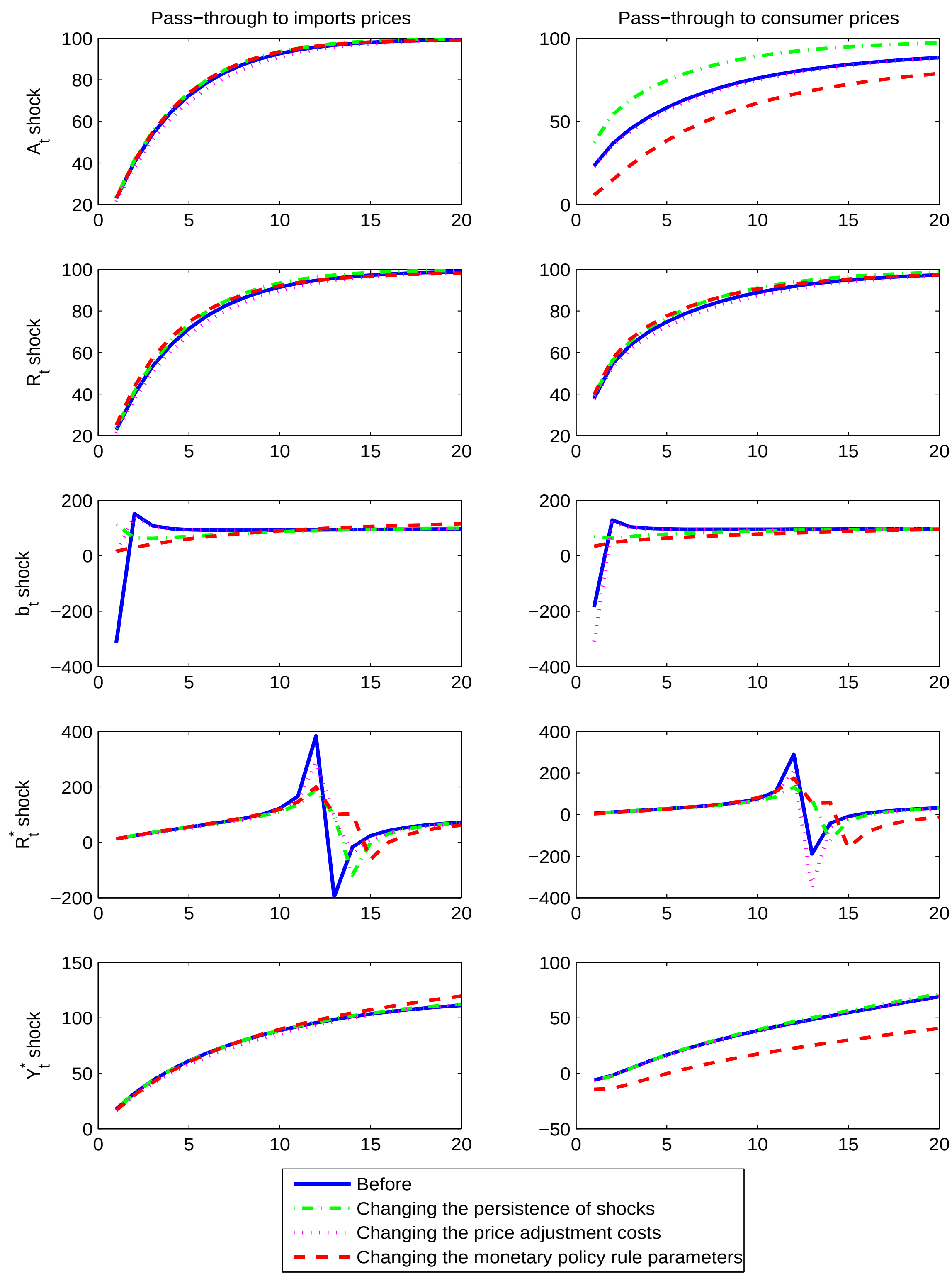

Figure 8: Robustness analysis: Counterfactual experiments with a Taylor-type monetary policy rule in both sub-samples