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September 2014

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Abstract

This paper incorporates home production into a real business cycle (RBC) model of a small open economy to provide a parsimonious explanation of the empirical pattern of international business cycles in developed economies and emerging markets. It is well known in the literature that in order for the RBC model to replicate quantitatively plausible empirical moments of small open economies, the model needs to feature counterfactually a small income effect on labor supply. This paper provides a plausible solution to this puzzle by considering home production that introduces substitutability between market consumption and home consumption, which in turn generates a high volatility in market consumption in accordance with the data, even in the presence of a sizable income effect on labor supply. Furthermore, the model with estimated parameter values based on the simulated method of moments is able to match other empirical moments, such as the standard deviations of output, investment and the trade balance and the correlations between output and other standard macroeconomic variables. Given that home production is more prevalent in emerging markets than in developed economies, the model is also able to replicate empirical differences between emerging markets and developed economies in the volatility of market consumption and the volatility/countercyclicality of the trade balance.

JEL classification: D13, E32, F41, O16
Keywords: small open economy; home production; emerging markets; business cycles.

The authors would like to thank Juin-Jen Chang, Nan-Kuang Chen, Yi-Chan Tsai and seminar participants at National Taiwan University for their helpful suggestions and comments. The usual disclaimer applies.

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1 Introduction

Developed small open economies are characterized by the following stylized facts. First, consumption is less volatile than output. Second, investment is more volatile than output. Third, the trade balance to GDP ratio is weakly countercyclical. In their pioneering works, Mendoza (1991), Correia *et al.* (1995), and Schmitt-Grohé and Uribe (2003) develop a workhorse real business cycle (RBC) model of a small open economy to explain these stylized facts.[1] In order for the RBC model to replicate quantitatively plausible empirical moments of small open economies, the model needs to feature counterfactually a small income effect on labor supply, which is accomplished by specifying the representative household's utility function in the form proposed by Greenwood *et al.* (1988) (hereafter the GHH preference). However, Correia *et al.* (1995) find that, when the income effect on labor supply is present as in the utility function proposed by King *et al.* (1988) (hereafter the KPR preference), volatilities of consumption and the trade balance to GDP ratio decrease significantly and the trade balance to GDP ratio becomes procyclical. With this understanding, we can infer that under the KPR preference with a sizable income effect on labor supply, it is difficult for the RBC model to replicate quantitatively plausible empirical moments of developed small open economies.

The intuition behind the above result can be explained as follows. Given that the world interest rate faced by a small open economy is exogenous, the variation in the marginal utility of consumption tends to be small in response to a domestic technology shock. In the case of the KPR preference that features a sizable income effect on labor supply, consumption and leisure are complements in utility. Thus, an increase in equilibrium labor led by a positive technology shock reduces leisure and restrains the increase in consumption. As a result, consumption is not as volatile as in the data. By contrast, under the GHH preference that does not feature any income effect on labor supply, consumption and leisure are substitutes in utility. In this case, a positive technology shock reduces leisure and increases consumption significantly. As a result, consumption can be as volatile as in the data. However, empirical studies, such as Imbens *et al.* (2001), Kimball and Shapiro (2010) and Khan and Tsoukalas (2011, 2012), often find a sizable income effect on labor supply, implying that the KPR preference is the more plausible specification for the utility function.

In this study, we provide a solution to this puzzle by considering home production. Specifically, we consider two distinctive products: a home-produced product and a market-produced product. The home-produced product is not traded in the market; instead, it is consumed by the representative household for its own satisfaction. An advantage of the introduction of home production is that it allows the household to substitute between home consumption and market consumption, which in turn generates a high volatility in market consumption in accordance with the data, even in the presence of a sizable income effect on labor supply. The presence of substitutability between market consumption and home consumption is supported by Blankenau and Kose (2007).[2]

[1] For seminal studies on the two-country RBC model; see for example Backus *et al.* (1992) and Stockman and Tesar (1995).

[2] Based on data of market variables in industrialized countries, Blankenau and Kose (2007) use the small open economy RBC model to generate artificial data of home variables. They find that market consumption is negatively correlated with home consumption, and market hours worked are negatively correlated with

Intuitively, in the presence of home production, when the domestic economy experiences a positive technology shock in the production of market goods, the representative household increases its market consumption and substitutes away from home consumption. This substitution effect between market consumption and home consumption introduces a channel for an increase in the volatility of market consumption. In addition, given that home production strengthens the increase in market consumption under a positive technology shock, it also dampens the increase in domestic savings (i.e., the trade balance plus aggregate investment). In order to finance the increased demand for aggregate investment, the household turns to borrow from the world market, thereby causing a reduction in the trade balance to GDP ratio. This result implies that the trade balance to GDP ratio becomes countercyclical and possibly more volatile. Accordingly, home production can be viewed as a plausible channel to explain business cycles in small open economies.

Moreover, some studies highlight the different features of business cycles between emerging markets and developed economies. In their influential articles, Neumeyer and Perri (2005) and Aguiar and Gopinath (2007) point out three important differences between these two types of economies. First, the volatility of output in emerging markets is higher than that in developed economies. Second, the volatility of output exceeds the volatility of consumption in developed economies, whereas output is less volatile than consumption in emerging markets. Third, the trade balance to GDP ratio is more volatile and more countercyclical in emerging markets than in developed economies. Some studies are devoted to explaining these empirical differences between emerging markets and developed economies. Neumeyer and Perri (2005) introduce a country risk shock to amplify the intertemporal substitution between current and future consumption. Aguiar and Gopinath (2007) and Boz *et al.* (2011) emphasize the importance of trend shocks to technology. In this study, we consider home production to be a parsimonious explanation of the empirical pattern of international business cycles in developed economies and emerging markets. Given that home production is more prevalent in emerging markets than in developed economies,[3] our model is able to replicate empirical differences between these two types of economies in the volatility of market consumption and the volatility/countercyclicality of the trade balance.

The remainder of this paper proceeds as follows. Section 2 documents stylized facts of developed economies and emerging markets. Section 3 develops a small open economy RBC model with home production and characterizes the domestic economy's competitive equilibrium. Section 4 analyzes the quantitative results and provides an analytical illustration of the main results. Section 5 discusses the concluding remarks.

2 Stylized facts

In this section, we first document stylized facts of business cycles in small open economies and update business cycle moments from previous studies. We begin by describing a data set in

home hours worked.

[3]Suppose we consider home production as part of the informal economy. Friedman *et al.* (2000) find that the size of the informal economy is negatively related to GDP per capita. Schneider and Enste (2000) estimate that the size of the informal economy is 39% of GDP in developing economies and 12% of GDP in developed economies. See also the evidence in Table 3.

which the sample includes 27 small open economies. According to the classification of Morgan Stanley Capital International (MSCI), the sample countries are divided into developed economies and emerging markets. In our sample, developed economies consist of 13 countries: Australia, Austria, Belgium, Canada, Denmark, Finland, Luxembourg, the Netherlands, New Zealand, Portugal, Spain, Sweden, and Switzerland. Emerging markets consist of 14 countries: Argentina, Brazil, the Czech Republic, Estonia, Hungary, Korea, Malaysia, Mexico, Poland, the Slovak Republic, Slovenia, South Africa, Thailand, and Turkey.

Table 1: Business cycle moments in developed economies

Country	sample	$std(\hat{y}_t)$	$\frac{std(\hat{c}_{m,t})}{std(\hat{y}_t)}$	$\frac{std(\hat{I}_t)}{std(\hat{y}_t)}$	$std(\hat{b}_t)$	$corr(\hat{c}_{m,t}, \hat{y}_t)$	$corr(\hat{I}_t, \hat{y}_t)$	$corr(\hat{b}_t, \hat{y}_t)$
Australia	78:I-08:III	1.38	0.80	3.51	0.95	0.35	0.81	−0.34
Austria	78:I-08:III	1.03	0.94	2.28	0.77	0.68	0.58	−0.05
Belgium	78:I-08:III	0.99	1.02	4.15	1.05	0.70	0.75	−0.31
Canada	78:I-08:III	1.47	0.78	2.91	0.91	0.61	0.73	−0.10
Denmark	78:I-08:III	1.37	1.28	4.16	1.06	0.74	0.69	−0.41
Finland	78:I-08:III	1.94	0.64	3.56	1.36	0.56	0.87	−0.26
Luxembourg	78:I-08:III	1.79	1.29	4.41	2.57	0.41	0.33	0.23
Netherlands	78:I-08:III	1.28	0.93	3.47	0.94	0.69	0.72	−0.10
New Zealand	78:I-08:III	1.80	1.04	3.42	1.41	0.52	0.59	0.02
Portugal	78:I-08:III	1.65	1.12	3.86	1.81	0.66	0.81	−0.48
Spain	78:I-08:III	1.09	1.18	4.00	1.02	0.78	0.76	−0.47
Sweden	78:I-08:III	1.35	0.99	3.79	0.99	0.46	0.78	−0.09
Switzerland	78:I-08:III	1.25	0.76	2.99	0.96	0.68	0.83	−0.44
Average		1.32	0.94	3.47	1.02	0.63	0.75	−0.25

Notes: For each country, the business cycle moments include the standard deviations of output $std(\hat{y}_t)$, market consumption $std(\hat{c}_{m,t})$, investment $std(\hat{I}_t)$ and the trade balance to GDP ratio $std(\hat{b}_t)$ and the correlation coefficients between consumption and output $corr(\hat{c}_{m,t}, \hat{y}_t)$, investment and output $corr(\hat{I}_t, \hat{y}_t)$, and the trade balance to GDP ratio and output $corr(\hat{b}_t, \hat{y}_t)$. All variables except the trade balance to GDP ratio $\hat{b}_t$ are in natural logarithms, and all variables (including $\hat{b}_t$) are de-trended by the HP-filter with the smoothing parameter set to 1600. The standard deviations of output, market consumption, investment, and the trade balance to GDP ratio are reported in percentage terms. In addition, the average moments are weighted by each country's share of each group's GDP (in US dollars in 2000).

The data that we use comes from the database of the Organisation for Economic Co-operation and Development (OECD) for the available period 1978:I-2008:III.[4] For each country, there are six time series of data used in the computation of empirical moments: GDP $\hat{y}_t$, private final consumption $\hat{c}_{m,t}$, gross fixed capital formation $\hat{I}_t$, the trade balance to GDP ratio $\hat{b}_t$, population (defined as persons 16 years of age and older), and the GDP deflator.[5]

[4] The only exceptions are that the data on Malaysia and Thailand come from the CEIC-Asia database and the data on population in Argentina come from the International Labor Organization (ILO) database.

[5] The series of the trade balance to GDP ratio $\hat{b}_t$ is derived from the trade balance divided by GDP, and the trade balance is derived by subtracting imports of goods and services from exports of goods and services. In addition, given the fact that the series of the GDP deflator is derived from nominal gross domestic product divided by real gross domestic product, we can then use the GDP deflator to deflate nominal values of the relevant variables.

The time series data we use is seasonally adjusted.[6] All variables except the trade balance to GDP ratio $\hat{b}_t$ are in natural logarithms, and all variables (including $\hat{b}_t$) are de-trended by the HP-filter with the smoothing parameter set to 1600.

Given the data, we compute the business cycle moments for each country including the standard deviation of output $std(\hat{y}_t)$, the standard deviation of market consumption $std(\hat{c}_{m,t})$, the standard deviation of investment $std(\hat{I}_t)$, the standard deviation of the trade balance to GDP ratio $std(\hat{b}_t)$, the correlation coefficient between consumption and output $corr(\hat{c}_{m,t}, \hat{y}_t)$, the correlation coefficient between investment and output $corr(\hat{I}_t, \hat{y}_t)$, and the correlation coefficient between the trade balance to GDP ratio and output $corr(\hat{b}_t, \hat{y}_t)$. The business cycle moments in developed economies and emerging markets are summarized in Table 1 and Table 2, respectively. Moreover, it should be noted that in Table 1 and Table 2, the average moments in the last row are weighted by each country's share of the group's aggregate GDP.

Table 2: Business cycle moments in emerging market economies

Country	sample	$std(\hat{y}_t)$	$\frac{std(\hat{c}_{m,t})}{std(\hat{y}_t)}$	$\frac{std(\hat{I}_t)}{std(\hat{y}_t)}$	$std(\hat{b}_t)$	$corr(\hat{c}_{m,t}, \hat{y}_t)$	$corr(\hat{I}_t, \hat{y}_t)$	$corr(\hat{b}_t, \hat{y}_t)$
Argentina	93:I-08:III	4.12	1.36	3.17	2.81	0.93	0.92	−0.82
Brazil	96:I-08:III	1.37	1.44	3.35	0.96	0.71	0.76	−0.32
Czech Republic	95:I-08:III	1.24	1.11	3.20	1.31	0.59	0.62	−0.35
Estonia	95:I-08:III	2.36	1.22	3.65	2.51	0.80	0.88	−0.58
Hungary	95:I-08:III	0.98	2.22	2.34	1.61	0.43	0.30	−0.26
Korea	78:I-08:III	2.42	1.35	2.41	2.55	0.76	0.76	−0.43
Malaysia	91:I-08:III	2.76	1.62	4.53	4.59	0.73	0.81	−0.62
Mexico	78:I-08:III	2.53	1.26	3.39	2.07	0.77	0.82	−0.60
Poland	95:I-08:III	1.35	1.33	4.58	1.08	0.54	0.77	−0.56
Slovak Republic	93:I-08:III	1.58	1.53	6.10	4.10	0.46	0.57	−0.26
Slovenia	96:I-08:III	0.86	1.30	5.03	1.68	0.26	0.51	−0.08
South Africa	78:I-08:III	1.79	1.46	3.27	2.44	0.62	0.69	−0.41
Thailand	94:I-08:III	3.60	1.08	3.43	4.17	0.93	0.91	−0.68
Turkey	78:I-08:III	3.01	1.35	3.38	1.67	0.66	0.79	−0.50
Average		2.34	1.36	3.30	2.07	0.73	0.78	−0.50

Notes: For each country, the business cycle moments include the standard deviations of output $std(\hat{y}_t)$, market consumption $std(\hat{c}_{m,t})$, investment $std(\hat{I}_t)$ and the trade balance to GDP ratio $std(\hat{b}_t)$ and the correlation coefficients between consumption and output $corr(\hat{c}_{m,t}, \hat{y}_t)$, investment and output $corr(\hat{I}_t, \hat{y}_t)$, and the trade balance to GDP ratio and output $corr(\hat{b}_t, \hat{y}_t)$. All variables except the trade balance to GDP ratio $\hat{b}_t$ are in natural logarithms, and all variables (including $\hat{b}_t$) are de-trended by the HP-filter with the smoothing parameter set to 1600. The trade balance to GDP ratio are reported in percentage terms. In addition, the average moments are weighted by each country's share of each group's GDP (in US dollars in 2000).

In view of the business cycle moments exhibited in Table 1 and Table 2, we can find three stylized facts of business cycles in developed economies and emerging markets, which are consistent with the findings in Neumeyer and Perri (2005), Aguiar and Gopinath (2007) and Ávarez-Parra *et al.* (2013). First, output is more volatile in emerging markets than in developed economies. Specifically, the average standard deviations of output $std(\hat{y}_t)$ are

[6] We employ the X-12 ARIMA program provided by the U.S. Census Bureau to produce the seasonally-adjusted data.

respectively 1.32 and 2.34 in developed economies and emerging markets. Second, market consumption is less volatile than output in developed economies, whereas it is more volatile than output in emerging markets. Specifically, the average ratios between the standard deviations of market consumption and output $std(\hat{c}_{m,t})/std(\hat{y}_t)$ are respectively 0.94 for developed economies and 1.36 for emerging markets. Third, the trade balance to GDP ratio is more volatile and more countercyclical in emerging markets than in developed economies. Specifically, the average standard deviations of the trade balance to GDP ratio $std(\hat{b}_t)$ are respectively 1.02 for developed economies and 2.07 for emerging markets. Furthermore, the average correlation coefficients between the trade balance to GDP ratio and output $corr(\hat{b}_t, \hat{y}_t)$ are respectively –0.25 for developed economies and –0.50 for emerging markets. With these stylized facts, we will develop a small open economy model in the next section and test the model by replicating the business cycle features exhibited above.

In the rest of this section, we document some stylized facts of market and home production in Canada and Mexico, given that we consider Canada and Mexico respectively as a representative developed economy and a representative emerging market. The time-use survey data for Canada are obtained from Statistics Canada, General Social Survey in 2005, and the time-use survey data for Mexico are from the Instituto Nacional de Estadística y Geografía (INEGI), Encuesta Nacional sobre Uso del Tiempo in 2009. Based on these time-use survey data for Canada and Mexico, both home hours worked and market hours worked are depicted in Table 3. As shown in Table 3, we calculate the ratio between time on home hours worked and market hours worked to be 0.89 in Canada and 1.42 in Mexico, showing that home production is more prevalent in an emerging market than in a developed economy. After estimating the model using other empirical moments, we will also compare the simulation results to the data in Table 3 as a robustness check.

Table 3: Business cycle moments in developed economies

	Canada	*Mexico*
Home hours worked per day	3.1	5.16
Market hours worked per day	3.5	3.624
The ratio between home hours worked and market hours worked	0.89	1.42

Notes: Based on the time-use data, market hours worked is measured by time spent on paid market work, and home market hours worked is measured by time spent on the activities of unpaid household work. Following Ramey and Francis (2009), we define home production activities as: planning, purchasing goods and services, care of children and adults, general cleaning, care and repair of the house and grounds, preparing and clearing food, making, mending, and laundering of clothing and other household textiles.

3 A small open economy RBC model with home production

The domestic economy is inhabited by a representative household. In what follows, we describe the behavior of the representative household and characterize the competitive equilibrium of the economy.

3.1 The representative household-producer

We follow Benhabib *et al.* (1991) and Baxter and Jermann (1999) to model home production in the RBC model. The representative household-producer derives utility from aggregate consumption C_t, which is composed of market consumption $c_{m,t}$ and home consumption $c_{h,t}$, and incurs disutility from total hours worked N_t, which is the sum of market hours worked $n_{m,t}$ and home hours worked $n_{h,t}$. In line with Jaimovich and Rebelo (2009), we propose the following utility function that nests the GHH preference and the KPR preference as special cases:

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \frac{(C_t - \omega N_t^{\chi} X_t)^{1-\sigma} - 1}{1-\sigma}, \tag{1}$$

where aggregate consumption C_t, total hours worked N_t and the geometric average of current and past consumption levels X_t are defined as follows:

$$X_t = C_t^{\gamma} X_{t-1}^{1-\gamma}, \tag{2a}$$

$$C_t = \left[\theta c_{m,t}^{\phi} + (1-\theta)\, c_{h,t}^{\phi}\right]^{\frac{1}{\phi}}, \tag{2b}$$

$$N_t = n_{m,t} + n_{ht}, \tag{2c}$$

where θ denotes the utility share of market consumption, ϕ governs the elasticity of substitution between market and home consumption (i.e., $e \equiv \frac{1}{1-\phi}$), σ stands for the inverse of the intertemporal elasticity of substitution in consumption, χ denotes the inverse of the Frisch labor supply elasticity, β represents the household's subjective discount factor, and ω denotes the scaling disutility of labor supply. A salient feature of the Jaimovich-Rebelo preference reported in equations (1) and (2a) is that γ parameterizes the short-run wealth effect of labor supply. When $\gamma = 1$, the sizable wealth effect leads to a reduction in labor supply upon experiencing a productivity improvement, and this is associated with the KPR preference.[7] When $\gamma = 0$, the absence of a wealth effect leads to an increase in labor supply upon the arrival of a productivity improvement, and this is associated with the GHH preference.

Each representative household produces market output and home consumption goods according to the following Cobb-Douglas form:

$$y_t = A_{m,t} k_{m,t}^{\alpha_m} n_{m,t}^{1-\alpha_m}, \tag{3a}$$

$$c_{h,t} = A_{h,t} k_{h,t}^{\alpha_h} n_{h,t}^{1-\alpha_h}, \tag{3b}$$

where $k_{m,t}$ and $k_{h,t}$ respectively denote market capital and home capital, α_m and α_h respectively denote the production share of market capital and home capital, and $A_{m,t}$ and $A_{h,t}$ respectively denote the level of total factor productivity in each production sector. We assume that the natural logarithms of both total factor productivity processes are persistent, following a first-order autoregressive process:

$$\log A_{m,t} = \rho_m \log A_{m,t-1} + \varepsilon_{m,t}, \tag{4a}$$

[7] In the case of a productivity improvement, the decrease in labor supply is offset by an increase in labor demand such that labor input increases in equilibrium.

$$\log A_{h,t} = \rho_h \log A_{h,t-1} + \varepsilon_{h,t}, \tag{4b}$$

where ρ_m and ρ_h denote persistent parameters and $\varepsilon_{m,t}$ and $\varepsilon_{h,t}$ denote exogenous innovations in the market and home production sectors, respectively. Both $\varepsilon_{m,t}$ and $\varepsilon_{h,t}$ are normally distributed with zero mean and finite variance $\sigma^2_{m,t}$ and $\sigma^2_{h,t}$. Following Baxter and Jermann (1999), we assume that there is no transmission of shocks from one sector to the other one.

In each period, the representative household can finance its budget deficit by borrowing from the world market, and a flow of foreign debt is linked to any difference between its expenditure and its income. Let d_t denote foreign debt measured in terms of domestic output and r_t represent the world real interest rate on foreign debt. The household's flow budget constraint can then be expressed as:

$$d_{t+1} = (1+r_t)d_t + c_{m,t} + I_{m,t}\left[1 + \Psi_m\left(\frac{I_{m,t}}{k_{m,t}}\right)\right] + I_{h,t}\left[1 + \Psi_h\left(\frac{I_{h,t}}{k_{h,t}}\right)\right] - y_t, \tag{5}$$

where $I_{m,t}$ and $I_{h,t}$ denote investment in market capital and home capital. The representative household installs market and home capital involving extra adjustment costs (installation costs). In line with Hayashi (1982) and Abel and Blanchard (1983), the adjustment cost functions in the two sectors are specified as follows:

$$\Psi_m\left(\frac{I_{m,t}}{k_{m,t}}\right) = \frac{\psi_m}{2}\frac{I_{m,t}}{k_{m,t}}, \tag{6a}$$

$$\Psi_h\left(\frac{I_{h,t}}{k_{h,t}}\right) = \frac{\psi_h}{2}\frac{I_{h,t}}{k_{h,t}}, \tag{6b}$$

where $\Psi_m\left(\frac{I_{m,t}}{k_{m,t}}\right)$ and $\Psi_h\left(\frac{I_{h,t}}{k_{h,t}}\right)$ reflect the adjustment costs incurred by each unit of market capital investment and home capital investment. ψ_m and ψ_h denote the intensity parameters of the investment adjustment costs in the market and home sectors. Unit adjustment costs that depend upon investment relative to the capital stock can be justified by learning-by-doing in the installation process. As is evident in equations (6a) and (6b), the investment adjustment cost functions satisfy the following properties: $\Psi'_m(\cdot) > 0$ and $\Psi'_h(\cdot) > 0$.

Aggregate investment and the law of motion of the capital stock in each sector can be specified as follows:

$$k_{m,t+1} = (1-\delta_m)\, k_{m,t} + I_{m,t}, \tag{7a}$$

$$k_{h,t+1} = (1-\delta_h)\, k_{h,t} + I_{h,t}, \tag{7b}$$

$$I_t = I_{m,t} + I_{h,t}, \tag{7c}$$

where δ_m and δ_h respectively stand for the depreciate rates of market capital and home capital and I_t denotes aggregate investment.

The sequence of $\{c_{m,t}, c_{h,t}, X_t, n_{m,t}, n_{h,t}, I_{m,t}, I_{h,t}, k_{m,t+1}, k_{h,t+1}, d_{t+1}\}$ is chosen by the household to maximize lifetime utility in equation (1) subject to equations (2a)-(7c). Let g_t, μ_t, λ_t, $q'_{m,t}$ and $q'_{h,t}$ be the Lagrange multipliers associated with (2a), (3b), (5), (7a) and (7b), respectively. We define $q_{m,t} \equiv \frac{q'_{m,t}}{\lambda_t}$ and $q_{h,t} \equiv \frac{q'_{h,t}}{\lambda_t}$ such that $q_{m,t}$ and $q_{h,t}$ represent the relative prices of additional installed market and home capital in terms of the marginal utility of consumption. The optimality conditions necessary for the representative household with respect to the indicated variables are:

$$c_{m,t}: \quad \left[(C_t - \omega N_t^{\chi} X_t)^{-\sigma} + g_t \gamma \left(\frac{C_t}{X_{t-1}} \right)^{\gamma-1} \right] \theta \left(\frac{c_{m,t}}{C_t} \right)^{\phi-1} = \lambda_t, \tag{8a}$$

$$c_{h,t}: \quad \frac{\theta}{1-\theta} \left(\frac{c_{m,t}}{c_{h,t}} \right)^{\phi-1} = \frac{\lambda_t}{\mu_t}, \tag{8b}$$

$$X_t: \quad (C_t - \omega N_t^{\chi} X_t)^{-\sigma} \omega N_t^{\chi} + g_t = \beta g_{t+1}(1-\gamma) \left(\frac{C_{t+1}}{X_t} \right)^{\gamma}, \tag{8c}$$

$$n_{m,t}: \quad \frac{(C_t - \omega N_t^{\chi} X_t)^{-\sigma} \omega \chi N_t^{\chi-1}}{(C_t - \omega N_t^{\chi} X_t)^{-\sigma} + g_t \gamma \left(\frac{C_t}{X_{t-1}} \right)^{\gamma-1}} \frac{X_t}{\theta} \left(\frac{c_{m,t}}{C_t} \right)^{1-\phi} = (1-\alpha_m) \frac{y_t}{n_{m,t}}, \tag{8d}$$

$$n_{h,t}: \quad \frac{\mu_t}{\lambda_t} = \frac{1-\alpha_m}{1-\alpha_h} \frac{y_t / n_{m,t}}{c_{h,t}/n_{h,t}}, \tag{8e}$$

$$I_{m,t}: \quad \frac{I_{m,t}}{k_{m,t}} = \frac{q_{m,t}-1}{\psi_m}, \tag{8f}$$

$$I_{h,t}: \quad \frac{I_{h,t}}{k_{h,t}} = \frac{q_{h,t}-1}{\psi_h}, \tag{8g}$$

$$k_{m,t+1}: \quad q_{m,t} = \beta \frac{\lambda_{t+1}}{\lambda_t} \left[\alpha_m \frac{y_{t+1}}{k_{m,t+1}} + \frac{(q_{m,t+1}-1)^2}{2\psi_m} + (1-\delta_m) q_{m,t+1} \right], \tag{8h}$$

$$k_{h,t+1}: \quad q_{h,t} = \beta \frac{\lambda_{t+1}}{\lambda_t} \left[\alpha_h \frac{\mu_{t+1}}{\lambda_{t+1}} \frac{c_{h,t+1}}{k_{h,t+1}} + \frac{(q_{h,t+1}-1)^2}{2\psi_h} + (1-\delta_h) q_{h,t+1} \right], \tag{8i}$$

$$d_{t+1}: \quad 1 = \beta \frac{\lambda_{t+1}}{\lambda_t} (1 + r_{t+1}). \tag{8j}$$

3.2 Competitive equilibrium

The representative household has access to the world capital market and is able to borrow from the international market. In line with Edwards (1984), Chung and Turnovsky (2010), Li (2011) and Heer and Schubert (2012), the household faces an upward-sloping curve for debt when borrowing from abroad. More specifically, to reflect the extent of default risk in association with foreign debt, the borrowing rate charged by the foreign country on debt is specified to be positively related to the debt to GDP ratio:

$$r_{t+1} = R + \eta \left[\exp\left(\frac{d_{t+1}}{y_t} - \upsilon \right) - 1 \right]. \tag{9}$$

In equation (9), the parameter R denotes the exogenous component of the world interest rate and the parameter υ reflects the stationary foreign debt to output ratio. The parameter η reflects the borrowing premium associated with default risk and can be interpreted as the extent of country default risk. For ease of exposition, we use b_t to denote the trade balance to GDP ratio; i.e., $b_t \equiv \frac{1}{y_t}[y_t - c_{m,t} - I_{m,t}(1 + \frac{\psi_m}{2}\frac{I_{m,t}}{k_{m,t}}) - I_{h,t}(1 + \frac{\psi_h}{2}\frac{I_{h,t}}{k_{h,t}})]$. Equation (5) can be reexpressed as:

$$d_{t+1} - d_t = -\left(b_t y_t - r_t d_t\right). \tag{10}$$

Equation (10) states that the economy's net accumulation of foreign debt is equal to the negative value of the current account (the trade balance minus the net interest payment on foreign debt). The competitive equilibrium of the economy is composed of 21 equations: (2a)-(3b), (5) and (7a)-(10). The endogenous variables are the sequences of quantities $\{y_t, c_{m,t}, c_{h,t}, C_t, X_t, N_t, n_{m,t}, n_{h,t}, I_{m,t}, I_{h,t}, I_t, k_{m,t}, k_{h,t}, d_t, b_t\}$ and prices $\{r_t, g_t, \mu_t, \lambda_t, q_{m,t}, q_{h,t}\}$.

4 Results

We consider Canada and Mexico respectively as a representative developed economy and a representative emerging market. We begin by characterizing a benchmark economy, in which structural parameters are divided into two groups. Each parameter in the first group is either set to a commonly used value or calibrated to match empirical evidence in Canada and Mexico. Each parameter in the second group is estimated by the simulated method of moments (hereafter SMM).

This section is arranged as follows. We first deal with the calibration of parameters in the first group. Next, we estimate parameters in the second group using SMM and report quantitative results to show that our theoretical model embodying home production is able to replicate standard business cycle moments in the two small open economies. In addition, we explore impulse responses in response to market-technology and home-technology shocks and report sensitivity analysis. Finally, we provide an analytical result to explain why home production enables the model to produce empirically plausible business cycle moments in the two types of economies, in the presence of a sizable income effect on labor supply.

4.1 Calibration

In the first group of parameters, we consider the following commonly used values in the literature: the discount factor $\beta = 0.98$, the inverse of the Frisch labor supply elasticity $\chi = 1.6$, and the inverse of the intertemporal elasticity of substitution in consumption $\sigma = 2$. Following Greenwood and Hercowitz (1991), Parente *et al.* (2000) and Karabarbounis (2013), we assume that the depreciation rates of market capital and home capital are identical; i.e., $\delta_m = \delta_h = \delta$, and δ is set to 0.025. The scaling disutility of labor supply ω is set to 0.943 for Canada and 0.573 for Mexico to match a steady-state value of market hours worked $n_m = 0.3$.

In line with Rupert *et al.* (1995), Schmitt-Grohé (1998) and Karabarbounis (2013), we set $\phi = 0.75$ and this implies an elasticity of substitution between market and home consumption of 4.[8] According to Greenwood *et al.* (1995), the production shares of market

[8] In their pioneering studies, Benhabib *et al.* (1991) and Greenwood and Hercowitz (1991) set the elasticity of substitution between market and home consumption e equal to 5 and 3, respectively. In addition, Rupert

capital and home capital are set to $\alpha_m = 0.29$ and $\alpha_h = 0.32$, respectively. Data show that the foreign debt to output ratio is 25% in Canada and 44% in Mexico. Hence, we set $\upsilon = 0.25$ in the developed economy and $\upsilon = 0.44$ in the emerging market. In line with Neumeyer and Perri (2005), Otsu (2008) and Jaimovich and Rebelo (2009), the parameter η reflecting the borrowing premium associated with default risk is set to 0.00001.[9] A summary of the calibrated parameter values is reported in Table 4.

Table 4: Parameter calibration

	β	χ	σ	δ	ω	ϕ	α_m	α_h	υ	η
Canada	0.98	1.6	2	0.025	0.943	0.75	0.29	0.32	0.25	0.00001
Mexico	0.98	1.6	2	0.025	0.573	0.75	0.29	0.32	0.44	0.00001

4.2 SMM estimation and quantitative results

We now consider the second group of parameters. Due to the model's complexity, we resort to numerical methods to solve the model by linearizing the dynamic equations around the steady state.[10] To reduce computational burden, we assume that the intensity parameters of the investment adjustment costs in both the market and home sectors are identical (i.e., $\psi_m = \psi_h = \psi$), the persistent parameters are identical (i.e., $\rho_m = \rho_h = \rho$), and the variances of technology shocks in the market and home sectors are identical (i.e., $\sigma_m^2 = \sigma_h^2 = \sigma^2$). Then, we employ SMM to estimate the following vector of parameters $\zeta = \{\theta, \gamma, \psi, \rho, \sigma^2\}$ by minimizing the difference between the empirical and simulated moments from the model. The data that we use for Canada and Mexico come from the OECD database for the period 1978:I-2008:III. We thus have a sample size of $T = 123$. Let m denote the vector of moments computed from actual data and m^s denote the vector of average simulated moments over $N = 10$ simulations from our model with the same sample size. Formally, the estimator of ζ can be described as:

$$\tilde{\zeta} = \arg\min J(\zeta) = \frac{TN}{1+N}[m - m^s(\zeta)]W[m - m^s(\zeta)]', \tag{11}$$

where W denotes a positive-definite of the weighting matrix.[11]

The six target moments we select are informative for estimating SMM parameters. The reasons for choosing these target moments to estimate the vector of parameters ζ can be explained as follows. First, it is reasonable to expect that the standard deviation of output

et al. (1995) estimate the plausible value of e to be in the range of 0 to 5 (see Baxter and Jermann (1999, p.909)). Accordingly, the value of $e = 4$ lies within the values reported in the previous studies.

[9] Based on Schmitt-Grohé and Uribe (2003), the presence of the parameter η reflecting the borrowing premium in association with the default risk ensures that the model is stationary. In addition, a small value of η implies that the borrowing premium in association with the default risk cannot affect the short-run dynamics of the model. Therefore, we set $\eta = 0.00001$ in the two economies to satisfy these two purposes. Moreover, we will show that the model is able to characterize business cycles in small open economies even with the strict restriction of an identical η in the two economies. Our model will have better performance to capture business cycles in small open economies when this restriction is relaxed.

[10] The stationary expressions of variables and derivations are relegated to Appendix A.

[11] W is computed by the Newey-West estimator.

$std(\hat{y}_t)$ can provide information on the variance of technology shock σ^2. Second, as we will show later, the standard deviation of market consumption $std(\hat{c}_{m,t})$ is crucially related to the utility share of market consumption θ, and hence it can provide information for estimating θ. Third, the standard deviation of investment $std(\hat{I}_t)$ and the correlation coefficient between investment and output $corr(\hat{I}_t, \hat{y}_t)$ are informative for estimating the intensity parameter of investment adjustment costs ψ. Fourth, the correlation coefficient between market consumption and output $corr(\hat{c}_{m,t}, \hat{y}_t)$ varies substantially in response to the distinctive values of the parameter γ, and hence $corr(\hat{c}_{m,t}, \hat{y}_t)$ is informative of γ. Finally as we will show later, the correlation coefficient between the trade balance to GDP ratio and output $corr(\hat{b}_t, \hat{y}_t)$ is closely related to the persistence of the total factor productivity process ρ. Accordingly, we use $corr(\hat{b}_t, \hat{y}_t)$ to estimate ρ.

Because this study proposes that the channel of home production is crucial for understanding business cycles in developed economies and emerging markets, it is necessary for us to check the importance of this channel. To this end, we use SMM to estimate the parameters in the benchmark model with home production and also in an alternative model without home production (i.e., $\theta = 1$). A summary of the estimated parameters in the benchmark model with home production for Canada and Mexico are reported in columns (1) and (3) of Table 5. A summary of the estimated parameters in the model without home production (i.e., $\theta = 1$) for Canada and Mexico are reported in columns (2) and (4) of Table 5. In addition, a summary of the targeted, selected, and simulated moments for Canada and Mexico are reported in Part A and Part B of Table 6, respectively.

Table 5: SMM parameters

	Canada		*Mexico*	
parameters	(1) benchmark	(2) $\theta = 1$	(3) benchmark	(4) $\theta = 1$
θ	0.505 (0.004)	–	0.455 (0.004)	–
γ	0.886 (0.159)	0.002 (0.002)	0.621 (0.229)	0.000 (0.000)
ψ	0.308 (0.068)	6.980 (0.548)	1.118 (0.137)	9.325 (0.401)
ρ	0.682 (0.045)	0.960 (0.006)	0.978 (0.006)	0.989 (0.004)
σ^2	0.490 (0.031)	0.585 (0.046)	0.981 (0.034)	1.555 (0.068)
J	0.38	6.27	1.25	46.76

Notes: Columns (1) and (3) denote the benchmark estimations for Canada and Mexico. Columns (2) and (4) stand for the estimations of the model without home production; i.e., $\theta = 1$ for Canada and Mexico, respectively. Based on the statistics of targeted moments in Table 6, the reported values of SMM parameters with the standard deviations in the parentheses are computed by using the 500 replications of the estimation procedure. The variances of the aggregate factor productivity shock are reported in percentage terms.

We first discuss the quantitative results generated from the theoretical model for Canada, which represents developed economies. In the estimation of the benchmark model with home production, as shown in column (1) of Table 5, the utility share of market consumption θ is estimated to be equal to 0.505, which gives rise to hours worked in the home sector of 0.233. The intensive parameter of the investment adjustment cost ψ is estimated to be 0.308. The parameter γ governing the income effect on labor supply is estimated to be 0.886. This reveals that the income effect on labor supply is significant, and hence the utility function is close to the setting of the KPR preference. The persistence of the total factor productivity process and the variance of technology shocks are estimated to be $\rho = 0.682$ and $\sigma^2 = 0.490$, respectively. It should be noted that the J statistic described in equation (11) is asymptotically chi-square with 1 degree of freedom (i.e., the number of over-identification restrictions). The chi-square statistic at the 95% level is $\chi^2_{0.95} = 3.84$, and the test statistic $J = 0.38$ implies that the model cannot be rejected by the data. Table 6 shows that simulated moments from the benchmark model are close to empirical moments from the Canadian economy. Specifically, the benchmark model correctly predicts that market consumption is less volatile than GDP (i.e., $std(\hat{c}_{m,t})/std(\hat{y}_t) = 0.78$), investment is more volatile than GDP (i.e., $std(\hat{I}_t)/std(\hat{y}_t) = 2.84$) and the trade balance to GDP ratio is weakly countercyclical (i.e., $corr(\hat{b}_t, \hat{y}_t) = -0.13$). Furthermore, the following simulated $corr(\hat{c}_{m,t}, \hat{y}_t) = 0.68$, $corr(\hat{I}_t, \hat{y}_t) = 0.80$ and $std(\hat{b}_t) = 0.71$ are very close to the data.

Table 6: Targeted, selected, and simulated moments

	Part A: Canada			*Part B: Mexico*		
Moments	(1) Data	(2) benchmark	(3) $\theta = 1$	(1) Data	(2) benchmark	(3) $\theta = 1$
$std(\hat{y}_t)$	1.47	1.52	1.78	2.53	2.52	2.87
$std(\hat{c}_t)$	1.15 (0.78)	1.18 (0.78)	1.28 (0.72)	3.19 (1.26)	3.19 (1.27)	2.73 (0.95)
$std(\hat{I}_t)$	4.28 (2.91)	4.31 (2.84)	4.37 (2.46)	8.57 (3.39)	8.04 (3.19)	8.41 (2.93)
$std(\hat{b}_t)$	0.91	0.71	0.14	2.07	2.69	0.91
$corr(\hat{c}_t, \hat{y}_t)$	0.61	0.68	1	0.77	0.80	1
$corr(\hat{I}_t, \hat{y}_t)$	0.73	0.80	0.98	0.82	0.77	0.98
$corr(\hat{b}_t, \hat{y}_t)$	−0.10	−0.13	−0.14	−0.60	−0.60	−0.90

Notes: Column (1) denotes the data moments, column (2) denotes the simulated moments generated from the benchmark model, and column (3) stands for the simulated moments generated from the model without home production; i.e., $\theta = 1$. All variables are de-trended by the HP-filter with the smoothing parameter set to 1600. The standard deviations of output and consumption are reported in percentage terms, and the ratios of each standard deviation to the standard deviation of output are stated in the parentheses. While the sampling period is 1978:I-2008:III, the simulated moments are the averages across 1000 replications of 123 periods.

As for the estimation of the model *without home production* (i.e., $\theta = 1$), as depicted in column (2) of Table 5, we find that the parameter γ governing the income effect on labor supply is estimated to be 0.002. An implication is that the income effect on labor supply needs to be very small, and the utility function approximates the GHH preference. This result is consistent with previous findings in Mendoza (1991), Correia *et al.* (1995) and Schmitt-Grohé and Uribe (2003): the volatility of market consumption from a model with the KPR preference is too low compared with the empirical value in a small open economy. Hence one needs to resort to the GHH preference ($\gamma = 0$) in order to raise the volatility of market consumption to match the data. However, Part A of Table 6 shows that in the absence of an income effect on labor supply, the model produces a simulated correlation coefficient between market consumption and output of $corr(\hat{c}_{m,t}, \hat{y}_t) = 1$, which is much higher than its empirical value of 0.61. Intuitively, in the presence of a large income effect on labor supply, market consumption is negatively related to the household's labor supply. As the economy experiences a positive and persistent shock in the market sector, the increase in permanent income causes the household to raise market consumption and reduce labor supply. This in turn mitigates the increase in output. As a result, a larger income effect on labor supply reduces $corr(\hat{c}_{m,t}, \hat{y}_t)$. In contrast, the absence of an income effect on labor supply implies a larger $corr(\hat{c}_{m,t}, \hat{y}_t)$.

In addition, the intensive parameter of the investment adjustment cost ψ is estimated to be as large as 6.980. Then, a smooth path of investment reflects a simulated correlation coefficient between investment and output $corr(\hat{I}_t, \hat{y}_t) = 0.98$. Given the high correlations between output, market consumption, and investment, the volatility of trade balance will be low. Specifically, the simulated standard deviation of the trade balance to GDP ratio $std(\hat{b}_t)$ of 0.14 is much lower then its empirical value of 0.91. These significant differences between the simulated and empirical values of $corr(\hat{c}_{m,t}, \hat{y}_t)$, $corr(\hat{I}_t, \hat{y}_t)$, and $std(\hat{b}_t)$ give rise to a test statistic of $J = 6.27$, which is higher than the chi-square statistic at the 95% level, where $\chi^2_{0.95} = 3.84$, thereby implying that the model without home production is rejected by the data.

We next focus on the quantitative results generated from the theoretical model estimated for Mexico, which represents an emerging market. In the estimation of the benchmark model with home production, as shown in column (3) of Table 5, the utility share of market consumption θ is estimated to be 0.455, which gives rise to hours worked in the home sector n_h of 0.428. This indicates that hours worked in the home sector in Mexico (0.428) are higher than that in Canada (0.233). Then, given that market hours worked n_m are normalized to 0.3 in the two economies, the estimation generates ratios between home hours worked and market hours worked of $\frac{n_h}{n_m} = 1.43$ in Mexico and 0.78 in Canada. These simulated values are close to the empirical values of 1.42 and 0.89 in Table 3. Therefore, the estimated value of θ is plausible and reflects that home production is more prevalent in emerging markets than in developed economies.[12]

The parameter governing the income effect on labor supply γ is estimated to be 0.621. This indicates that the income effect on labor supply is significant, but the estimated value for Mexico (0.621) is lower than that for Canada (0.886). The intensive parameter of the investment adjustment cost ψ is estimated to be 1.118. The persistence of the total factor productivity process and the variance of technology shocks are estimated to be $\rho = 0.978$ and $\sigma^2 = 0.981$, respectively. It is worth mentioning that the estimate for the persistence of

[12] In this paper, we focus on the share of market consumption θ reflecting the scale of the market sector to explain the major differecnes of business cycles in developed economies and emerging markets. A related study by Gomme and Zhao (2011) instead focuses on the long-run technology levels in the market and home sectors and the transmission of technology shocks across the market and home sectors. Specifically, they offer an explanation of the high volatility of market consumption in Mexico by proposing that the long-run technology level is lower in the market sector than in the home sector and that market technology shocks can be transmitted to the home sector. Moreover, in the present study, we use a general preference that nests the KPR and GHH preferences to discuss the major features of business cycles involving the volatility and countercyclicality of the trade balance to GDP ratio in emerging markets in addition to the volatility of market consumption.

the total factor productivity process ρ is higher in Mexico (0.978) than in Canada (0.682). This result is consistent with the finding of Aguiar and Gopinath (2007), since they point out that permanent shocks to the total factor productivity are relatively more important for Mexico relative to Canada.

In addition, it is useful to note that the chi-square statistic at the 95% level is $\chi^2_{0.95} = 3.84$, and thus the test statistic $J = 1.25$ implies that the model cannot be rejected by the data. As reported in Part B of Table 6, simulated moments from the benchmark model are close to the empirical moments from Mexico. More importantly, given the estimated values of the parameters, we find that market consumption is more volatile than GDP (i.e., $std(\hat{c}_{m,t})/std(\hat{y}_t) = 1.27$) and the trade balance to GDP ratio is more volatile and more countercyclical (i.e., $std(\hat{b}_t) = 2.69$ and $corr(\hat{b}_t, \hat{y}_t) = -0.60$) in the emerging market.

Moreover, in the estimation of the model *without home production* (i.e., $\theta = 1$), as depicted in column (4) of Table 5, we find that the parameter γ is estimated to be equal to 0, implying that the income effect on labor supply needs to be absent. This result is similar to the estimation for Canada and implies that the utility function approximates the GHH preference. However, as shown in column (3) of Part B in Table 6, when the channel of home production is absent, the ratio of the standard deviations between market consumption and GDP is estimated to be $std(\hat{c}_{m,t})/std(\hat{y}_t) = 0.95$. In other words, the model has difficulty matching an important stylized fact that the volatility of market consumption exceeds the volatility of GDP. In addition, the estimate indicates the high correlations between output, market consumption, and investment, and a low volatility of the trade balance to GDP ratio. Accordingly, these significant differences between the simulated and empirical values of $std(\hat{c}_{m,t})$, $corr(\hat{c}_{m,t}, \hat{y}_t)$, $corr(\hat{I}_t, \hat{y}_t)$, and $std(\hat{b}_t)$ give rise to a test statistic of $J = 46.76$, implying that the model without home production is rejected by the data.

4.3 Impulse responses

This subsection explores impulse responses when the economy experiences a positive technology shock in either the market-production sector or the home-production sector. Before proceeding with the analysis, an important point should be mentioned here. The presence of home consumption allows for substitutability between home consumption and market consumption, and the engine driving this substitutability is the change in the relative price between home consumption and market consumption. To shed light on the importance of home production, it is helpful to discuss how the relative price between market and home consumption $p_t(= \frac{\lambda_t}{\mu_t})$ will react in response to technology shocks.

From equations (3a), (3b), (8b), and (8e), the relative price between market and home consumption can be expressed as:

$$p_t = \frac{\theta}{1-\theta}\left(\frac{c_{m,t}}{c_{h,t}}\right)^{\phi-1} = \frac{1-\alpha_h}{1-\alpha_m}\frac{A_{h,t}k_{h,t}^{\alpha_h}n_{h,t}^{-\alpha_h}}{A_{m,t}k_{m,t}^{\alpha_m}n_{m,t}^{-\alpha_m}}. \tag{12}$$

Equation (12) indicates the optimal allocation between market and home consumption. It states that the relative price of market consumption equals the marginal rate of substitution between market and home consumption. It also equals the ratio between the marginal product of home hours worked and the marginal product of market hours worked.[13] As is clear in equation (12), a rise in the marginal product of market hours worked leads to a lower relative price p_t, which in turn causes the household to raise market consumption and reduce home consumption.

We are now in a position to analyze impulse responses in association with technology shocks in the market and home sectors. Based on the benchmark estimation in the previous section, the impulse responses to technology shocks in Canada and Mexico can then be depicted in Figures 1 and 2, respectively. It should be noted that the solid line and dashed line represent the impulse responses to a 1% increase in market technology and home technology, respectively.

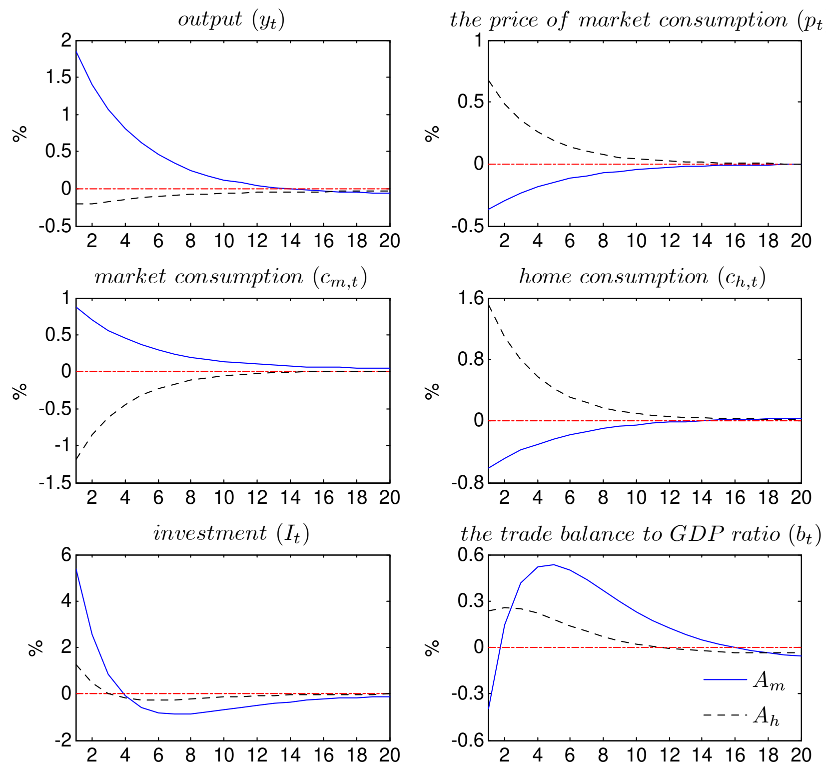

Figure 1: Impulse responses: Canada

[13]Based on equations (3a), (3b), and (8e), the household's optimal allocation between market and home hours worked can be inferred as:

$$1 = \frac{\lambda_t}{\mu_t} \frac{(1-\alpha_m)A_{m,t}k_{m,t}^{\alpha_m}n_{m,t}^{-\alpha_m}}{(1-\alpha_h)A_{h,t}k_{h,t}^{\alpha_h}n_{h,t}^{-\alpha_h}}.$$

This equation indicates that the marginal rate of substitution between market and home hours worked (on the left-hand side) is equal to the marginal rate of transformation between market and home hours worked (on the right-hand side). Since $p_t = \frac{\lambda_t}{\mu_t}$ denotes the relative price of market consumption, i.e., the ratio between the marginal utilities of market and home consumption, from equations (8a) and (8b) the relative price of market consumption p_t can then be derived as the expression in equation (12).

In Canada, as exhibited in Figure 1, a positive *market* technology shock raises market output y_t. Therefore, the price of market consumption p_t declines in response, and the household tends to raise market consumption $c_{m,t}$ and reduce home consumption $c_{h,t}$. In addition, this leads to an increase in aggregate investment $I_t(= I_{m,t} + I_{h,t})$. Because the increase in investment is greater than the increase in domestic savings (i.e., the trade balance plus aggregate investment), the trade balance to GDP ratio b_t decreases in response.

A positive *home* technology shock increases the relative price between market and home goods p_t, which in turn causes the household to reduce market consumption $c_{m,t}$ and raise home consumption $c_{h,t}$. In addition, because the household accumulates more capital in the home-production sector, it leads to a rise in aggregate investment I_t. Although aggregate investment I_t increases, a lower price of market good p_t induces more resources to be allocated to the home-production sector, thereby causing a decline in market output y_t. When the rise in domestic savings exceeds that in aggregate investment I_t, it leads to a rise in the trade balance to GDP ratio b_t, thereby rendering the trade balance to GDP ratio countercyclical. Consequently, the model featuring home production is able to replicate business cycles in Canada even if the income effect on labor supply is present and significant.

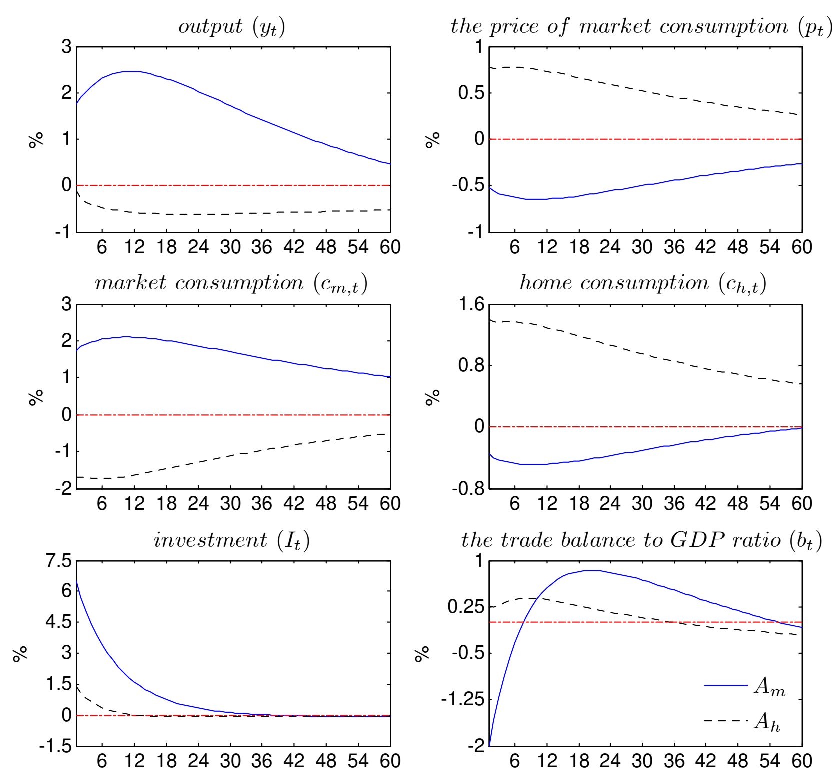

Figure 2: Impulse responses: Mexico

Figure 2 depicts impulse responses to a 1% increase in technology in Mexico. By comparing the impulse responses depicted in Figure 2 with those in Figure 1, we find that the patterns of movement in y_t, p_t, $c_{m,t}$, $c_{h,t}$, I_t, and b_t are similar to the ones in Canada. However, the adjustments of these variables are more persistent (recall that the estimated value of $\rho = 0.978$ in Mexico is higher than the corresponding $\rho = 0.682$ in Canada). As a result, the volatilities of these variables increase in response. Moreover, the estimated values of the market consumption share θ in Mexico 0.455 is lower than that in Canada where $\theta = 0.505$, which in turn yields an increase in the volatility of the relative price p_t in Mexico.

By comparing the impulse responses to technology shocks in Canada in Figure 1 (in association with $\theta = 0.505$) with those in Mexico in Figure 2 (in association with $\theta = 0.455$), we can establish the following findings. First, given that the volatility of market consumption in Mexico is higher than that in Canada, an increase in the home consumption share $1 - \theta$ tends to raise the volatility of market consumption. Second, when the increase in market consumption is driven by a positive market technology shock, the household turns to borrow from the world market to finance the increased demand for aggregate investment causing a reduction in the trade balance to GDP ratio. Given the larger increase in consumption and investment in Mexico in response to a positive market technology shock, the trade balance to GDP ratio is more volatile and more countercyclical in Mexico than in Canada.

4.4 Sensitivity analysis

Figure 3 depicts the sensitivity analysis of simulated moments $std(\hat{c}_{m,t})/std(\hat{y}_t)$, $std(\hat{b}_t)$, and $corr(\hat{b}_t, \hat{y}_t)$ in Canada and Mexico. The effects of the market consumption share θ on $std(\hat{c}_{m,t})/std(\hat{y}_t)$, $std(\hat{b}_t)$, and $corr(\hat{b}_t, \hat{y}_t)$ are respectively presented in Parts A, B and C. In Figure 3, the solid line and the dashed line denote the simulated moments of $std(\hat{c}_{m,t})/std(\hat{y}_t)$, $std(\hat{b}_t)$, and $corr(\hat{b}_t, \hat{y}_t)$ in Canada and Mexico, respectively. Each point is computed from the average across 1,000 replications under a value of θ. We take the estimated value of θ as our benchmark and vary its value while holding other parameter values constant.

In Part A of Figure 3, it can be seen that $std(\hat{c}_{m,t})/std(\hat{y}_t)$ in both countries is decreasing in the value of θ. When home production is absent (i.e., $\theta = 1$), $std(\hat{c}_{m,t})/std(\hat{y}_t)$ equals 0.20 in Canada and 0.53 in Mexico, respectively. These simulated values are lower than the empirical values of 0.78 in Canada and 1.26 in Mexico. In addition, because the relative volatility between market consumption and output $std(\hat{c}_{m,t})/std(\hat{y}_t)$ is decreasing in θ, $std(\hat{c}_{m,t})/std(\hat{y}_t)$ converges to its empirical values when θ decreases toward the estimated values of 0.505 in Canada and 0.455 in Mexico. Moreover, given the estimated values of income effect parameter $\gamma = 0.886$ in Canada and $\gamma = 0.621$ in Mexico, we conclude that even in the presence of a significant income effect on labor supply, home production is still a useful channel for explaining business cycles in small open economies. In particular, market consumption is more volatile than output in the emerging market economy.

Part B of Figure 3 shows that when home production is absent (i.e., $\theta = 1$), the volatility of the trade balance to GDP ratio equals 0.48 in Canada and 0.74 in Mexico. These simulated values are substantially smaller than the empirical values of 0.91 in Canada and 2.07 in Mexico. We also find that the volatility of the trade balance to GDP ratio is decreasing in θ. When θ decreases from 1 to the estimated values of 0.505 in Canada and 0.455 in Mexico, the volatility of the trade balance to GDP ratio increases and becomes 0.71 in Canada and 2.69 in Mexico. These values are much closer to the empirical values.

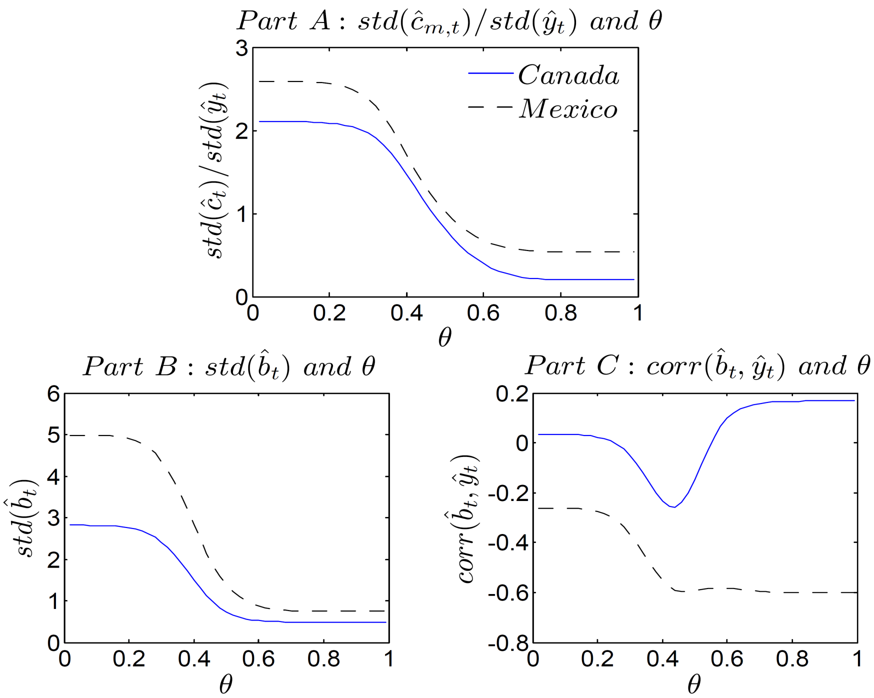

Figure 3: Sensitivity analysis

Finally, we find that when home production is absent (i.e., $\theta = 1$), $corr(\hat{b}_t, \hat{y}_t)$ in Canada equals 0.17. This value differs significantly from the empirical value of -0.10 in Canada featuring a countercyclical trade balance to GDP ratio. As is clear from Part C of Figure 3, $corr(\hat{b}_t, \hat{y}_t)$ in Canada is increasing in θ for $\theta \geq 0.44$. We find that as home production emerges and θ converges to 0.505, $corr(\hat{b}_t, \hat{y}_t)$ equals -0.13, which is close to the empirical value for the Canadian economy. On the other hand, $corr(\hat{b}_t, \hat{y}_t)$ in Mexico is largely invariant with respect to θ for $\theta \geq 0.44$, and it is close to its empirical value of -0.60. In the next subsection, we will provide an economic intuition for the responses of $std(\hat{c}_{m,t})/std(\hat{y}_t)$, $std(\hat{b}_t)$, and $corr(\hat{b}_t, \hat{y}_t)$ to the market consumption share θ as shown in Parts A, B and C.

4.5 An analytical illustration

From the previous analysis, the following observation emerges: a fall in the market consumption share θ (i.e., a rise in the home consumption share) tends to raise the volatility of market consumption. In this subsection, we provide the intuition behind this observation. To highlight the role of home production, in this subsection we focus on the extreme case of the KPR preference under which the income effect on labor supply is very significant.[14] In addition, for simplicity, we assume that $\sigma = 1$, $\alpha_m = \alpha_h = \alpha$ and $\psi_m = \psi_h = \psi = 0$. With $\psi_m = \psi_h = \psi = 0$, the investment adjustment costs are absent in this special case, and hence $q_{m,t} = q_{h,t} = 1$ in each period. In this special case, given that the marginal utility of

[14] Some intuition regarding the relationship between the market consumption share θ and the volatility of market consumption in the GHH preference is provided in an unpublished appendix; see Appendix B.

market consumption λ_t is fixed at a given level, from equations (8a) and (12) we can define the substitution effect between market and home consumption:[15]

$$\Omega \equiv -\frac{\partial \hat{c}_{m,t}}{\partial \hat{p}_t}\bigg|_{\lambda_t=\bar{\lambda}} = \frac{\phi/(1-\phi)}{1+[\theta/(1-\theta)]^{\frac{1}{1-\phi}}} > 0; \quad \frac{\partial \Omega}{\partial \theta} = \frac{-\Omega[\theta/(1-\theta)]^{\frac{2-\phi}{1-\phi}}/\theta^2}{(1-\phi)\{1+[\theta/(1-\theta)]^{\frac{1}{1-\phi}}\}} < 0. \quad (13)$$

Given that p_t denotes the relative price between market consumption and home consumption, Ω then reflects the extent of the substitution effect between the two types of consumption in the KPR preference. It is quite easy to infer from the definition of Ω reported in equation (13) that the extent of the substitution effect is negatively related to the value of the parameter θ. If home production is absent, i.e., $\theta = 1$, it is implied that $\Omega = 0$; and if the channel of home production emerges, i.e., $\theta < 1$, it is implied that $\Omega > 0$.

Moreover, in association with $\gamma = 1$, from equations (5), (8a), (8j), (9), (12) and (13), the Euler equation linearized around the steady state in the KPR preference can then be derived as:

$$\hat{c}^{KPR}_{m,t} = -\Omega\hat{p}_t - \eta\hat{\Lambda}_{1,t}, \quad (14a)$$

where the superscript "*KPR*" denotes the KPR preference, and

$$\hat{\Lambda}_{1,t} = \sum_{j=0}^{\infty} \frac{-c_m\Omega\hat{p}_{t+j} + I\hat{I}_{t+j} + (1+r)\hat{d}_{t+j} + rd\hat{r}_{t+j} - (y+d)\hat{y}_{t+j}}{\left(\frac{y}{\beta}\right)\left[1+\beta\eta\left(\frac{c_m}{y}\right)\right]^{1+j}}. \quad (14b)$$

Equation (14a) states that market consumption consists of two terms. The first term $\Omega\hat{p}_t$ stems from the substitution effect between market and home consumption, which is referred to in equation (13). The second term $\eta\hat{\Lambda}_{1,t}$ arises from the discounted sum of the future price of market consumption and the future interest rate premium.

As is clear in equation (14a), it is a common practice in the literature on small open economy business cycles to treat the parameter for the borrowing premium associated with default risk η as very close to 0 (i.e., $\eta \to 0$), under which the variance of market consumption can then be expressed as:[16]

$$var(\hat{c}^{KPR}_{m,t})|_{\eta\to 0} = \frac{2\Omega^2\sigma^2}{1-\rho^2}; \quad \frac{\partial var(\hat{c}^{KPR}_{m,t})|_{\eta\to 0}}{\partial \theta} = \frac{4\Omega\sigma^2}{1-\rho^2}\frac{\partial\Omega}{\partial\theta} < 0.$$

This implies that the substitution effect between market and home consumption Ω is decreasing in the value of θ. A decrease in θ causes a rise in the variance of market consumption

[15] A detailed derivation of equation (13) is provided in an unpublished appendix; see Appendix C.

[16] Given $\alpha_m = \alpha_h = \alpha$ and $\psi_m = \psi_h = \psi = 0$, it can be found that from equations (8e), (8h) and (8i), the capital to labor ratios in the market and home sectors are identical i.e., $\frac{k_{m,t}}{n_{m,t}} = \frac{k_{h,t}}{n_{h,t}}$. Then, based on equation (12), the relative price between market consumption and home consumption linearized around the steady state can be expressed as: $\hat{p}_t = \hat{A}_{h,t} - \hat{A}_{m,t}$. Finally, since market technology shocks and home technology shocks have an identical variance (i.e., $var(\hat{A}_{m,t}) = var(\hat{A}_{h,t}) = \frac{\sigma^2}{1-\rho^2}$) and there is no transmission of shocks across the market and home sectors (i.e., $corr(\hat{A}_{m,t}, \hat{A}_{h,t}) = 0$), we can derive the variance of the price of market consumption: $var(\hat{p}_t) = \frac{2\sigma^2}{1-\rho^2}$.

$var(\hat{c}_{m,t}^{KPR})$. As a result, the presence of home production creates a stimulus to boost the volatility of market consumption to match the empirical evidence, even if η is very close to 0. The larger share of home consumption in the emerging market causes it to have a higher volatility of market consumption. As a consequence, the stylized facts that market consumption is more volatile than GDP in the emerging market economy and that market consumption is less volatile than GDP in the developed market economy can be explained by the difference in the substitution effect between market and home consumption in these two economies.

We now turn to discuss the volatility of the trade balance to GDP ratio $std(\hat{b}_t)$ and the correlation coefficient between the trade balance to GDP ratio and output $corr(\hat{b}_t, \hat{y}_t)$ when home production is present. Following Mendoza (1991) and Tesar (1991), we define domestic savings as being equal to the trade balance plus aggregate investment, i.e., $S_t = b_t y_t + I_t$. Then, the trade balance to GDP ratio linearized around the steady state can be expressed as:

$$\hat{b}_t = \frac{1}{y}\left(S\hat{S}_t - I\hat{I}_t\right) - b\hat{y}_t, \tag{15}$$

where S, I, y, and b denote the stationary values of domestic savings, aggregate investment, output, and the trade balance to GDP ratio, respectively. From equation (15), we can find that when the economy experiences either market technology shocks or home technology shocks, the net effect concerning the movement of $\hat{b}_t$ is determined by two terms: the gap between domestic savings and aggregate investment $S\hat{S}_t - I\hat{I}_t$ and the movement of output $b\hat{y}_t$. In addition, given that the trade balance to GDP ratio in the steady state b is close to being 0 in the two benchmark economies ($b = 0.005$ in Canada and 0.009 in Mexico), the effect from the second term of equation (15) is very small. Accordingly, in what follows, we only focus on the effect caused by the gap between domestic savings and aggregate investment. The movement of $\hat{b}_t$ in equation (15) is helpful in explaining the two results exhibited in Figure 3.

First, as depicted in Parts B and C of Figure 3, the sensitivity analysis for Canada indicates that $std(\hat{b}_t)$ is negatively related to θ, while $corr(\hat{b}_t, \hat{y}_t)$ has a U-shaped relationship with the value of θ. To be more specific, $corr(\hat{b}_t, \hat{y}_t)$ is increasing in θ for $\theta \geq 0.44$ and decreasing in θ for $\theta < 0.44$. These relationships can be explained intuitively as follows.

When the market consumption share θ is relatively high ($\theta \geq 0.44$), in response to a positive market technology shock $A_{m,t}$, the increase in the percentage of market consumption $\hat{c}_{m,t}$ is larger than that of output $\hat{y}_t$. Therefore, the increase in domestic savings will be restrained. In order to finance the excess demand of aggregate investment, the household turns to borrow from the world market, hence causing a negative gap between domestic savings and aggregate investment, $S\hat{S}_t - I\hat{I}_t < 0$. Consequently, the trade balance to GDP ratio $\hat{b}_t$ is negatively related to output $\hat{y}_t$. Moreover, as explained and emphasized above, the volatility of market consumption $\hat{c}_{m,t}$ is negatively related to θ. Thus, as displayed in Parts B and C of Figure 3, $std(\hat{b}_t)$ is decreasing in θ and $corr(\hat{b}_t, \hat{y}_t)$ is increasing in θ for $\theta \geq 0.44$.

On the other hand, when the market consumption share θ is relatively low ($\theta < 0.44$), the market sector is relatively small. In this case, the fluctuations in $\hat{b}_t$ are mostly attributed to the home technology shocks $A_{h,t}$, and market consumption $\hat{c}_{m,t}$ does not play an important role in the economy. As such, when the economy is impacted by a positive home technology shock $A_{h,t}$, in order to accumulate more home capital the household is motivated to provide more market hours worked to raise market output $\hat{y}_t$, thereby causing a rise in domestic savings.[17] This leads to a positive gap between domestic savings and aggregate investment $S\hat{S}_t - I\hat{I}_t > 0$. As a result, the correlation coefficient between the trade balance to GDP ratio and output $corr(\hat{b}_t, \hat{y}_t)$ tends to be positive. In addition, when the positive gap between domestic savings and aggregate investment $S\hat{S}_t - I\hat{I}_t > 0$ is decreasing in θ for $\theta < 0.44$, then $std(\hat{b}_t)$ and $corr(\hat{b}_t, \hat{y}_t)$ are negatively related to θ.

Second, as depicted in Parts B and C of Figure 3, $std(\hat{b}_t)$ is higher and $corr(\hat{b}_t, \hat{y}_t)$ is lower in Mexico than in Canada. These results can be explained intuitively as follows. We have estimated the persistence of shocks in Mexico to be higher than that in Canada (i.e., $\rho = 0.978$ in Mexico and $\rho = 0.682$ in Canada). When the increase in output $\hat{y}_t$ is led by a positive market technology shock $A_{m,t}$, a higher value of ρ strengthens the increase in the discounted sum of the future marginal benefits of holding capital. Then, the excess demand of aggregate investment leads to a negative gap between domestic savings and aggregate investment, $S\hat{S}_t - I\hat{I}_t < 0$. The trade balance to GDP ratio $\hat{b}_t$ is thus shown to be more countercyclical and more volatile in Mexico than in Canada.

5 Conclusion

Neumeyer and Perri (2005) and Aguiar and Gopinath (2007) point out three important differences between emerging markets and developed economies. First, the volatility of output in emerging markets is higher than that in developed economies. Second, the volatility of output exceeds the volatility of consumption in developed economies, whereas the volatility of output falls short of the volatility of consumption in emerging markets. Third, the trade balance to GDP ratio is more volatile and more countercyclical in emerging markets than in developed economies. It is commonly accepted that the presence of an income effect on labor supply would render the RBC model of a small open economy incapable of replicating these business cycle moments because the presence of income effect on labor supply would result in insufficient volatility of market consumption.[18] Moreover, it would cause the trade balance to GDP ratio to become procyclical. Given that empirical studies including Imbens *et al.* (2001), Kimball and Shapiro (2010), and Khan and Tsoukalas (2011, 2012) support the view that the income effect on labor supply is significantly sizeable, it is necessary to find a plausible channel to explain the business cycles of small open economies.

In this paper, we argue that home production serves as a plausible vehicle to capture the major features of business cycles in small open economies. Several main findings emerge from the analysis. First, we find that upon experiencing a positive technology shock in the market sector (or a negative technology shock in the home sector), the presence of home production will induce the representative household to consume more market consumption

[17] In this paper, we specify that home capital can be accumulated by the production of market goods rather than the production of home goods. When the value of θ is low, it is implied that market consumption is minor. Under such a situation, when the economy experiences a positive home technology shock, it is not possible for investment in home capital to be raised by the decrease in market consumption. Therefore, in order to accumulate home capital, the production in the market sector has to be increased.

[18] See for example Correia *et al.* (1995) and Schmitt-Grohé and Uribe (2003).

and substitute away from home consumption. Therefore, this substitution effect between market and home consumption provides room for a higher volatility of market consumption. Second, when a positive market technology shock increases market consumption, the household turns to borrow from the world market in order to finance the increase in aggregate investment, which in turn reduces the trade balance. This result implies that the trade balance to GDP ratio tends to become more volatile and more countercyclical in the presence of home production. As a result, home production is a helpful mechanism for the empirical patterns exhibited in developed economies; i.e., output is more volatile than market consumption, investment is more volatile than output, and the trade balance to GDP ratio is weakly countercyclical. Third, we find that the extent of substitution between market and home consumption is positively related to the scale of the home sector. Because the home sector in emerging markets is larger than that in developed economies, market consumption is more volatile in emerging markets than in developed economies. As a consequence, the larger home sector is helpful in capturing the stylized fact that the volatility of market consumption is higher than the volatility of GDP in emerging markets. Finally, the higher volatility of market consumption causes the trade balance to GDP ratio to be more volatile and more countercyclical in emerging markets than in developed economies. Accordingly, home production provides a parsimonious explanation for the empirical pattern of international business cycles in developed economies and emerging markets.

Appendix A

This appendix provides a brief derivation of the equilibrium conditions from the nonlinear form to the linearized version in terms of percentage deviations from the steady state. The full macroeconomic competitive equilibrium for the economy is composed of 21 equations: (2a)-(3b), (5) and (7a)-(10). The endogenous variables are the sequences of quantities $\{y_t, c_{m,t}, c_{h,t}, C_t, X_t, N_t, n_{m,t}, n_{h,t}, I_{m,t}, I_{h,t}, I_t, k_{m,t}, k_{h,t}, d_t, b_t\}$ and prices $\{r_t, g_t, \mu_t, \lambda_t, q_{m,t}, q_{h,t}\}$. Given $A_m = 1$ and $A_h = 1$ in the steady state, based on the full macroeconomic competitive equilibrium model, the stationary relationship can be stated as:

$$b = \frac{rd}{y}, \tag{A1}$$

$$r = \frac{1}{\beta} - 1, \tag{A2}$$

$$q_m = 1 + \psi_m \delta_m, \tag{A3}$$

$$q_h = 1 + \psi_h \delta_h, \tag{A4}$$

$$k_m = \left[\frac{\left(\frac{1}{\beta} - 1 + \delta_m\right) q_m - \frac{(q_m - 1)^2}{2\psi_m}}{\alpha_m} \right]^{\frac{1}{\alpha_m - 1}} n_m, \tag{A5}$$

$$k_h = \left[\frac{\left(\frac{1}{\beta} - 1 + \delta_h\right) q_h - \frac{(q_h - 1)^2}{2\psi_h}}{\frac{1-\alpha_m}{1-\alpha_h} \left(\frac{k_m}{n_m}\right)^{\alpha_m} \alpha_h} \right]^{-1} n_h, \tag{A6}$$

$$c_m = \left[\frac{\theta}{1-\theta} \frac{1-\alpha_m}{1-\alpha_h} \frac{(k_m/n_m)^{\alpha_m}}{(k_h/n_h)^{\alpha_h}} \right]^{\frac{1}{1-\phi}} c_h, \tag{A7}$$

$$n_m = \frac{\frac{c_m}{c_h}\left(\frac{k_h}{n_h}\right)^{\alpha_h} + \frac{q_h^2 - 1}{2\psi_h}\left(\frac{k_h}{n_h}\right)}{(1 - r\upsilon)\left(\frac{k_m}{n_m}\right)^{\alpha_m} - \frac{q_m^2 - 1}{2\psi_m}\left(\frac{k_m}{n_m}\right)} n_h, \tag{A8}$$

$$N = \left\{ \frac{\omega\chi}{1-\alpha_h} \left[\frac{\theta}{1-\theta} \left(\frac{c_m}{c_h}\right)^{\phi} + 1 \right] / \left(\frac{n_m}{n_h} + 1\right) - \frac{\omega\gamma}{\beta(1-\gamma) - 1} \right\}^{-\frac{1}{\chi}}, \tag{A9}$$

$$n_h = \frac{N}{\frac{n_m}{n_h} + 1}, \tag{A10}$$

$$c_h = A_h k_h^{\alpha_h} n_h^{1-\alpha_h}, \tag{A11}$$

$$y = A_m k_m^{\alpha_m} n_m^{1-\alpha_m}, \tag{A12}$$

$$I_m = \delta_m k_m, \tag{A13}$$

$$I_h = \delta_h k_h, \tag{A14}$$

$$I = I_m + I_h, \tag{A15}$$

$$C=\left[\theta c_m^{\phi}+(1-\theta)\,c_h^{\phi}\right]^{\frac{1}{\phi}}, \tag{A16}$$

$$X=C, \tag{A17}$$

$$d=\upsilon y, \tag{A18}$$

$$g=\frac{(C-\omega N^{\chi}C)^{-\sigma}\,\omega N^{\chi}}{\beta\,(1-\gamma)-1}, \tag{A19}$$

$$\lambda=\left[(C-\omega N^{\chi}C)^{-\sigma}+g\gamma\right]\theta\left(\frac{c_m}{C}\right)^{\phi-1}, \tag{A20}$$

$$\mu=\left[(C-\omega N^{\chi}C)^{-\sigma}+g\gamma\right](1-\theta)\left(\frac{c_h}{C}\right)^{\phi-1}. \tag{A21}$$

Let $\hat{d}_t=d_t-d$ and $\hat{b}_t=b_t-b$, and $\hat{z}_t=(z_t-z)/z$, where z_t can be any endogenous variable in the model except for d_t and b_t. By log-linearizing the macroeconomic model around its steady state, we can derive the following linear expressions in terms of percentage deviations:

$$\begin{aligned}\hat{\lambda}_t \;&=\; (\phi-1)\left(\hat{c}_{m,t}-\hat{C}_t\right)-\frac{\sigma\,(C-\omega N^{\chi}C)^{-\sigma-1}\,C\left[\hat{C}_t-\omega N^{\chi}\left(\chi\hat{N}_t+\hat{X}_t\right)\right]}{(C-\omega N^{\chi}C)^{-\sigma}+g\gamma}\\ &\quad+\frac{g\gamma\left[\hat{g}_t+(\gamma-1)\left(\hat{C}_t-\hat{X}_{t-1}\right)\right]}{(C-\omega N^{\chi}C)^{-\sigma}+g\gamma},\end{aligned} \tag{A22}$$

$$(\phi-1)\left(\hat{c}_{m,t}-\hat{c}_{h,t}\right)=\hat{\lambda}_t-\hat{\mu}_t, \tag{A23}$$

$$\frac{\beta g\,(1-\gamma)\left[\hat{g}_{t+1}+\gamma\left(\hat{C}_{t+1}-\hat{X}_t\right)\right]-g\hat{g}_t}{(C-\omega N^{\chi}C)^{-\sigma}\,\omega N^{\chi}}=\chi\hat{N}_t-\sigma\frac{\hat{C}_t-\omega N^{\chi}\left(\chi\hat{N}_t+\hat{X}_t\right)}{1-\omega N^{\chi}}, \tag{A24}$$

$$(\chi-1)\,\hat{N}_t+\hat{X}_t-\sigma\frac{\hat{C}_t-\omega N^{\chi}\left(\chi\hat{N}_t+\hat{X}_t\right)}{1-\omega N^{\chi}}=\hat{\lambda}_t+\hat{y}_t-\hat{n}_{m,t}, \tag{A25}$$

$$\hat{\mu}_t-\hat{\lambda}_t=\hat{y}_t-\hat{n}_{m,t}-\hat{c}_{h,t}+\hat{n}_{h,t}, \tag{A26}$$

$$\hat{I}_{m,t}-\hat{k}_{m,t}=\frac{q_m}{\delta_m\psi_m}\hat{q}_{m,t}, \tag{A27}$$

$$\hat{I}_{h,t}-\hat{k}_{h,t}=\frac{q_h}{\delta_h\psi_h}\hat{q}_{h,t}, \tag{A28}$$

$$\hat{q}_{m,t}=\hat{\lambda}_{t+1}-\hat{\lambda}_t+\beta\left[\frac{\alpha_m y_m}{q_m k_m}\left(\hat{y}_{m,t+1}-\hat{k}_{m,t+1}\right)+\hat{q}_{m,t+1}\right], \tag{A29}$$

$$\hat{q}_{h,t}=\hat{\lambda}_{t+1}-\hat{\lambda}_t+\beta\left[\frac{\mu\alpha_h c_h}{\lambda q_h k_h}\left(\hat{\mu}_{t+1}-\hat{\lambda}_{t+1}+\hat{c}_{h,t+1}-\hat{k}_{h,t+1}\right)+\hat{q}_{h,t+1}\right], \tag{A30}$$

$$0=\hat{\lambda}_{t+1}-\hat{\lambda}_t+\beta r\hat{r}_{t+1}, \tag{A31}$$

$$\hat{d}_{t+1} - (1+r)\hat{d}_t - rd\hat{r}_t = c_m\hat{c}_{m,t} + \left(\frac{q_m^2}{\psi_m}k_m\hat{q}_{m,t} + \frac{q_m^2-1}{2\psi_m}k_m\hat{k}_{m,t}\right) + \left(\frac{q_h^2}{\psi_h}k_h\hat{q}_{h,t} + \frac{q_h^2-1}{2\psi_h}k_h\hat{k}_{h,t}\right) - y\hat{y}_t, \tag{A32}$$

$$\hat{X}_t = \gamma\hat{C}_t + (1-\gamma)\,\hat{X}_{t-1}, \tag{A33}$$

$$\hat{c}_{h,t} = \hat{A}_{h,t} + \alpha_h\hat{k}_{h,t} + (1-\alpha_h)\,\hat{n}_{h,t}, \tag{A34}$$

$$\hat{y}_t = \hat{A}_{m,t} + \alpha_m\hat{k}_{m,t} + (1-\alpha_m)\,\hat{n}_{m,t}, \tag{A35}$$

$$\hat{k}_{m,t+1} = (1-\delta_m)\,\hat{k}_{m,t} + \delta_m\hat{I}_{m,t}, \tag{A36}$$

$$\hat{k}_{h,t+1} = (1-\delta_h)\,\hat{k}_{h,t} + \delta_h\hat{I}_{h,t}, \tag{A37}$$

$$\hat{b}_t = \frac{(1+r)\,\hat{d}_t + rd\hat{r}_t - \hat{d}_{t+1}}{y} - \frac{rd}{y}\hat{y}_t \tag{A38}$$

$$\hat{r}_t = \frac{\eta\upsilon}{r}\left(\frac{\hat{d}_{t+1}}{d} - \hat{y}_t\right), \tag{A39}$$

$$\hat{C}_t = \frac{\frac{\theta}{1-\theta}\left(\frac{c_m}{c_h}\right)^{\phi}\hat{c}_{m,t} + \hat{c}_{h,t}}{\frac{\theta}{1-\theta}\left(\frac{c_m}{c_h}\right)^{\phi} + 1}, \tag{A40}$$

$$N\hat{N}_t = n_m\hat{n}_{m,t} + n_h\hat{n}_{h,t}, \tag{A41}$$

$$I\hat{I}_t = I_m\hat{I}_{m,t} + I_h\hat{I}_{h,t}. \tag{A42}$$

Appendix B (not for publication)

This appendix provides some intuition to explain the relationship between the utility share of market consumption θ and the volatility of market consumption in the GHH preference (i.e., $\gamma = 0$). For simplicity, we assume that $\sigma = 1$, $\alpha_m = \alpha_h = \alpha$ and $\psi_m = \psi_h = \psi = 0$. It should be noted that with $\psi_m = \psi_h = \psi = 0$ the investment adjustment costs are absent in our model, and hence $q_{m,t} = q_{h,t} = 1$ in each of the periods.

From equations (5), (8a), (8j), (9), (12), and (13) with $\gamma = 0$ the Euler equation linearized around the steady state in the GHH preference can then be inferred as:

$$\hat{c}_{m,t}^{GHH} = -\left[1 - \frac{(1-\phi)\omega N^{\chi}}{\phi(\chi - 1)}\right]\Omega\hat{p}_t + \frac{\chi\omega N^{\chi}(\hat{A}_{m,t} - \frac{\alpha r}{r+\delta}\hat{r}_t)}{(\chi-1)(1-\alpha)} - \eta\hat{\Lambda}_{2,t}, \tag{B1}$$

where the superscript "*GHH*" denotes the GHH preference, and

$$\begin{aligned}\hat{\Lambda}_{2,t} &= \sum_{j=0}^{\infty} \frac{c_m\left\{-\left[1 - \frac{(1-\phi)\omega N^{\chi}}{\phi(\chi-1)}\right]\Omega\hat{p}_{t+j} + \frac{\chi\omega N^{\chi}\left(\hat{A}_{m,t+j} - \frac{\alpha r}{r+\delta}\hat{r}_{t+j}\right)}{(\chi-1)(1-\alpha)}\right\}}{\frac{y}{\beta(1-\omega N^{\chi})}\left[1 + (1-\omega N^{\chi})\beta\eta\left(\frac{c_m}{y}\right)\right]^{1+j}} \\ &\quad + \sum_{j=0}^{\infty} \frac{I\hat{I}_{t+j} + (1+r)\hat{d}_{t+j} + rd\hat{r}_{t+j} - (y+d)\,\hat{y}_{t+j}}{\frac{y}{\beta(1-\omega N^{\chi})}\left[1 + (1-\omega N^{\chi})\beta\eta\left(\frac{c_m}{y}\right)\right]^{1+j}}.\end{aligned} \tag{B2}$$

By comparing equation (B1) with (14a), it can be found that an additional term $\chi\omega N^{\chi}(\hat{A}_{m,t} - \frac{\alpha r}{r+\delta}\hat{r}_t)/(\chi-1)/(1-\alpha)$ referred to as the substitution effect between market consumption and leisure in the utility function is present, where $\chi\omega N^{\chi}$ measures the extent of this effect.[19] Once the employment is increased by positive technology shocks, it leads to a synchronized rise in market consumption. This can cause a higher volatility of market consumption, even if home production is absent (i.e., $\theta = 1$ and $\Omega = 0$).

To be more specific, given that the parameter for the borrowing premium associated with default risk η is set very close to 0 (i.e., $\eta \to 0$), from equation (B1), if home production is absent (i.e., $\theta = 1$ and $\Omega = 0$), the variance of market consumption can then

[19] When home production is absent in the model (i.e., $\theta = 1$), it is implied that $c_{m,t} = C_t$ and $n_{m,t} = N_t$. From equations (8a) and (8c) we have the following inference. In association with the setting of the GHH preference (i.e., $\gamma = 0$), the marginal utility λ_t is taken as given, and hence consumption linearized around the steady state can be stated as: $\hat{c}_t = \omega N^{\chi}\chi\hat{N}_t$. This expression indicates that market consumption is negatively (positively) related to leisure (hours worked), and $\omega N^{\chi}\chi$ measures the extent of substitutability between consumption and leisure. In addition, from equations (8c), (8d), (8h) and (8j), the aggregate hours worked linearized around the steady state can be expressed as:

$$\hat{N}_t = \frac{\hat{A}_{m,t} - \frac{\alpha r}{r+\delta}\hat{r}_t}{(\chi-1)(1-\alpha)}.$$

Therefore, we have $\hat{c}_t = \frac{\omega N^{\chi}\chi\left[\hat{A}_{m,t} - \frac{\alpha r}{r+\delta}\hat{r}_t\right]}{(\chi-1)(1-\alpha)}$. It is found from this expression that consumption can be $\hat{A}_{m,t}$ affected by indirectly via the response of aggregate hours worked to $\hat{A}_{m,t}$. As is evident, following a rise in $\omega N^{\chi}\chi$, consumption tends to be more volatile in response.

be derived as $var(\hat{c}_{m,t}^{GHH})\big|_{\theta=1} = [\frac{\chi\omega N^{\chi}}{(\chi-1)(1-\alpha)}]^2\frac{\sigma^2}{1-\rho^2}$.[20] As is clear in this expression, the rise in $[\frac{\chi\omega N^{\chi}}{(\chi-1)(1-\alpha)}]^2\frac{\sigma^2}{1-\rho^2}$ led by the increase in the substitution effect between market consumption and leisure contributes to raising $var(\hat{c}_{m,t}^{GHH})\big|_{\theta=1}$. This is the reason why a plausible volatility of market consumption is possibly generated from a model associated with the GHH preference to match the data in the developed economy, even if η is very close to 0.

On the other hand, when home production is present (i.e., $\theta < 1$ and $\Omega > 0$), the variance of market consumption can then be expressed as $var(\hat{c}_{m,t}^{GHH})\big|_{\theta<1} = [1 - \frac{(1-\phi)\omega n^{\chi}}{\phi(\chi-1)}]^2\frac{2\Omega^2\sigma^2}{1-\rho^2} + 2[\frac{\chi\omega N^{\chi}}{(\chi-1)(1-\alpha)}][1-\frac{(1-\phi)\omega n^{\chi}}{\phi(\chi-1)}]\frac{\Omega\sigma^2}{1-\rho^2} + var(\hat{c}_{m,t}^{GHH})\big|_{\theta=1}$. If the substitution effect between market and home consumption Ω is increased by a lower θ, then the variance of market consumption $var(\hat{c}_{m,t}^{GHH})\big|_{\theta<1}$ can be raised. In other words, it can be inferred that the presence of home production being able to raise the volatility of consumption is a robust outcome in the GHH preference (i.e., $\gamma = 0$).

[20] Based on equation (9), the world interest rate linearized around the steady state can be inferred as: $\hat{r}_t = \frac{\eta\upsilon}{R}(\frac{\hat{d}_{t+1}}{d} - \hat{y}_t)$. Due to the fact that η is set very close to 0, we can then infer from this expression that the variance of $\hat{r}_t$ is also very close to 0.

Appendix C (not for publication)

Given $\sigma = 1$, $\psi_m = \psi_h = \psi = 0$, $\alpha_m = \alpha_h = \alpha$, and $p_t = \frac{\lambda_t}{\mu_t}$, the linearized version of equations (2b), (8a) and (8b) can be expressed as:

$$\hat{C}_t = \frac{\frac{\theta}{1-\theta}\left(\frac{c_m}{c_h}\right)^{\phi}\hat{c}_{m,t} + \hat{c}_{h,t}}{\frac{\theta}{1-\theta}\left(\frac{c_m}{c_h}\right)^{\phi} + 1}, \tag{C1}$$

$$(\phi - 1)\,\hat{c}_{m,t} - \phi\hat{C}_t = \hat{\lambda}_t, \tag{C2}$$

$$(\phi - 1)\,(\hat{c}_{m,t} - \hat{c}_{h,t}) = \hat{p}_t. \tag{C3}$$

Then, substituting equations (C1) and (C3) into equation (C2), we have:

$$\hat{c}_{m,t} = -\frac{\phi/(1-\phi)}{1 + \frac{\theta}{1-\theta}\left(\frac{c_m}{c_h}\right)^{\phi}}\hat{p}_t - \hat{\lambda}_t. \tag{C4}$$

In addition, form equation (A7), the ratio between market consumption and home consumption in the steady state can be expressed as:

$$\frac{c_m}{c_h} = \left[\frac{\theta}{1-\theta}\frac{1-\alpha_m}{1-\alpha_h}\frac{(k_m/n_m)^{\alpha_m}}{(k_h/n_h)^{\alpha_h}}\right]^{\frac{1}{1-\phi}}. \tag{C5}$$

Given $\alpha_m = \alpha_h = \alpha$ and $\psi_m = \psi_h = \psi = 0$, it is clear that from equations (8e), (8h) and (8i), the capital to labor ratios in the market and home sectors are identical i.e., $\frac{k_{m,t}}{n_{m,t}} = \frac{k_{h,t}}{n_{h,t}}$. This implies that equation (C5) can be rewritten as: $\frac{c_m}{c_h} = [\theta/(1-\theta)]^{\frac{1}{1-\phi}}$. Eventually, substituting this equation into (C4), the market consumption linearized around the steady state is derived as:

$$\hat{c}_{m,t} = -\frac{\phi/(1-\phi)}{1 + [\theta/(1-\theta)]^{\frac{1}{1-\phi}}}\hat{p}_t - \hat{\lambda}_t. \tag{C6}$$

Accordingly, based on equation (C6), we can derive equation (13) in the main text.

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