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Abstract

Using Bayesian methods, we estimate a small open economy model in which consumers face limits to credit determined by the value of their housing stock. The purpose of this paper is to quantify the role of collateralized household debt in the Canadian business cycle. Our findings show that the presence of borrowing constraints improves the performance of the model in terms of overall goodness of fit. In particular, the presence of housing collateral generates a positive correlation between consumption and house prices. Finally we find that housing collateral induced spillovers account for a large share of consumption growth during the housing market boom-bust cycle of the late 1980s.

JEL classification: E21, E32, E44, E52, R21
Bank classification: Business fluctuations and cycles; Credit and credit aggregates; Transmission of monetary policy

Résumé

À l'aide de techniques bayésiennes, les auteurs estiment le modèle d'une petite économie ouverte au sein de laquelle le pouvoir d'emprunt des consommateurs est limité par la valeur de leur patrimoine immobilier. L'étude vise à quantifier le rôle joué par les emprunts des ménages adossés à des actifs réels dans le cycle économique au Canada. D'après les résultats obtenus, l'introduction de contraintes de crédit améliore l'adéquation générale du modèle. En particulier, la présence de garanties immobilières permet d'établir une corrélation positive entre la consommation et le prix des maisons. Les auteurs constatent en dernier lieu que les effets induits par ce type de garantie expliquent dans une large mesure la croissance de la consommation pendant le cycle d'envolée et d'effondrement des prix du logement à la fin des années 1980.

Classification JEL : E21, E32, E44, E52, R21
Classification de la Banque : Cycles et fluctuations économiques; Crédit et agrégats du crédit; Transmission de la politique monétaire

1. Introduction

Consumption expenditures and house prices comove over the business cycle. This positive correlation can be found in macroeconomic time-series estimates for a variety of countries (Case et al. (2005)) including Canada (Pichette and Tremblay (2003)). As the recent experience in many OECD countries has shown, house prices can fluctuate considerably over time, making it important to understand how changing house prices influence consumption behaviour.

The goal of this paper is to investigate the importance of the link between rising house prices and higher consumption expenditures that operates through improvements in household debt capacity. To this end, we construct a New Keynesian model in which a fraction of households borrow against the value of their houses. We estimate the model with Canadian data using Bayesian methods. We then assess the importance of the model's collateral effect in its ability to capture key features of consumption and house price data.

From an aggregate perspective there are a number of reasons to think that house prices could influence consumption decisions in Canada. First, residential structures and land account for a large share of Canadian household sector wealth. Sixty eight per cent of Canadian households own a home and for many it represents their largest asset. Second, house price growth is associated with higher household borrowing. The positive correlation between consumption and house prices may be related to housing's role as collateral. Between 2000 and 2007 the real price of existing homes increased by 52 per cent. At the same time, the ratio of household debt to GDP rose dramatically from 58 per cent in 2000 to 76 percent in 2007. By 2007 roughly 80 per cent of Canadian household debt was secured by real estate.

Our paper is related to the business cycle literature on the role of collateral constraints in the transmission of shocks. A key feature of these models is that collateral effects are a propagation mechanism rather than a driving force of macro fluctuations on their own. Using U.S. time series data, Iacoviello (2005) estimates a New Keynesian DSGE model in which borrowers face collateral constraints tied to their house value. He finds that collateral effects allow the model to reproduce the positive response of spending to a house price shock generated by a Vector Autoregressive model.

Our model shares many features with Iacoviello (2005). At the core of the model is the borrowers-lenders setup developed by Kiyotaki and Moore (1997). There are two types of households differentiated by the degree to which they discount the future. In equilibrium one type of household is a lender and the other type a borrower. Borrowers face a collateral constraint that limits their ability to borrow to a fraction of the value of their housing assets. Rising house values can therefore improve the debt capacity of borrowers, allowing them to increase consumption. Households buy and sell housing in a centralized market.

Since our goal is to quantify the links between consumption and house prices in Canada, we estimate the model with Canadian data using Bayesian methods. To this end we extend the model of Iacoviello (2005) along two important dimensions. First, we introduce open-economy features into this closed economy framework. This extension allows for foreign savers to supply funds to the domestic economy, which affects the response of interest rates and house prices to shocks.[1] Second, we relax the assumption of a fixed housing stock, allowing for investment in structures. Allowing the supply of housing to fluctuate affects the price of housing and, potentially, the role of collateralized debt in business cycle fluctuations.

We find statistical evidence that suggests collateral links between the housing market and the rest of the economy are important. We estimate two versions of the model, one nested in the other. In the benchmark model, housing collateral values can have an impact on aggregate consumption and in the alternative specification this channel is not allowed to operate. We find statistical evidence that the model with collateral effects outperforms the model without in 1-step ahead prediction. In addition, our estimates of the fraction of households facing collateral constraints are plausible when compared to a range of international evidence.

Our results also highlight that there are important differences across models in the response of consumption to a number of shocks. In particular, housing collateral generates a positive response of consumption to a housing demand shock, a feature that is necessary for our empirical model to capture the observed correlation between consumption and house prices. Despite their importance for consumption, we find the effects of housing market shocks on aggregate GDP are relatively small, similar to estimates for the U.S. [2]

Finally, the model suggests that housing collateral-induced spillovers accounted for a large share of consumption growth during the housing boom of the late 1980s and the sharp declines in consumption growth in the early 1990s. While collateral effects boosted consumption growth in the early part of the post-2000 housing boom, these effects were less important for the continued rise in consumption and house prices from 2005-2007. External developments

[1] Aizenman and Jinjarak (2008) emphasize the links between open economy considerations and housing markets. They find evidence for a strong positive relationship between current account deficits and appreciation of real estate prices in cross-country panel data.

[2] See for instance (Jarocinski and Smets (2008)) for the US and (IMF (2008)) for Canada.

reflected in the high real exchange rate played an important role in this latter period.

Our work is closely related to Iacoviello and Neri (2009), who also adapt the model of Iacoviello (2005) to include residential investment. Their objective is to quantify the spillovers of the housing market in the U.S. business cycle. The main difference between Iacoviello and Neri (2009) and our model is the open economy considerations. This paper is also related to micro data studies of the links between consumption and house prices. Campbell and Cocco (2007) find that consumption expenditures and house prices are more strongly related among household groupings that are likely to face financial constraints. Attanasio et al. (2005) argue that the comovement of consumption and house prices represents their responses to some other common factor, such as a productivity shock. In our general equilibrium framework there are a variety of aggregate disturbances, including shocks related to productivity, that can drive both consumption and house prices.

We present the details of the model in section 2. Section 3 outlines the estimation strategy and the data. Section 4 describes the empirical results. In Section 5 we conclude and highlight future work

2. Model

As in Iacoviello (2005), we consider a sticky-price economy populated by two types of households. Credit flows are generated by assuming ex-ante heterogeneity in agents' subjective discount factors. Impatient consumers differ from patient consumers in that they discount the future at a faster rate. Hence, in equilibrium, patient agents are net lenders while impatient agents are net borrowers. To prevent borrowing from growing without limit, we assume that borrowers face credit constraints tied to the expected future value of collateral. We also assume perfectly competitive intermediate-good-producing firms, retailers that operate in a monopolistically competitive market, and a monetary authority.

2.1 Households

Households supply labour and derive utility from consumption, housing services, and real money holdings. They maximize expected utility:

$$\max E_0 \sum_{t=0}^{\infty} (\beta_i)^t \, \epsilon_{b,t} \left[\ln(c_{i,t} - bC_{i,t-1}) + j_t \ln h_{i,t} - \frac{\epsilon_{L,t}}{\eta} (L_{i,t})^{\eta} + x \ln \frac{M_{i,t}}{P_t} \right],$$

where households can be one of two types, denoted $i = 1, 2$, that are distinguished by their time-discount rates β_1 and β_2. $bC_{i,t-1}$ represent external habits in consumption. $\epsilon_{b,t}$ represents a shock to the discount rate that affects the intertemporal substitution of households, $j_{i,t}$ is a shock to the preference for housing services and $\epsilon_{L,t}$is a shock to labour supply. We will refer to $j_{i,t}$ as a housing demand shock.

Lenders. Patient households (denoted by 1), have a higher propensity to save, i.e. $\beta_1 > \beta_2$. So, in equilibrium, they supply loans to impatient households, $b_{1,t}$, and accumulate properties for housing purposes, $h_{1,t}$. Patient households also buy foreign bonds, b_t^*. The return on foreign debt depends on a country specific risk premium ς. Lenders also receive dividends, F_t, from the final-good-producing firms. They maximize their expected utility subject to the budget constraint,

$$c_{1,t} + q_{h,t}(\tilde{h}_{1,t} - (1-\delta_h)\tilde{h}_{1,t-1}) + q_{k,t}(k_t - (1-\delta_h)k_{t-1}) + s_t\left(\frac{R^*_{t-1}\varsigma_{t-1}b^*_{t-1}}{\pi^*_t} - b^*_t\right) = ... \\ w_{1,t}L_{1,t} - \frac{R_{t-1}b_{1,t-1}}{\pi_t} + F_t + b_{1,t} + T_t - \frac{\Delta M_{1,t}}{P_t}\ , \tag{1}$$

where $\pi_t = P_t/P_{t-1}$ is the gross inflation rate, $q_{h,t}$ is the price of housing, $q_{k,t}$ is the price of capital, $w_{1,t}$ real wages of type-1 households, and s_t the real exchange rate. All the variables, except for the gross nominal interest rates on domestic and foreign bonds,R_t, and R_t^*, are expressed in real terms. We assume that the housing stock is variable. Thus, differently from Iacoviello (2005), households accumulate properties that depreciate at a rate δ_h. Lenders' optimal choices are characterized by

$$j_{1,t}\frac{1}{h_{1,t}} = U_{c_{1,t}}q_{h,t} - \beta_1 E_t U_{c_{1,t+1}}q_{h,t+1}(1-\delta_h) \tag{2}$$

$$U_{c_{1,t}} = \beta_1 E_t \frac{U_{c_{1,t+1}}R_t}{\pi_{t+1}} \tag{3}$$

$$U_{c_{1,t}}q_{k,t} - \beta_1 E_t U_{c_{1,t+1}}q_{k,t+1}(1-\delta_k) = \beta_1 E_t U_{c_{1,t+1}}R_{k,t+1} \tag{4}$$

$$U_{c_{1,t}}q_{h,t} - \beta_1 E_t U_{c_{1,t+1}}q_{h,t+1}(1-\delta_h) = \beta_1 E_t U_{c_{1,t+1}}R_{h,t+1} \tag{5}$$

$$\zeta'_t s_t = \beta' E_t \zeta'_{t+1} s_{t+1}\frac{R^*_t\varsigma_t}{\pi^*_{t+1}}\ . \tag{6}$$

Unlike Iacoviello (2005) we augment our model with a demand function for foreign loanable funds (6). The introduction of the risk-premium, ς_t, is required for the model to feature a stationary distribution.[3] Following Adolfson et al. (2007) we assume that the risk premium

[3]See, e.g., Schmitt-Grohe and Uribe (2003) for further details.

depends on the ratio of net foreign debt to domestic output and the expected exchange rate

$$\varsigma_t = \exp\left[\phi(\frac{s_t b_t^*}{P_t^d Y_t}) + \phi_s\left(\frac{E_t s_{t+1}}{s_t}\frac{s_t}{s_{t-1}} - 1\right) + \epsilon_{s,t}\right] .$$

The inclusion of the expected exchange rate in the risk premium is motivated by empirical findings of a strong negative correlation between the risk premium and the expected depreciation, as reported by Fama (1984) and Duarte and Stockman (2005). The demand for foreign funds combined with the demand function for domestic loanable funds, implies an uncovered interest parity condition, which in log-linearized form obeys

$$\hat{r}_t - \hat{r}_t^* = (1+\phi_s)E_t\Delta s_{t+1} + \phi_s\Delta s_t + \phi$$

where $r_t = R_t - E_t\pi_{t+1}$.

Borrowers. Impatient households (denoted by 2) maximize their stream of expected future utility subject to a budget constraint

$$c_{2,t} + q_{h,t}(h_{2,t} - (1-\delta_h)h_{2,t-1}) = w_{2,t}L_{2,t} - \frac{R_{t-1}b_{2,t-1}}{\pi_t} + b_{2,t} - \frac{\Delta M_{2,t}}{P_t} , \tag{7}$$

and a borrowing constraint

$$b_{2t} \leq mE_t\frac{q_{h,t+1}\pi_{t+1}h_{2t}}{R_t} . \tag{8}$$

Following Iacoviello (2005) we assume that borrowing is limited to a fraction of the value of borrowers housing stock; where, $(1-m)$ represents the cost that lenders have to pay in order to repossess the asset in case of default. We also assume that impatient households do not have access to the foreign bond market. Labour supply and borrowing demand are given by

$$U_{c_{2,t}} - \mu_t = \beta_2 E_t\frac{U_{c_{2,t+1}}R_t}{\pi_{t+1}} , \tag{9}$$

where μ_t is the Lagrange multiplier associated to the borrowing constraint.[4] For the borrowers, the marginal benefit of holding one extra unit of housing also takes into account the marginal benefit of being allowed to borrow more

$$\frac{j_{2,t}}{h_{2,t}} + \mu_t\gamma E_t\frac{q_{t+1}\pi_{t+1}}{R_t} = U_{c_{2,t}}q_{h,t} + \beta_2 E_t U_{c_{2,t+1}}q_{h,t+1}(1-\delta_h) . \tag{10}$$

[4]Impatient households borrow up to the maximum in the neighborhood of the deterministic steady state. In fact, if we consider the Euler equation of the impatient household evaluated at the deterministic steady state $\mu_2 = \left(1 - \frac{\beta_2}{\beta_1\pi}\right)U_{c_2} > 0$

Finally, as in Erceg et al. (2000) each household is a monopoly supplier of differentiated labour services which allows them to set their own wage. Wage setting is subject to a Calvo style rigidity with each household facing a probability θ_w that it will not be able to reset its wage in given period. Those households who do not reoptimize their wage, $w_{i,t}$, index to the steady state rate of inflation. Note that the wages for each household type are determined separately, but we assume that both household types face the same degree of wage stickiness.

Specifically, each household $z \in (0,1)$ of type $i \in \{1,2\}$ sets their nominal wage $\widetilde{W}_{i,t}(z)$ such that

$$\sum_{k=0}^{\infty} \theta_w^k E_t \left\{ \left(U_{c_{i,t+k}} \frac{\widetilde{W}_{i,t}}{P_{t+k}} - \left(L^d_{i,t+k}(z)\right)^{\eta-1} \right) L_{i,t+k}(z) \right\} = 0. \tag{11}$$

In the special case that $\theta_w = 0$ labour supply satisfies a more standard first order condition

$$\frac{\widetilde{W}_{i,t}(z)}{P_t} = \frac{\left(L^d_{i,t}(z)\right)^{\eta-1}}{U_{c_{1,t}}}. \tag{12}$$

Overall labour supply of type i, $L_{i,t}$, is a composite of the individual labour supplies aggregated using a Dixit-Stiglitz aggregator, such that

$$L_{i,t} = \left[\int_o^1 (L_{i,t}(z))^{\frac{\epsilon_w - 1}{\epsilon_w}} dz \right]^{\frac{\epsilon_w}{\epsilon_w - 1}}, \tag{13}$$

where the price elasticity ϵ_w is subject to a shock. This implies that the nominal wage $W_{i,t}$, is given by

$$W_{i,t} = \left[\int_o^1 (W_{i,t}(z))^{1-\epsilon_w} dz \right]^{\frac{1}{1-\epsilon_w}} \tag{14}$$

and individual labour supplies $L_{i,t}(z)$ satisfy $L_{i,t}(z) = \left(\frac{W_{i,t}(z)}{W_{i,t}} \right)^{-\epsilon_w} L_{i,t}$.

As all households of each type are the same, the wage aggregator implies a process for the nominal wage $W_{i,t}$

$$W_{i,t} = \left(\theta_w (W_{i,t-1})^{1-\epsilon_w} + (1-\theta_w)(\widetilde{W}_{i,t})^{1-\epsilon_w}\right)^{\frac{1}{1-\epsilon_w}}. \tag{15}$$

2.2 Production

Domestic producers make the intermediate input, $Y^{d,int}$, using rented capital, k, and labour supplied by patient agents, L_1, and impatient agents, L_2. The hours worked of the two households enter into the production function in a Cobb-Douglas form implying that the two labour types are complements.[5] Under this formulation the parameter α is a measure of the labour income share of the unconstrained households. Intermediate goods are produced in a perfectly competitive market by the following technology

$$Y_t^{d,int} = z_t \left(L_{1,t}^{\alpha} L_{2,t}^{1-\alpha} \right)^{1-\gamma} k_{t-1}^{\gamma} \ , \tag{16}$$

where z_t is an aggregate productivity shock. Intermediate domestic goods are sold at the competitive price mc_t^d, i.e. at domestic marginal cost.

Firms solve the following static problem

$$\max \frac{Y_t}{X_t} - \{ w_{1,t} L_{1,t} + w_{2,t} L_{2,t} + R_{k,t} k_{t-1} \} \tag{17}$$

where $X_t = \frac{P_t^w}{P_t}$ is the markup of final over wholesale goods. First order conditions for the firms are standard and available in Appendix A.

2.2.1 Wholesaler's Problem

Domestic brands The producers of domestic brands buy the domestic intermediate input, $Y^{d,int}$, from entrepreneurs, at price mc^d, and transform it using a linear technology into $Y_t^d(z^d)$. Each firm faces a Calvo price rigidity, with a non-zero probability, θ_d, of being unable to adjust its nominal price in a given period. Firms maximize the expected present value of their real dividends setting $\tilde{P}_t^d$ such that

$$\sum_{k=0}^{\infty} \theta_d^k E_t \left\{ U_{c_1,t+k} \left(\frac{\tilde{P}_t^d}{P_{t+k}} - mc_{t+k}^d \right) Y_{t+k}^d(z^d) \right\} = 0. \tag{18}$$

The demand curve for each good obeys

$$Y_t^d(z) = \left(\frac{P_t^d(z^d)}{P_t^d} \right)^{-\epsilon_{p,t}} Y_t^d, \tag{19}$$

[5] As in Iacoviello and Neri (2009), the primary motivation for this is to allow us to obtain a closed-form solution fo rthe steady-state of the model.

where the price elasticity ϵ_p is subject to a shock. We interpret this as a cost-push or markup shock. Each domestic brand is then aggregated into a domestic wholesale good, Y^d. Specifically,

$$Y_t^d = \left[\int_o^1 (Y_t^d(z^d))^{\frac{\epsilon_{p,t}-1}{\epsilon_{p,t}}} dz^d \right]^{\frac{\epsilon_{p,t}}{\epsilon_{p,t}-1}}. \tag{20}$$

This implies that the price of the domestic intermediate good, P_t^d, is given by

$$P_t^d = \left[\int_o^1 (P_t^d(z^d))^{1-\epsilon_{p,t}} dz^d \right]^{\frac{1}{1-\epsilon_{p,t}}}. \tag{21}$$

The Calvo adjustment process implies the following price index

$$P_t^d = (\theta_d (P_{t-1}^d)^{1-\epsilon_{p,t}} + (1-\theta_d)(\tilde{P}_t^d)^{1-\epsilon_{p,t}})^{\frac{1}{1-\epsilon_{p,t}}}. \tag{22}$$

Imported brands Finally, there is a continuum of intermediate-good-importing firms $z^m \in [0,1]$. They import a homogeneous intermediate foreign good at price P_t^* to produce a differentiated good $Y_t^m(z^m)$. Importers face a Calvo price rigidity, with each firm facing a non-zero probability, θ_m, of being unable to adjust its nominal price in a given period. Firms that are able to revise the price, choose $\tilde{P}_t^m$ such that

$$\sum_{k=0}^{\infty} \theta_m^k E_t \left\{ U_{c1,t+k} \left(\frac{\tilde{P}_t^m}{P_{t+k}} - s_{t+k} \right) Y_{t+k}^m(z^m) \right\}, \tag{23}$$

where the demand curve for each good obeys

$$Y_t^m(z^m) = \left(\frac{P_t^m(z^m)}{P_t^m} \right)^{-\epsilon_{p,t}} Y_t^m. \tag{24}$$

Imported intermediate goods are imperfect substitutes in the production of the composite imported good Y_t^m, where

$$Y_t^m = \left[\int_o^1 (Y_t^m(z^m))^{\frac{\epsilon_{p,t}-1}{\epsilon_{p,t}}} dz^m \right]^{\frac{\epsilon_{p,t}}{\epsilon_{p,t}-1}}. \tag{25}$$

Thus, the price of the intermediate imported good, P_t^m, is a composite of the individual prices for the inputs,

$$P_t^m = \left[\int_o^1 (P_t^m(z^m))^{1-\epsilon_p} dz^m \right]^{\frac{1}{1-\epsilon_{p,t}}} . \tag{26}$$

The Calvo adjustment process implies a process for the price index of

$$P_t^m = \left(\theta_m (P_{t-1}^m)^{1-\epsilon_{p,t}} + (1-\theta_m)(\widetilde{P}_t^m)^{1-\epsilon_{p,t}} \right)^{\frac{1}{1-\epsilon_{p,t}}} . \tag{27}$$

2.2.2 Retailer's Problem

Retailers combine domestic brands of intermediate goods Y^d, and imported intermediate goods Y^m, to form a final good Y. Retailers operate in a perfectly competitive market using a CES production function

$$Y_t = \left[(1-\omega)^{\frac{1}{\phi}} \left(Y_t^d \right)^{\frac{\phi-1}{\phi}} + \omega^{\frac{1}{\phi}} \left(Y_t^m \right)^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}} , \tag{28}$$

where $\omega > 0$ is the share of imported goods in the final domestic goods basket and $\phi > 0$ is the elasticity of substitution between domestic and imported intermediate goods. Cost minimization entails the following demand curves for Y^d and Y^m

$$Y_t^d = (1-\omega) \left[\frac{P_t^d}{P_t} \right]^{-\phi} Y_t \tag{29}$$

$$Y_t^m = \omega \left[\frac{P_t^m}{P_t} \right]^{-\phi} Y_t + \epsilon_{m,t} , \tag{30}$$

and a domestic aggregate price level P corresponding to the CPI, such that

$$P_t = \left[(1-\omega) (P_t^d)^{1-\phi} + \omega (P_t^m)^{1-\phi} \right]^{\frac{1}{1-\phi}} . \tag{31}$$

2.3 Housing producer's problem

Housing producers are competitive firms that use final goods and rented housing to produce new units of installed housing capital $A_{h,t} I_{h,t}$ that they sell for price q_t^h. Thus they choose the level of $I_{h,t}$ that maximizes the profits.

$$\max q_t^h I_{h,t} - \frac{1}{A_{h,t}} \left(I_{h,t} + \frac{\psi_h}{2\delta_h} \left(\frac{I_{h,t}}{H_{t-1}} - \delta_h \right)^2 H_{t-1} \right), \tag{32}$$

We assume a quadratic cost of adjusting the housing stock as in Aoki et al. (2004) where ψ_h governs the slope of the housing adjustment cost function. In addition, we include $A_{h,t}$, i.e. an AR(1) shock to the equilibrium condition of housing investment. Since this is a shock to the marginal efficiency of producing housing, we interpret it as a housing-specific technology shock. New housing capital goods are sold at price q_t^h

$$q_t^h = \frac{1 + \frac{\psi_h}{2\delta_h} \left(\frac{I_{h,t}}{H_{t-1}} - \delta_h \right)}{A_{h,t}} \tag{33}$$

This equation is similar to the Tobin's q relationship for investment, in which the marginal cost of a unit of housing is related the marginal cost of adjusting the housing stock. Note that a positive shock to the housing specific technology will reduce the price of installed housing.

2.4 Capital producer's problem

Capital producers take final goods and transform them into capital in a way that is analogous to the housing producers, only they face adjustment costs related to the change in investment as in Christiano et al. (2005). ψ_k governs the slope of the capital producers adjustment cost function. Thus they choose the level of $I_{h,t}$ that maximizes the profits.

$$\max \sum_{k=0}^{\infty} \beta^k E_t \frac{\zeta'_{t+k}}{\zeta'_t} \left(q_t^k I_{k,t} - \frac{1}{A_{k,t}} \left(I_{k,t} + \frac{\psi_k}{2} \left(\frac{I_{k,t}}{I_{k,t-1}} - 1 \right)^2 \right) \right), \tag{34}$$

where $\frac{\psi_k}{2} \left(\frac{I_{k,t}}{I_{k,t-1}} - 1 \right)^2 I_{k,t-1}$is the adjustment cost function. Producers sell the capital at price q_t^k.

$$q_t^k = \frac{1}{A_{k,t}} \left(1 + \psi_k \left(\frac{I_{k,t}}{I_{k,t-1}} - 1 \right) \right) - E_t \frac{\zeta'_{t+1}}{\zeta'_t} \left(\frac{1}{A_{k,t+1}} \psi_k \left(\frac{I_{k,t+1}}{I_{k,t}} - 1 \right) \frac{I_{k,t+1}}{I_{k,t}^2} \right), \tag{35}$$

where $A_{k,t}$ is an AR(1) shock that we interpret as a capital-investment-specific shock as in Greenwood et al. (1998) and Fisher (2006).

2.5 Monetary policy

For simplicity we assume that the central bank uses the Taylor-type interest rate rule:

$$\hat{R}_t = \rho_R \hat{R}_{t-1} + (1-\rho_R)\rho_\pi(\hat{\pi}_t - \hat{\pi}_t^*) + (1-\rho_R)\rho_Y \widehat{GDP} + \epsilon_{MP,t}.$$

The monetary authority adjusts the nominal interest rate in response to deviations of inflation from its target, and deviations of GDP from its steady state value. We also allow for interest-rate smoothing behaviour. The central bank's target, $\hat{\pi}_t^*$, is assumed to be time varying and is subject to an AR(1) shock as in Smets and Wouters (2003) and Adolfson et al. (2007). $\epsilon_{MP,t}$ is an i.i.d. monetary policy shock.

2.6 Market clearing conditions

Domestic output Y_t, can be consumed, invested or exported

$$Y_t = c_{1,t} + c_{2,t} + q_{k,t} I_t^k + q_{h,t} I_t^h + Y_t^x$$

and real GDP is $GDP_t = c_{1,t} + c_{2,t} + q_{k,t} I_t^k + q_{h,t} I_t^h + Y_t^x - s_t Y_t^m$.[6]

Capital is accumulated according to

$$I_{h,t} = H_t - (1-\delta_h) H_{t-1} \tag{36}$$

where the aggregate stock of housing is $H_t = h_{1,t} + h_{2,t}$; and the usual capital accumulation equation holds

$$I_{k,t} = k_t - (1-\delta_k) k_{t-1}. \tag{37}$$

The domestic loan market condition implies that total borrowed funds are equal to funds lent out by patient households

$$b_{2,t} = -b_{1,t} \tag{38}$$

Finally, the trade balance equals economy-wide net saving, so that

$$Y_t^x - s_t Y_t^m = \left[s_t \left(\frac{R_t^f \varsigma_{t-1}}{\pi_t^f} \right) b_{t-1}^f - b_t^f \right]. \tag{39}$$

[6] As in Iacoviello and Neri (2009) and Davis and Heathcote (2005) we set the relative prices q^h, q^k, s equal to their steady state values.

2.7 Rest of the World

We assume Canada to be a small open economy. Thus, domestic developments do not affect the rest of the world economy. By analogy with the import demand function of the local economy, the demand for the domestic economy's exports is captured by

$$\hat{Y}_t^x = \hat{Y}_t^g - \phi \hat{P}_t^x + \epsilon_{ex,t}$$

and $\hat{P}_t^x = \dfrac{P_t^x}{P_t^g}$ is the real price of local brands in the global economy and $\epsilon_{ex,t}$ is an export demand shock. It can be shown that the process for $\pi_t^x \equiv \dfrac{P_t^x}{P_{t-1}^x}$ obeys

$$\hat{\pi}_t^x - \beta_f E\hat{\pi}_{t+1}^x = \frac{(1-\theta_x)(1-\beta\theta_x)}{\theta_x}(-\hat{s}_t - \hat{P}_t^x), \tag{40}$$

where θ_x is the probability that the price of a local brand will remain sticky in the global economy in a given period.

2.7.1 Shock processes

Apart from $\epsilon_{MP,t}$, a zero-mean i.i.d. shock with variance σ_{MP},the other structural shocks in the model, $\chi_t = \{\epsilon_{b,t}, j_t, \epsilon_{s,t}, z_t, A_{h,t}, A_{k,t}, \epsilon_{IO,t}, \epsilon_{L,t}, \epsilon_{ex,t}, \epsilon_{m,t}, \epsilon_{p,t}\}$, follow an AR(1) process

$$\ln(\chi_t) = \rho_\chi \ln(\chi_{t-1}) + \varepsilon_{\chi_t}, \quad \varepsilon_{\chi_t} \backsim^{iid} N(0, \sigma_{\varepsilon_\chi}), \quad 0 < \rho_\chi < 1 \ . \tag{41}$$

3. Data and model estimation strategy

The vector of structural parameters of the model, Λ, describing preferences, technology, the monetary policy rule and the shocks is estimated using Bayesian techniques. First, for given parameter values we solve the model using standard first-order approximation techniques (see, for example Uhlig, 1999). Then, we use the Kalman filter to compute the likelihood $L(\Gamma_t \,|\Lambda)$ for the given sample of data Γ_t , as in Hamilton (1994). We use some informative priors, $\varphi(\Lambda)$, in order to downweight regions of the parameter space that are widely accepted to be uninteresting. Using Bayes's rule, the posterior distribution can be written as the product of the likelihood function of the data given the parameters, $L(\Gamma_t \,|\Lambda)$, and the prior, $\varphi(\Lambda)$:

$$P(\Lambda|\Gamma_t) \ltimes L(\Gamma_t\,|\Lambda)\varphi(\Lambda) \tag{42}$$

We start by estimating the posterior distribution's mode by maximizing the log posterior function. Second, we obtain a random draw of size 300 000 from the posterior distribution using the random-walk Metropolis-Hastings algorithm. The posterior distribution of the parameters can be used to draw statistical inference on the parameters themselves or functions of the parameters, such as second moments.

3.1 The Data

We estimate the model using Canadian data for consumption, capital investment, residential investment, exports, imports, hours worked, real wages, real house prices, short and long-term nominal interest rates, the real bilateral exchange rate (with the United States) and the inflation rate. The availability of the house price data and a desire to have a sample over which the conduct of monetary policy and the statistical properties of inflation have been relatively stable restrict us to considering data from 1981Q1 to 2007Q4.

All of our expenditures data is from the Canadian Income and Expenditure Accounts published by Statistics Canada. Consumption is measured by real personal expenditure on consumer goods and services, while residential investment is real residential structures investment. For capital investment we use real business fixed investment (equipment and structures). The data for exports and imports include both goods and services trade.

Data on actual hours worked are taken from the Labour Force Survey and wage data include wages, salaries and supplementary labour income taken from the Income and Expenditure Accounts.

Our measure of real house prices is the Multiple Listing Service existing house sales price. This index measures the average sale price of all existing residential dwellings sold in a given period.[7] We calculate the real house price by deflating this house price series using the CPI measure described below.

The overnight rate, the interest rate at which major financial institutions borrow and lend one-day (or "overnight") funds among themselves, is our measure of the short-term

[7] This series is highly correlated with an alternative index of resale housing prices from Royal Lepage that measures the prices of houses with similar characteristics in different regions across the country. For this reason we do not think that composition bias is important enough to affect our results.

nominal interest rate. We subtract the 10-year Government of Canada bond rate from this short-term rate to obtain a measure of the yield spread. We chose to use this term spread series rather than the overnight rate on its own because the latter implies that real interest rates have been trending down over our sample.[8] This implies that stance of monetary policy was restrictive throughout the 1980s and easy after the early 1990s, which is at odds with the historical interpretation of events reported in Armour et al. (1996). In contrast the term spread appears to be more consistent with the historical record and also similar to other measures of the stance of Canadian monetary policy described in Fung and Yuan (1999).

We use the Bank of Canada's measure of "core" CPI inflation. This measure of inflation in consumer prices excludes the effects of price changes from eight of the most volatile components of the CPI (e.g. mortgage interest costs, vegetables and gasoline) and changes in indirect taxes.[9]The inflation rate is expressed as a quarterly rate. We subtract 0.5 per cent (the Bank of Canada's inflation target expressed in quarterly rates) from this series before estimation. Though this is not the full-sample mean, it has the advantage that the treatment of the data is consistent with inflation being at the Bank of Canada's target in the steady state. In practice, the inflation objective shock will then account for the transition from the higher inflation of the 1980s to the period in which the Bank of Canada formally adopted inflation targeting.

Finally, the real exchange rate is calculated as the product of the nominal exchange rate (price of a U.S. dollars in terms of Canadian dollars) and U.S. CPI (excluding food and energy) divided by Canadian "core" CPI.

The borrowing constraint in the model has implications for the dynamics of the components of GDP making these series important for identifying the share of constrained households. In addition, using separate series for consumption, capital investment and housing investment gives us the best chance of estimating the adjustment costs parameters for the two types of investment.

All of our series are taken at a quarterly frequency. The real series are logged and detrended separately using a linear trend. The model also implies that the value of the housing stock, $q_t h_t$, is a constant proportion of consumption. The different trends in the raw

[8]DeGraeve et al. (2007) is another example of a medium-scale DSGE model estimated with yield curve data (for the United States).

[9]Unlike the U.S. consumer price index, the Canadian CPI data do not include the cost of imputed rents. Nonetheless, house prices do affect our measure of inflation through owned accommodation prices, which include such costs as home insurance, house depreciation and property taxes.

consumption and housing investment data imply that the real price of housing should also have an upward trend if it is to obey the balanced growth restriction of the model. However, the trend in our real house price series is higher than is implied by this relationship. Since this may reflect some other structural change that is not well captured by the model, for example financial innovation, we also remove a linear trend from the house price data.

A detailed description of the data sources and plots of the detrended data are presented in Figure C1 and the Data Appendix.

3.2 Calibrated Parameters

We calibrate a number of parameters based on sample means or other information because they would be difficult to identify. The calibrated parameters include: the discount factors β_1, β_2, the weight on housing in the utility function j, factor share γ, depreciation rates δ_h, δ_k, the steady-state gross markups for all price-setting firms, and the household loan-to-value ratio m^h.

We set the housing preference parameter j to match the ratio of personal sector residential housing (land plus structures in the National Balance Sheet Accounts) to quarterly GDP, which for our sample period averages about 6.9[10]. We follow Iacoviello (2005) who draws from micro-studies of the range of discount factors of consumers, in setting the discount factor of patient agents β_1 to 0.99 and the discount factor of impatient agents β_2 to 0.95[11]. The patient agent's discount factor implies a steady-state real interest rate of 4 per cent on an annual basis.

We set the elasticity of demand for individual domestic intermediate goods ϵ so as to give an average markup of five percent in steady-state. Individual imported intermediate goods have the same elasticity of demand. The share of imported goods in the final domestic goods basket, ω, is set to 0.3.

As a typical house has a much longer lifetime than a typical piece of equipment, the housing depreciation rate, δ_H, should be lower than δ_k. The value of δ_H compatible with

[10] To calculate these ratios we measure Gross Domestic Product as the sum of the consumption, residential investment, business fixed investment (i.e. excluding inventory accumulation) and net exports. Since the real National Accounts aggregates are produced on a Chain Fisher basis we calculate these ratios using the nominal series.

[11] This value is in accordance with estimates of discount factors for poor or young households (see Samwick (1998) and Lawrence (1991)) and falls into the empirical distribution for discount factors estimated by Carroll and Samwick (1997).

the housing investment to GDP ratio was 0.01, implying an annual depreciation rate that is somewhat higher than the range of values reported in Kostenbauer (2001). However, this value is much lower than the depreciation rate for capital which is set to $\delta_k = 0.023$, implying and annual depreciation of the capital stock of 9.5 per cent. We treat non-residential construction as part of business fixed investment, but exclude residential construction. Consistent with this classification, the capital share in the production of final goods, γ =0.23, is lower than is typically used in models that aggregate all types of capital. The depreciation rate for capital along with the capital share in production of final goods, γ =0.23, imply a ratio of business fixed investment to GDP of about 0.165, approximately that seen in the data.

We also need to set a value for the loan-to-value ratio m^h. This value should reflect the typical loan-to-value ratio for a constrained household. This household, who we think of as being a first-time home buyer, borrows the maximum possible against their real estate holdings[12]. Over most of our sample, Canadian law required mortgages in excess of 75 per cent of the value of the property to be insured. In practice, home buyers were able to obtain loans at considerably higher loan-to-value ratios with insurance. The minimum downpayment required by insurers has varied over our sample, dropping from 10 per cent to 5 per cent in 1992 and to 0 per cent in 2004. It has returned to 5 per cent more recently. Thus, on average over our sample, loan-to-value ratios for constrained households are likely to have fallen in the 0.75 to 0.95 range. With no direct estimates for Canada, we set $m^h = 0.80$, slightly lower than the value chosen by Iacoviello and Neri (2008) based on U.S. data on new-home buyers.

3.3 Prior distributions of the estimated parameters

Table 1 summarizes the assumptions for the prior distributions of the estimated parameters. We set the prior mean on the income share of unconstrained households to 0.65, with a standard error of 0.075. This is within the range of estimates of the fraction of households who are financially constrained reported in the literature. Campbell and Mankiw (1991) estimate the fraction of constrained agents from Canadian macro data to be near 50 per cent. Estimates based on micro data for the U.S. (Jappelli (1990)) and the U.K. (Benito and

[12]Ultimately we would like to incorporate information from observed financial variables such as mortgage debt into the model. However, aggregate measures of mortgage debt in Canada include debt held by unconstrained households who have had time to accumulate other assets and are better thought of as patient consumers. It is not possible to capture this in the model since lenders own housing, but do not have mortgages. This forces the impatient households to hold all of the observed stock of debt if we are to match the household debt-to-asset ratio in the data. In future, we may be able to exploit information from microdata to determine a more appropriate target debt-to-asset ratio.

Mumtaz (2006)) put the share of the population that is liquidity constrained between 20 and 40 per cent. We set the prior mean of the habit parameter in consumption b to 0.7 with a standard error of 0.05. The prior mean for the labour supply elasticity is set to 2.0.

The prior means for the monetary policy rule are similar to those used in Smets and Wouters (2007) and the standard errors are relatively large allowing the priors to be consistent with the estimates for Canada by Lam and Tkacz (2004) and also the Canadian policy rules discussed in Cote et al. (2004). We use a beta distributed prior on the inverse of the coefficient on inflation (ρ_π^{-1}).Ultimately this results in a prior that is less informative than the normal distribution that is more widely used. The prior mean on the smoothing parameter ρ_r is set to 0.5 and the prior mean for ρ_y is 0.125.

For the fixed capital and housing capital adjustment costs we chose a gamma-distribution with mean of about 1 and a standard error of 0.5 in both cases. We set a prior mean for the probability that a retailer will be unable to adjust prices, θ, to 0.5 implying that retail prices are fixed for 2 quarters on average. This is in line with the evidence on the price-setting behaviour of Canadian firms reported in Amirault et al. (2006). The median firm in their survey sample adjusted prices 2 to 4 times a year. We use the same prior distributions for the frequency of price adjustment by importers and export retailers in the foreign economy. We also centre the prior mean for the frequency of wage adjustment at 0.5. Similar priors for wage and price stickiness appear in Smets and Wouters (2007) and Adolfson et al. (2007).

The prior mean for the elasticity of the country risk premium with respect to the ratio of foreign debt-to-output, $\phi = 0.001$, is lower than found in previous work on estimation of small-open economy models by Adolfson et al. (2007), Christoffel et al. (2007), and Dib (2003).

We use inverse gamma priors on all the structural parameters governing the standard deviations of the shocks. For the persistence parameters of the shock processes, we choose a beta-distribution with a prior mean of 0.5 and standard deviation of 0.25. At our prior means the model is able to match a set of key steady-state ratios observed in our data sample.

4. Empirical results

We estimate the model presented above and a representative agent version of the model in which there are no borrowing constraints.[13] We refer to our model as the FA model since it has an active financial accelerator and the model without the borrowing constraints as the NoFA model. Our objective is to document the role that the collateral constraints play in the ability of the model to capture the moments of interest in the data. Initially, we report mainly on the fit of the model over the entire sample. However, later we also consider the whether the financial accelerator helps the model to account for episodes in history such as housing booms/busts or a severe recession.

4.1 Posterior Distributions

We report the posterior mean and 95 per cent probability interval for the structural parameters, along with their priors, for the model with the borrowing constraint (FA model, in Table 1) and the model without the borrowing constraint (NOFA model, in Table 2). Except where noted, most of the parameters are within the ranges specified in the priors.

The habit persistence parameter, b is estimated to be 0.79, while the long-run elasticity of labour demand η is 0.55; the estimated habits are on the high end of our prior, and the labour elasticity on the lower end.

The estimated range of ρ_π^{-1} implies a range for the inflation weight in the monetary policy rule, ρ_π, from 1.4 to 2.1, while the weight on output, ρ_y, is fairly small (between 0.01 and 0.06). The interest rate smoothing term, ρ_R, is between 0.41 and 0.68. The estimated policy rule coefficients are similar to those reported in other studies (Ortega and Rebei (2006), Dib (2008), and Dib et al. (2008)).

The mean estimate of Calvo price stickiness for domestic goods θ^d implies an average duration of price stickiness of about six quarters. Such estimates for average price stickiness are high relative to findings on price adjustment from micro studies, but they are in line with previous DSGE models' estimates – even with more elaborate systems of nominal stickiness (for example Adolfson et al. (2007) and Smets and Wouters (2003)). Wage stickiness on the other hand is much lower than in many other studies, with a typical wage being unchanged for only four months on average.

[13] In this model the household still derives utility from housing services, but it also purchases capital and rents it to the intermediate goods producer. The other households are no longer present in the model so that there are no borrowers or lenders. All other features of the model are preserved.

The price stickiness for imports θ^m is about the same as for domestically produced goods. However, price stickiness for exports θ^x is much lower, the average export price being sticky for only about 1.25 quarters on average. The long run elasticity of import demand σ is much lower (about 0.3) than that of export demand σ^f (about 1.5). Such estimates reflect a much faster response of exports than imports to a change in the real exchange rate. This may reflect the composition of exports and imports. For example, Canada exports proportionately more commodities that have relatively elastic demand, while importing more finished goods for which the demand is relatively inelastic.

The estimate of the wage share of unconstrained households, α, is about 0.62, implying a share of labour income to credit constrained agents of about 38 percent, on the high end of the range of empirical estimates in the literature.

4.1.1 FA versus NoFA

As measured by the Bayes factor (an estimate of the ratio of the marginal likelihoods of the two models), FA outperforms NoFA in overall goodness of fit: the difference of the log Bayes factors is $3540.07 - 3520.57 = 19.50$, implying a posterior odds ratio of about $2.94 \times 10^7 : 1$ in favour of FA.

The biggest differences in the parameter estimates between FA and NoFA are related to preferences. The NoFA estimates of habits are lower than the FA estimates, and the NoFA estimate of labour supply elasticity is higher than FA's. In addition, the estimated volatility and persistence of the discount factor shock are higher in the NoFA model.

As the Bayes factor tends to be sensitive to the priors, including those on "nuisance" parameters, we also calculate the ratios of the Schwarz criteria (Schwarz 1978) of the two competing models. This commonly used as a "prior-free" approximation of the Bayes factor, as it is essentially a ratio of the maximum likelihoods of the two models and does not depend on the prior.[14] In addition, the Schwarz criterion includes a penalty for the number of estimated parameters, which should reduce the advantage of the FA model. We estimated both models, FA and NoFA, by maximum likelihood and calculated the log ratio of the Laplace approximations of the marginal likelihood assuming flat priors on all parameters, including standard deviation terms, as well as the ratio of the Schwarz criteria of the two models.

[14] One drawback of the Schwarz criterion is that the difference between it and the true Bayes factor does not go to zero as T gets large (see Kass and Raftery 1995 for a discussion).

The log Bayes factor as measured by the Schwarz criterion is 22.4; the implied posterior odds ratio of FA and NOFA is approximately 5.5 x 10^9 to 1 in favour of FA. The maximum likelihood estimate of alpha was about 0.63, similar to the posterior mean estimate when we use an informative prior. The log of the Laplace odds ratio was about 20.9, implying a posterior odds ratio of 1.2*10^9 to 1 in favour of FA. The Laplace approximation and the Schwarz approximation of the Bayes factor are within the same order of magnitude, and both suggest that the data strongly favour the FA model over the NOFA model.[15]

4.2 Model Dynamics

4.2.1 How do model dynamics differ with borrowing constraints?

We now compare the responses from the FA model presented against the estimated NOFA model. The objective is to document the implications of the borrowing constraints for the dynamics of our model. In Figure C2 we plot two lines summarizing the posterior distribution of the model impulse responses for consumption from the NoFA model. The upper and lower dashed lines represent the interval in which that model's IRFs fall for 95 per cent of the draws from the posterior distribution of parameters. Also plotted is the mean impulse response from the FA model. A one percent rise in a variable is denoted as 0.01 on the y-axis and the number of quarters elapsed since the shock are indicated on the x-axis.

The results show that for the housing demand, the housing investment and the monetary policy shock the responses of consumption show important differences. Most striking is the housing demand shock which generates a positive consumption response that can clearly not be produced by the model without collateral effects. The FA model also generates a stronger peak response of consumption to a monetary policy shock, as well as a more persistent one. Monacelli (2009) shows similar effects resulting from the presence of collateral constraints. It also amplifies the decline in consumption after a housing investment shock. For the other shocks the FA model's IRFs fall within the probability interval generated by the NoFA model. For these shocks, including the neutral technology, country risk premium and export demand shock, there is not a large difference between model dynamics if one takes into account parameter uncertainty. These model responses show that the influence of the collateral constraints on model dynamics will be more important for some shocks than others and can

[15] We did find that the estimates of some of our structural parameters were sensitive to the relaxation of priors. In particular, the standard deviation of the monetary shock and the parameter governing the degree of export price rigidity went to zero. For the maximum likelihood estimation we set those parameters equal to zero a priori.

even change the sign of some responses. It also indicates that the collateral constraints affect the model most for shocks that are directly linked to the real price of housing.

The housing demand shock can be interpreted as a shock to the price of housing.[16] In the standard representative agent model, consumption falls in response to an housing demand shock because households give up consumption today to purchase more housing. In the model with collateralized debt, a rise in housing demand increases house prices and relaxes the borrowing constraint, allowing impatient households to increase consumption closer to desired levels.

To illustrate the importance of different features of the model we plot impulse responses (Figure C3) to a housing demand shock from the estimated model along with the responses obtained when i) the borrowing households make up a very small fraction of the wage bill (alpha=1); ii) wages are flexible (calvow=0); and iii) access to the international bond market is more costly (phi rises from 0.0006 to 0.1). We see that presence of borrowing constrained households is crucial to obtain the positive response of consumption. In addition, the rise in residential investment is initially more pronounced in the presence of constrained households. The low estimated cost to access the foreign bond market is another factor that is important for the consumption response. Reduced access to foreign savings (higher phi) increases the response of the real interest rate and the yield spread[17] to this shock as more savings must come from internal sources. The higher internal demand is met by reducing the increase in consumption and further expanding hours worked. Finally, the wage stickiness in our model reduces the impact of the housing demand shock on marginal cost and inflation. As a result the interest rate rises less (relative to the calvow = 0 case) and there is a greater expansion of hours worked supporting the boom.

4.3 Business Cycle Properties

In this section we compare the statistical properties of the model against those of the data. Here we focus on the model characteristics at horizons that are most relevant for policy makers, rather than on unconditional moments. To generate these moments in the data we estimate a Bayesian Vector Autoregression (BVAR) model using the same data set.[18]

[16] Indeed, as we report below, the variance decompositions show that this is the shock responsible for the largest part of house price fluctuations in the model.

[17] Recall that the yield spread rises (above its steady state value) when the real interest rate rises above its steady-state value.

[18] The variances from the BVAR were calculated from a BVAR with four lags estimated with a Normal-Wishart prior (see Kadiyala and Karlsson (1997) for details), with prior variance hyperparameter (pi_1) set

BVARs are a useful benchmark in this context because they are generally viewed to have good forecasting properties and impose much weaker restrictions on the data than the DSGE model.[19] The statistics we consider are essentially the properties of the forecast errors of each model at different horizons up to two years.

Standard deviations. In Table 3 we report the standard deviations of key variables in the data and from the models. These are conditional statistics that show the standard deviation of the forecast of variable X at a 4-quarter horizon relative to the standard deviation of GDP. We focus on the 4-quarter horizon as an illustration, but the results are broadly similar for horizons up to 8-quarters.

Overall the standard deviations are quite similar for the model with collateral effects and the model estimated with those effects constrained to zero (NoFA). There is an important exception. The volatility of consumption in FA is 1.6 per cent and NoFA is 2.0 per cent versus 1.2 per cent for the VAR. The collateral effects appear to improve the model's ability to match consumption volatility.

Table 3 shows the relative standard deviation of selected variables relative to the standard deviation of GDP.[20] The relative standard deviation of consumption in both models is close to the data, though the consumption is somewhat less volatile in the model with the collateral effects. Both models are able to generate a high degree of volatility in residential investment and house prices, though still less than in the VAR. In addition, both models underpredict the relative volatility of imports. The relative volatilities of inflation, the real exchange rate and the yield spread are all close to their values in the data.

Cross-correlations. Table 4 reports the cross-correlations for our key variables. These statistics are the correlations in the forecast-errors of X and Y at a 4-quarter horizon, rather than the infinite horizon correlation. The results are qualitatively similar at the 1-step and 8-step forecast horizons.

In the model, consumption and both types of investment are positively correlated with GDP, as they are in the VAR. The model-implied correlations between GDP and consumption are quite close to the correlation in the data and the correlation of fixed capital investment

at 0.012 and lags decaying at a rate 1/k^2, and 13 degrees of freedom (the minimum permissible) on the Inverse Wishart prior on the error covariance matrix. Further, only draws from the posterior that resulted in a stationary process (permitting a finite unconditional variance) were used, further restricting the BVAR.

[19] In an early example, Schorfheide (2000) evaluates the ability of two DSGE models to match the correlation between inflation and output produced by a VAR.

[20] In general, the models generate considerably more volatility than the VAR.

implied by the models is slightly stronger. Though the model with collateral effects generates a higher correlation between residential investment and GDP it is still well below the correlation in the data.

Turning to cross correlations with real house prices, we see that the model with collateral effects generates a correlation between consumption and real house prices that is very close to the VAR. The collateral effects appear to be important for this finding, since the model without those effects generates only a very weak correlation. Both models produce a correlation between house prices and residential investment that is close to that seen in the VAR.

Overall, the model with collateral effects matches some key facts about consumption, particularly its correlation with GDP and house prices. In addition, it produces a plausible correlation between housing investment and house prices, despite a highly stylized housing production sector. Though the model is capturing the procyclical nature of residential investment, the correlation is weak relative to the data.

Variance decomposition. Figures C4 - C9 show the decomposition of the forecast error variance of output, inflation, consumption, housing investment, house prices at the 1,4,8 and infinite horizons.

House prices and residential investment are dominated by the housing market shocks. At all horizons the variance of house prices is due primarily to the housing demand shock, though the housing investment-specific shock plays a role at longer horizons (Figure C5). Residential investment fluctuations are largely due to the housing investment-specific shock (about 60 per cent of the variance up to 8 quarter ahead), but housing demand shocks also account for an important share, especially at longer horizons.

The housing demand shock also plays a role in the variance of consumption at horizons up to 8 quarters (Figure C7), another sign of spillovers from the housing market. Not surprisingly, the discount factor shock accounts for large fraction of the variance of consumption at very short horizons. At longer horizons consumption fluctuations are driven primarily by aggregate productivity shocks and export demand. The importance of the export demand shock is due, in part, to a long-lived rise in net foreign assets (wealth) that results from an increased demand for domestic goods.

Finally, we consider what drives GDP and inflation in our model. Figure C8 shows that housing market shocks account for roughly 5 per cent of the variance of GDP, making them about as important as shocks to the country risk premium in this model. The housing demand shocks alone account for about 2.5 per cent of the GDP variation at 8 quarters, mirroring the post-1983 VAR evidence for Canada presented in IMF (2008). Studies of the U.S. have also found relatively small impacts of housing demand shocks on aggregate output (see Jarocinski and Smets (2008) and Iacoviello and Neri (2009)). Demand shocks in general play a more important role at short horizons particularly the import demand and discount factor shocks. At long horizons the neutral productivity shock accounts for the bulk of the fluctuations in GDP. Figure C6 shows the variance decomposition for deviations of inflation around the target. Mark-up and productivity shocks and shocks to the country risk premium (exchange rate) play an important role in the variance of inflation deviations at all horizons.

It is worth comparing the importance of the shocks most affected by financial frictions in the FA and NoFA models. In the FA model, housing demand shocks explain about 3.6 percent of the variation of GDP (given that output includes housing investment), and about 6 percent of consumption variation. In the NoFA model, by contrast, housing demand shocks explain only 0.5 percent of GDP and 0.6 percent of consumption. The drivers of house prices and residential investment in NoFA are almost identical to the results reported for FA: housing demand accounts for about 83 per cent of short horizon variance of house prices and housing demand and investment-efficiency shocks account for over 90 per cent of the variance of residential investment.

Much of the variance of consumption attributed to the housing demand shock under FA is attributed to the discount factor shock in the model where collateral effects are constrained to be zero. The discount factor shocks explain 50 percent of consumption variance at the 4-quarter horizon under NOFA, but only 30 percent under FA. The greater importance of the housing demand shock in the FA model and lesser importance of the consumption preference shock, suggests that the borrowing constraints are helping the model to capture some of the comovement between consumption and house prices.

Historical decompositions. The statistics reported above help us to evaluate the ability of each model to capture the full sample moments in the data. However, we are also interested in how well the model can explain particular episodes in the Canadian business cycle where financial frictions are likely to have been important.

To quantify the role played by collateral effects in our model we can compare consumption over history from the model (actual consumption) against a counterfactual consumption path produced by turning off the collateral mechanism in the model (setting $\alpha = 1$) and using the same historical shocks to generate a new Kalman smoothed estimate for consumption. We interpret the difference in these two consumption paths as the impact of collateral effects implied by our model. In figure C10 we plot the contribution of these collateral effects to the year-over-year growth rate of consumption. The figure reveals a number of interesting insights.

First, much of the growth in consumption in the early part of the housing boom of the late 1980s is attributed to collateral effects. More specifically, rising house prices played an important role in consumption growth through the increase in value of housing collateral. This positive effect peaked in late 1986 but continued to have a positive effect on consumption growth until 1989.

Second, after 1989 the collateral effects begin to negatively affect consumption growth, and have a pronounced impact on consumption in 1991. The sharp collateral effect on consumption also occurs in 1982, suggesting that it an important role in accounting for consumption dynamics in recessions. These collateral effects broadly reflect developments in the Canadian housing market at this time.

Finally, we consider the post-2000 period during which many OECD countries, including Canada, have seen sharp increases in house prices and consumption. Our model suggests that collateral effects contributed as much as 1.0 per cent to yearly consumption growth in 2000 and had a positive effect for most of the remainder of the sample. This contribution is less than in the period from 1986 to 1990, but one simple reason is that the house price increases since 2000 have been more gradual than in the late eighties when they rose to the same level in 3 years rather than 6.

The collateral effects shown in Figure C10 are driven predominantly by the differential response of the model to housing demand shocks. As discussed above, reducing the share of borrowers in the model leads to a consumption decline rather than an increase. Explaining the differences between the 1980s housing boom and recent one is thus partly due the fact that the housing demand shocks were more important in the earlier period. However, since consumption and house prices have reached the same peaks attained in 1989, why are housing demand shocks less important? We find that this is related to differences in the residential construction and external factors.

Unlike the real house price, the level of residential construction does not continue to rise after 2005 (though well above trend). To explain this fact the model uses a decline in the housing-investment efficiency shock. One interpretation is that residential investment becomes more costly and the housing stock more difficult to adjust. In the housing sector this might be the result of bottlenecks in production, including the difficulty in finding and keeping skilled trades and reduced availability of serviced land. As a result, prices continue to rise but housing construction does not.

Our model also highlights external developments as a major difference between the late 1980s and the period after 2000. A decomposition of consumption over this period shows a rising contribution from the country-risk premium. This shock is very important for capturing the pronounced rise in the real exchange rate vis-a-vis the United States. A key factor driving the exchange rate movement in the data is a large improvement in Canada's terms of trade. The result in the model is a sharply increasing net foreign asset position. The long-lived effects on wealth lead households to consume more and work less. One key distinction between a positive housing demand and a negative risk premium shock is that the latter implies a reduction in hours worked. Together these two shocks are able to generate rising consumption and house prices and relatively little movement in hours worked consistent with the data from 2005 onward.

5. Conclusion

We estimate an open-economy DSGE model with residential investment and household borrowing constraints for Canada. In this model housing plays a key role as collateral and house prices add a new channel of transmission to consumption from aggregate shocks. Our goal is to better understand the links between the housing market and aggregate consumption in Canada. In particular we assess the empirical support for housing collateral effects on consumption.

We compare two estimated versions of the model, one with the financial accelerator effects and one where these effects are removed. We find that the FA model has a better fit to the data as measured by Bayes Factor comparisons. In addition, we obtain a parameter estimate associated with the share of constrained households that is empirically plausible. The FA model's main empirical advantage is in explaining the dynamics of consumption and its correlation with house prices. Overall the main impact of collateral constraints on the dynamics of our model come from the model response to a housing demand shock–a shock that has been emphasized in Jarocinski and Smets (2008) and in IMF (2008).

The model with credit frictions is able to generate rising consumption in response to a shock to housing demand. A positive housing demand shock increases the price of housing and the value of collateral, improving the borrowing capacity of credit constrained agents. As a result, our estimated model generates an increase in aggregate consumption after a rise in housing prices. The model attributes an important role to housing demand shocks for the consumption boom in the late 1980s and the drop in consumption that occurred in the recessions of the 1980s and 1990s. We find that this shock has been important in the recent housing boom, but, relative to the 1980s, external factors have played a larger role in housing market and consumption developments.

One result that merits further investigation is that the estimated collateral effects on consumption growth were smaller in the post-2000 period than in the late 1980s. This appears to be at odds with the fact that home-equity secured borrowing was much higher in the latter period. Home equity borrowing was less than 10 per cent of consumer credit in the late 1980s and is currently over 50 per cent. Extending the dataset to use information on credit flows could help to more directly identify these collateral effects. However, using financial flows information brings other challenges, in particular reconciling the differences between the financial instruments and the people who use them in the data with the environment in our model.

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Appendix A: Data sources

GDP Statistics Canada, National Income and Expenditure Accounts, Series v1992067 Real Gross Domestic Product, Expenditure-based - Canada; Millions Chained 1997 dollars; Seasonally adjusted at annual rates; Gross Domestic Product at market prices

Consumption Statistics Canada, National Income and Expenditure Accounts, Series v1992044 Real Gross Domestic Product, Expenditure-based - Canada; Millions Chained 1997 dollars; Seasonally adjusted at annual rates; Personal expenditure on consumer goods and services

Residential structures investment Statistics Canada, National Income and Expenditure Accounts, Series v1992053 Real Gross Domestic Product, Expenditure-based - Canada; Millions Chained 1997 dollars; Seasonally adjusted at annual rates; Residential structures

Business Fixed Investment Statistics Canada, National Income and Expenditure Accounts, Series v1992054 Real Gross Domestic Product, Expenditure-based - Canada; Millions Chained 1997 dollars; Seasonally adjusted at annual rates; Non-residential structures and equipment

Exports Statistics Canada, National Income and Expenditure Accounts, Series v1992060 Real Gross Domestic Product, Expenditure-based - Canada; Millions Chained 1997 dollars; Seasonally adjusted at annual rates; Exports of goods and services

Imports Statistics Canada, National Income and Expenditure Accounts, Series v1992063 Real Gross Domestic Product, Expenditure-based - Canada; Millions Chained 1997 dollars; Seasonally adjusted at annual rates; Imports of goods and services

Housing Stock Annual; Millions; Nominal; Book value:V33464 National balance sheet accounts by sectors - Canada; Persons and unincorporated business; Residential structures. V33469 National balance sheet accounts by sectors - Canada; Persons and unincorporated business; Land

House prices MLS102003 National Quarterly res. average price actual; seasonally adjusted (Monthly) and deflated data by core inflation.

Inflation Quarter to quarter change of PCPIX. CPIX Consumer price index (CPI) seasonally adjusted 2001 basket content - Canada; Core consumer price index (CPI); monthly

Interest rates BR.CDN Bank Rate (as at Wednesday);v122501 Government of Canada Bond yield averages - 10 yrs & over (average of the Wednesday values) ; monthly

Real Exchange Rate Nominal bilateral exchange rate multiplied by US CPI divided by Cdn CPIX with 2002 as base year

V37426 nominal bilateral exchange rate; Level of Canadian Dollar per US Dollar recorded at noon; Based on information obtained from the Foreign Interbank Market; Average of daily data

m.cusa0l1e US CPI; All items less food and energy - index base 1982-84 = 1.0; Seasonally adjusted - all urban consumers

Hours Worked v4391505 Labour force survey estimates (LFS) actual hours worked by North American Industry Classification System (NAICS) seasonally adjusted - Canada; Total actual hours worked all industries; monthly

Labour Compensation v498166 Sector accounts persons and unincorporated businesses - Canada; Wages salaries and supplementary labour income; Seasonally adjusted at annual rates;

Appendix B: Tables

Table 1: FA Parameters

Parameter		Prior Distribution			Posterior Distribution		
		Type	Mean	St. Dev.	Mean	5%	95%
Habit formation	γ	beta	0.5	0.25	0.7832	0.7267	0.8413
Slope of Labour Supply	η	gamma	2	1	0.5487	0.2823	0.7928
Adj. Cost for Housing	ψ_h	gamma	1	0.5	1.1723	0.8659	1.4425
Adj. Cost for capital	ψ_k	gamma	1	0.5	1.6102	0.9607	2.2711
Price Stickiness Domestic	θ_d	beta	0.5	0.1	0.8396	0.7970	0.8808
Price Stickiness Imports	θ_m	beta	0.5	0.1	0.8085	0.7580	0.8634
Price Stickiness Exports	θ_x	beta	0.5	0.1	0.2067	0.1123	0.2934
Price Stickiness Wages	θ_w	beta	0.5	0.25	0.3334	0.2817	0.3898
Elast. of Country Risk Prem.	Φ	inv. gamma	0.001	Inf	0.0006	0.0003	0.0009
UIP Lag	Φ_s	beta	0.25	0.15	0.1016	0.0190	0.1752
Share of Patient Households	α	beta	0.65	0.075	0.6234	0.5606	0.6831
Import Demand	σ	gamma	1	0.5	0.3455	0.1900	0.5041
Export Demand	σ_f	gamma	1	0.5	1.6418	1.1193	2.1309
Monetary Policy Rule							
Int. Rate Smoothing	ρ_r	beta	0.5	0.25	0.5279	0.4005	0.6600
Response to Inflation	ρ_π^{-1}	beta	0.5	0.25	0.5939	0.4787	0.7132
Response to Output	ρ_y	gamma	0.125	0.0625	0.0327	0.0103	0.0546

Auto-Regressive Coefficients of Shocks							
Housing Demand	ρ_j	beta	0.5	0.25	0.9758	0.9590	0.9943
Housing Supply	ρ_{Ah}	beta	0.5	0.25	0.9348	0.8989	0.9709
Capital Supply	ρ_{Ak}	beta	0.5	0.25	0.5021	0.3400	0.6692
Price Mark-Up	ρ_p	beta	0.5	0.25	0.7573	0.6292	0.8870
Labour Supply	ρ_L	beta	0.5	0.25	0.2418	0.0941	0.3791
Technology	ρ_z	beta	0.5	0.25	0.9850	0.9724	0.9967
Import Demand	ρ_m	beta	0.5	0.25	0.9039	0.8653	0.9433
Export Demand	ρ_x	beta	0.5	0.25	0.9850	0.9696	0.9968
Exchange Rate	ρ_s	beta	0.5	0.25	0.9420	0.9120	0.9780
Discount Factor	ρ_b	beta	0.5	0.25	0.2247	0.0304	0.4044
Inflation Objective	ρ_{IO}	beta	0.5	0.25	0.9939	0.9890	0.9995
Standard Deviations of Shocks							
Housing Demand	σ_j	inv. gamma	0.300	Inf	0.2986	0.2523	0.3404
Housing Supply	σ_{Ah}	inv. gamma	0.030	Inf	0.0334	0.0295	0.0372
Capital Supply	σ_{Ak}	inv. gamma	0.020	Inf	0.0180	0.0146	0.0212
Price Mark-Up	σ_w	inv. gamma	0.020	Inf	0.0228	0.0129	0.0323
Labour Supply	σ_L	inv. gamma	0.070	Inf	0.0817	0.0522	0.1105
Technology	σ_z	inv. gamma	0.010	Inf	0.0119	0.0105	0.0132
Monetary Policy	σ_{MP}	inv. gamma	0.003	Inf	0.0010	0.0007	0.0013
Import Demand	σ_M	inv. gamma	0.020	Inf	0.0219	0.0194	0.0243
Export Demand	σ_X	inv. gamma	0.025	Inf	0.0357	0.0265	0.0446
Exchange Rate	σ_s	inv. gamma	0.025	Inf	0.0197	0.0119	0.0268
Discount Factor	σ_b	inv. gamma	0.030	Inf	0.0291	0.0218	0.0365
Inflation Objective	σ_{IO}	inv. gamma	0.001	Inf	0.0020	0.0015	0.0024

Table 2: NOFA Parameters

Parameter		Prior Distribution			Posterior Distribution		
		Type	Mean	St. Dev.	Mean	5%	95%
Habit formation	γ	beta	0.5	0.25	0.6466	0.5442	0.7426
Slope of Labour Supply	η	gamma	2	1	0.6172	0.2996	0.9294
Adj. Cost for Housing	ψ_h	gamma	1	0.5	1.1403	0.8489	1.4283
Adj. Cost for capital	ψ_k	gamma	1	0.5	1.8293	1.1347	2.5245
Price Stickiness Domestic	θ_d	beta	0.5	0.1	0.8485	0.8079	0.8843
Price Stickiness Imports	θ_m	beta	0.5	0.1	0.8178	0.7628	0.8702
Price Stickiness Exports	θ_x	beta	0.5	0.1	0.2389	0.1147	0.3504
Price Stickiness Wages	θ_w	beta	0.5	0.25	0.3047	0.2503	0.3554
Elast. of Country Risk Prem.	Φ	inv. gamma	0.001	Inf	0.0005	0.0002	0.0007
UIP Lag	Φ_s	beta	0.25	0.15	0.0973	0.0155	0.1696
Import Demand	σ	gamma	1	0.5	0.3669	0.1941	0.5343
Export Demand	σ_f	gamma	1	0.5	1.3968	0.8871	1.8531
Monetary Policy Rule							
Int. Rate Smoothing	ρ_r	beta	0.5	0.25	0.4589	0.3321	0.5941
Response to Inflation	ρ_π	gamma	1.65	0.25	0.6144	0.5039	0.7271
Response to Output	ρ_y	gamma	0.125	0.0625	0.0277	0.0071	0.0465

Auto-Regressive Coefficients of Shocks							
Housing Demand	ρ_j	beta	0.5	0.25	0.9622	0.9389	0.9886
Housing Supply	ρ_{Ah}	beta	0.5	0.25	0.9391	0.9004	0.9786
Capital Supply	ρ_{Ak}	beta	0.5	0.25	0.4497	0.2669	0.6373
Price Mark-Up	ρ_w	beta	0.5	0.25	0.7665	0.6377	0.8859
Labour Supply	ρ_L	beta	0.5	0.25	0.3212	0.1750	0.4662
Technology	ρ_z	beta	0.5	0.25	0.9778	0.9628	0.9933
Import Demand	ρ_m	beta	0.5	0.25	0.9259	0.8923	0.9599
Export Demand	ρ_x	beta	0.5	0.25	0.9763	0.9628	0.9945
Exchange Rate	ρ_s	beta	0.5	0.25	0.9700	0.9495	0.9902
Discount Factor	ρ_b	beta	0.5	0.25	0.6595	0.5470	0.7772
Inflation Objective	ρ_{IO}	beta	0.5	0.25	0.9910	0.9844	0.9987
Standard Deviations of Shocks							
Housing Demand	σ_j	inv. gamma	0.300	Inf	0.3266	0.2801	0.3703
Housing Supply	σ_{Ah}	inv. gamma	0.030	Inf	0.0335	0.0298	0.0373
Capital Supply	σ_{Ak}	inv. gamma	0.020	Inf	0.0175	0.0136	0.0211
Price Mark-Up	σ_w	inv. gamma	0.020	Inf	0.0208	0.0121	0.0298
Labour Supply	σ_L	inv. gamma	0.070	Inf	0.0690	0.0447	0.0927
Technology	σ_z	inv. gamma	0.010	Inf	0.0120	0.0107	0.0134
Monetary Policy	σ_{MP}	inv. gamma	0.003	Inf	0.0009	0.0007	0.0012
Import Demand	σ_m	inv. gamma	0.020	Inf	0.0220	0.0196	0.0244
Export Demand	σ_x	inv. gamma	0.025	Inf	0.0318	0.0236	0.0396
Exchange Rate	σ_s	inv. gamma	0.025	Inf	0.0283	0.0163	0.0404
Discount Factor	σ_b	inv. gamma	0.030	Inf	0.0223	0.0164	0.0278
Inflation Objective	σ_{IO}	inv. gamma	0.001	Inf	0.0022	0.0017	0.0027

Table 3: Four-Step Ahead Standard Deviations

	Standard Deviations (Relative to the S.D. of GDP)		
	VAR Model	FA Model	NOFA Model
C	0.8227	0.7664	0.9346
L	0.8085	0.8645	0.8691
w	0.8936	0.7991	0.7804
I^k	3.2270	3.4813	3.4533
I^h	4.6170	3.2290	3.2850
qh	2.8936	2.3224	2.3458
π	0.2128	0.2477	0.2523
Y^x	2.4752	2.3785	2.3551
Y^m	2.6241	2.0234	1.8738
s	2.8298	2.5093	2.4252
yield spr.	0.1348	0.1589	0.1542

Table 4: Four-Step-Ahead Correlations

	Correlations		
	VAR Model	FA Model	NOFA Model
	Correlation with GDP		
C	0.6718	0.6433	0.5980
L	0.4522	0.3188	0.3648
I^k	0.4077	0.5438	0.5078
I^h	0.7148	0.2835	0.2071
π	-0.1128	-0.1359	-0.1395
	Correlation with House Prices		
C	0.4748	0.4617	0.1157
I^k	0.2307	0.1098	0.2157
I^h	0.5666	0.4757	0.4883

Appendix C: Figures

Figure C1: Detrended Data Series Used in Estimation

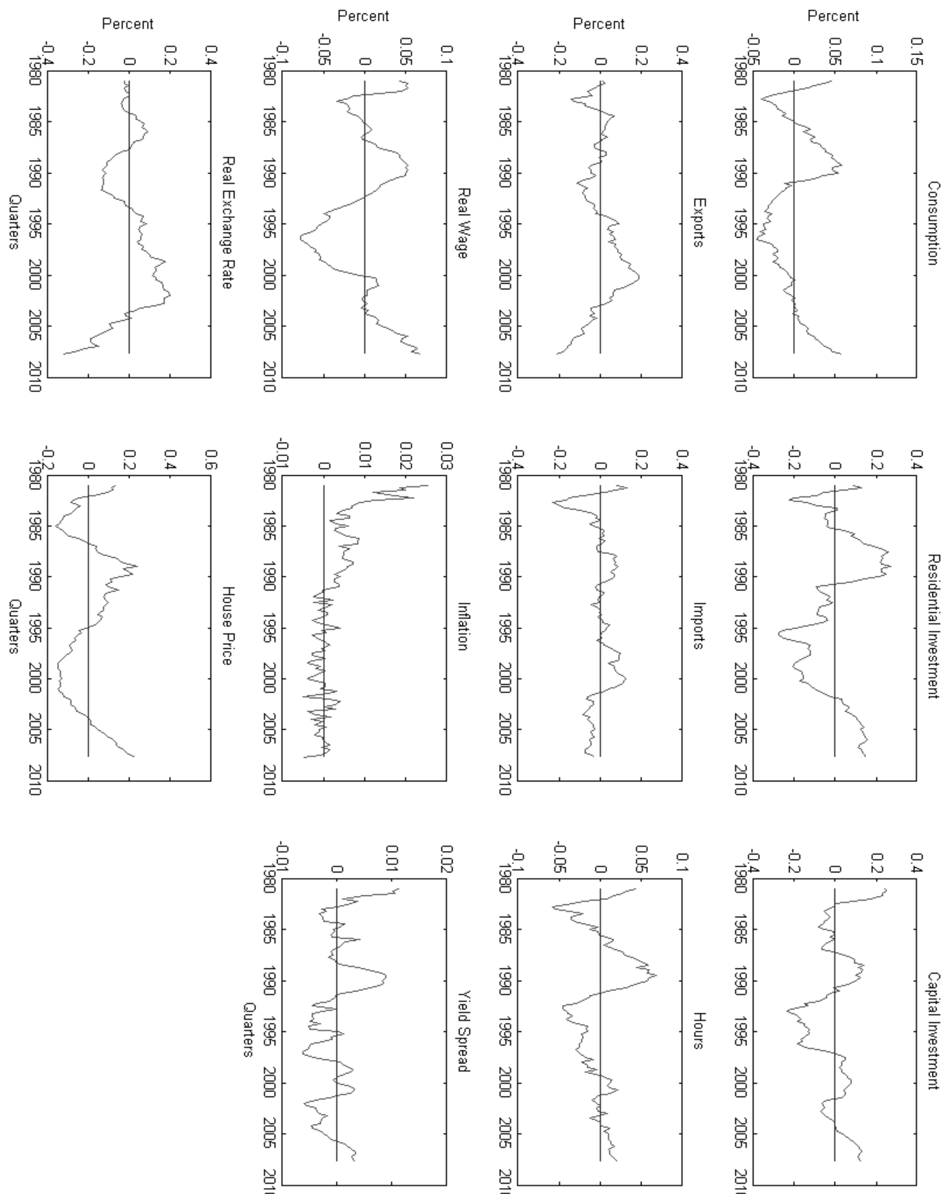

Figure C2: Mean responses of consumption to various shocks under the FA model (solid), vs. the 95% confidence bands under the NoFA model (dashed)

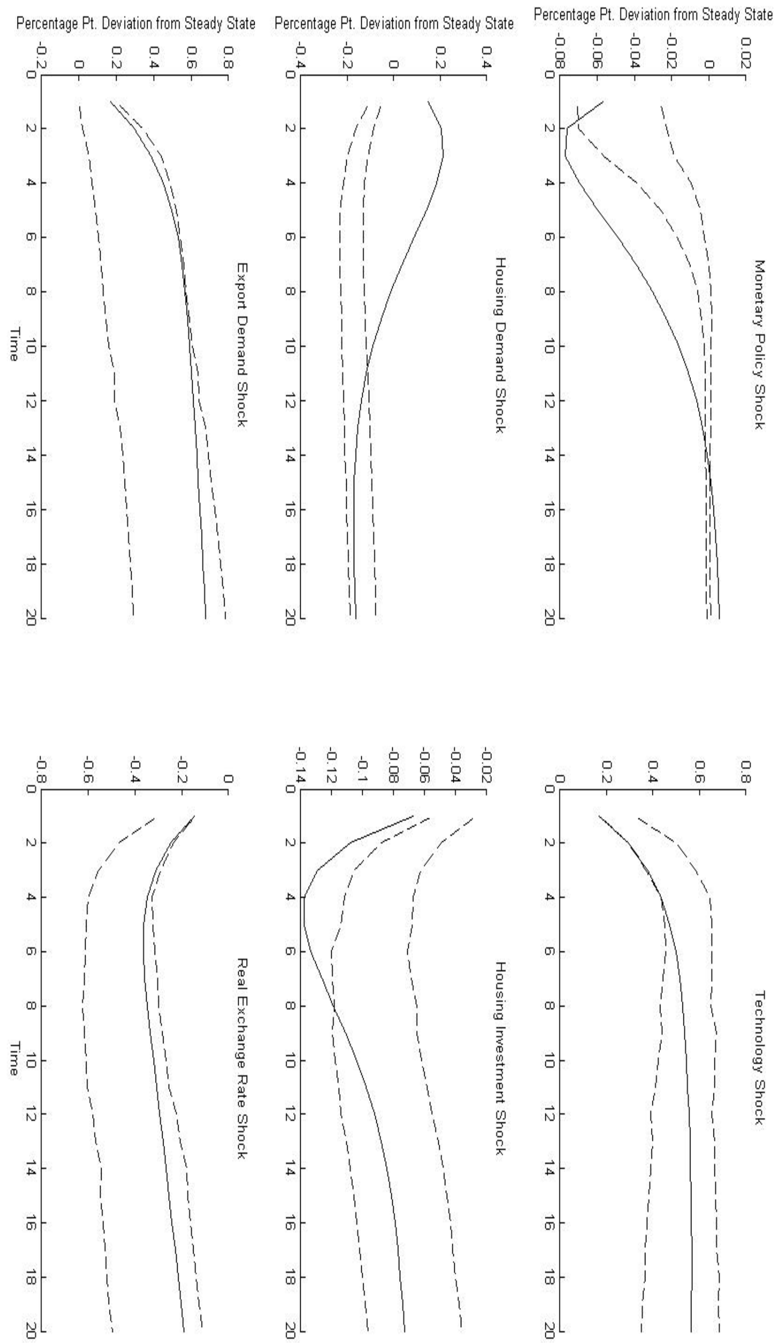

Figure C3: Impulse Responses to a Housing Demand Shock

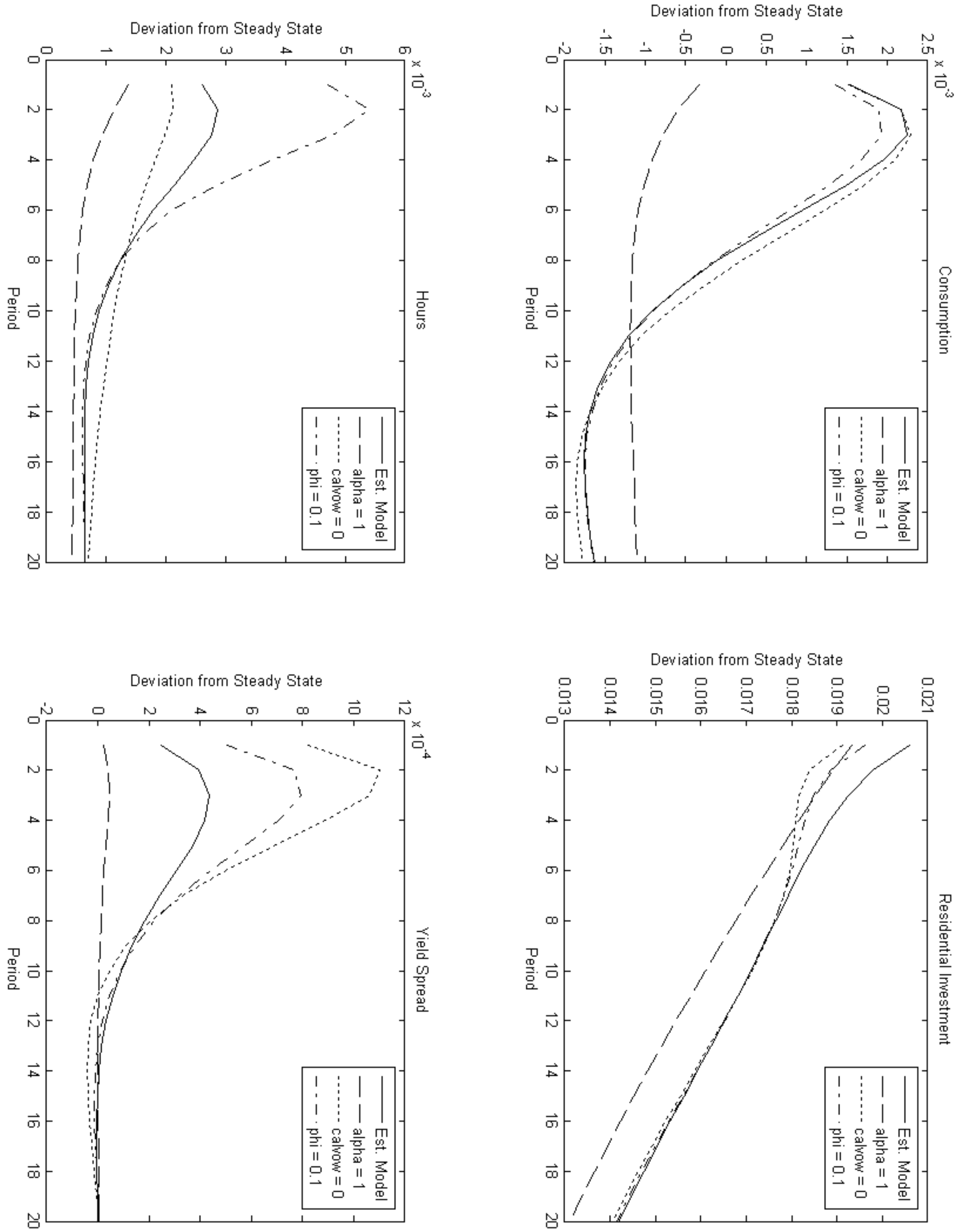

Figure C4: Decomposition of Housing Investment Variance (FA Model)

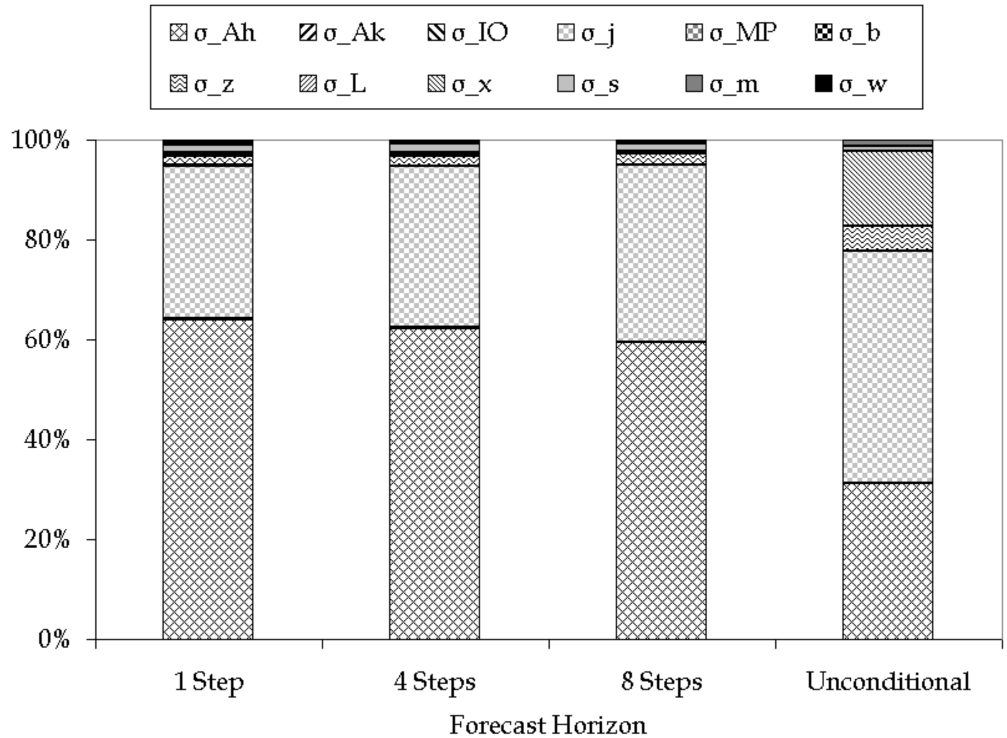

Figure C5: Decomposition of House Price Variance (FA Model)

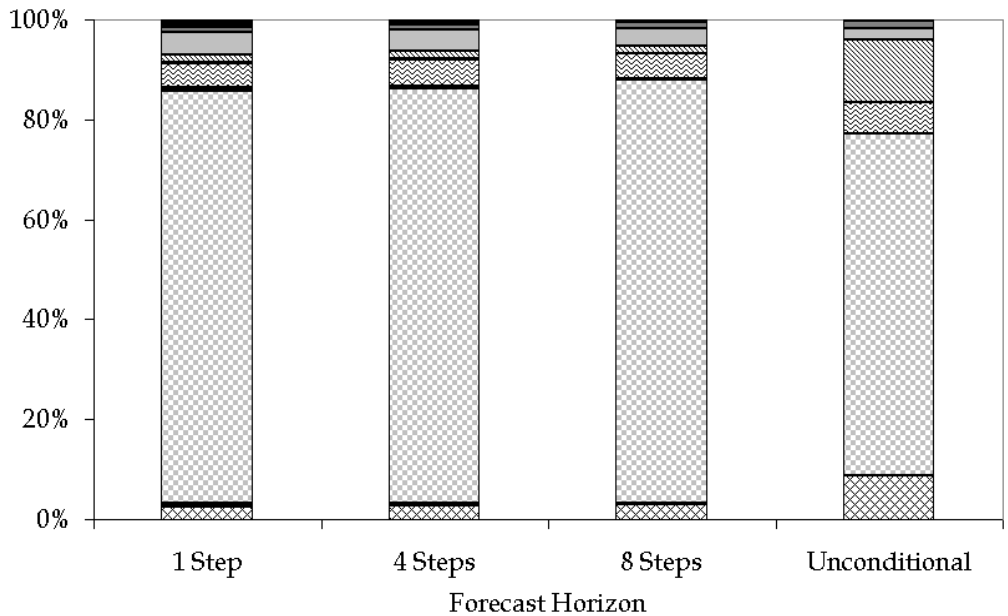

Figure C6: Decomposition of Variance of Inflation Deviation from Target (FA Model)

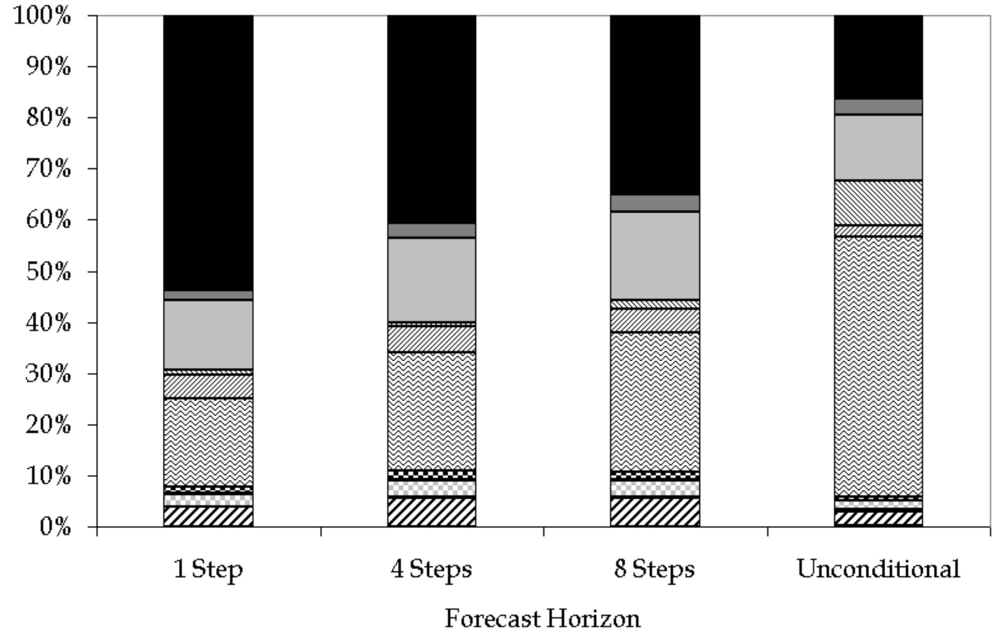

Figure C7: Decomposition of Consumption Variance (FA Model)

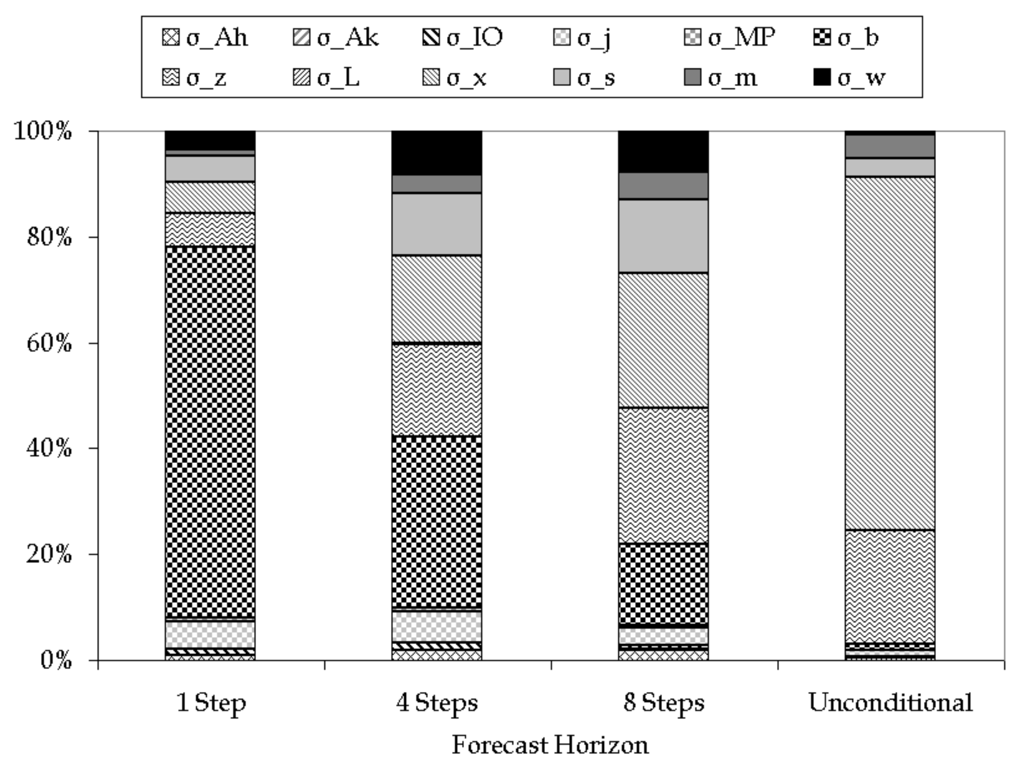

Figure C8: Decomposition of GDP Variance (FA Model)

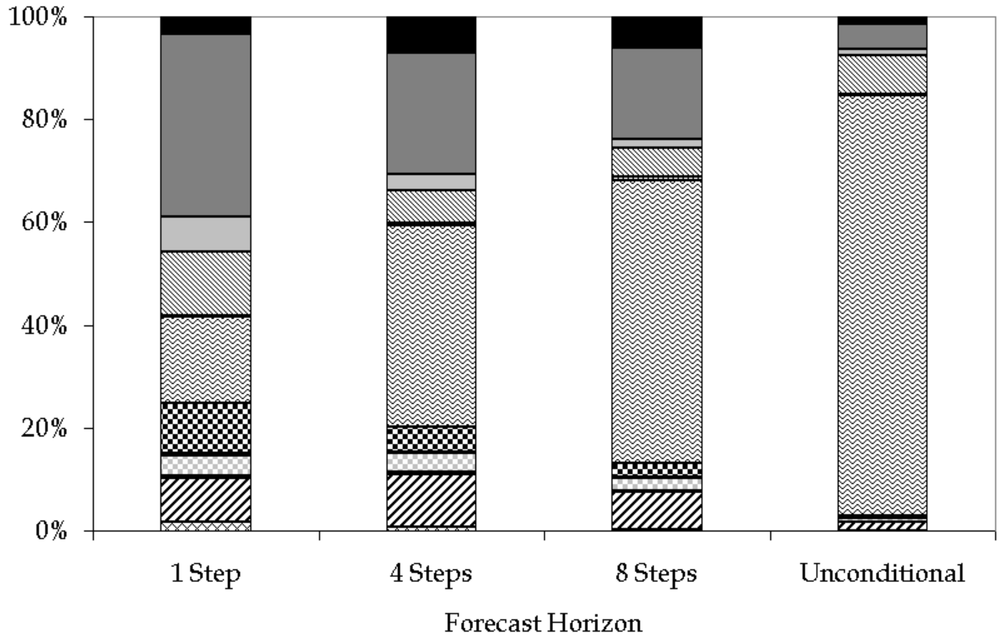

Figure C9: Decomposition of Yield Spread Variance (FA Model)

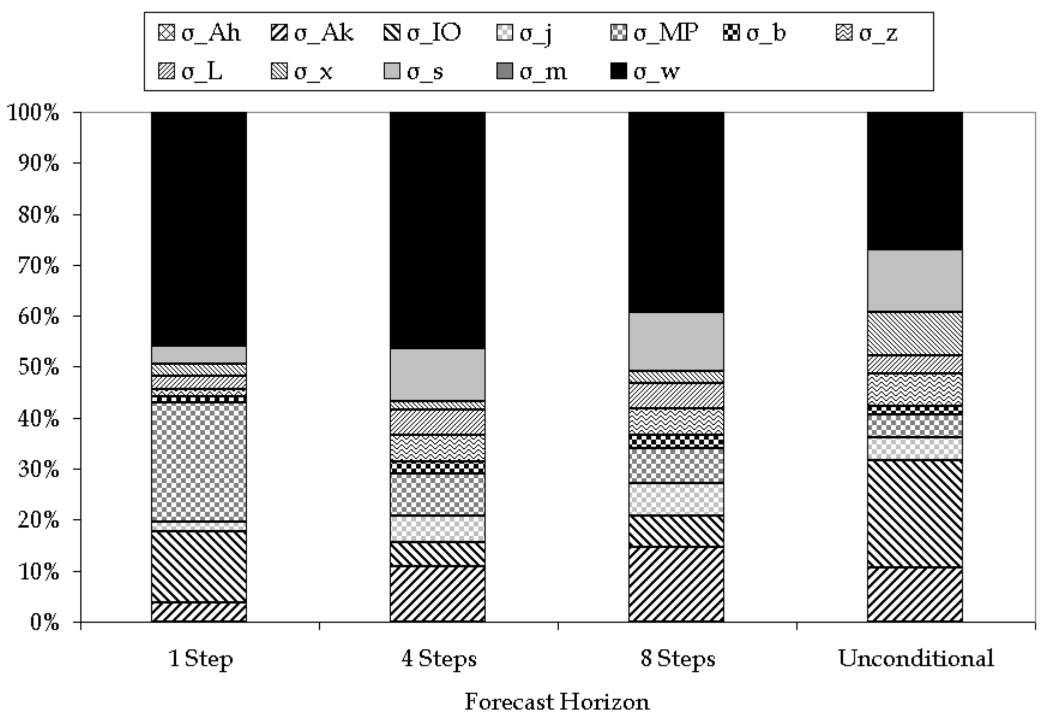

Figure C10: Contribution of Collateral Effects to Consumption