Feast and Famine: Explaining Big Swings in the Hong Kong Economy between 1981 and 2007

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Abstract

On average between 1981 and 2007, output per capita in Hong Kong grew at an annual rate of 3.2 percent. But economic performance over the period was far from even. Between 1987 and 1997, output per capita averaged 9.7 percent above its long run growth path. In 1997, the feast ended and the famine began. Over the next 11 years, output per capita averaged 5.2 percent below its long run path. This paper attempts to explain this big swing. We use two types of analysis. First, we use a nine-variable Bayesian Vector Autoregression and summarize the results as a set of stylized facts. Chief among these is the finding that economic activity in Hong Kong is highly senstitive to shocks of foreign origin. Second, we set our and estimate a dynamic, general equilbrium model which is able to account, at least qualitatively, for our stylized facts. We use the model to infer the relative importance of different shocks in accounting for feast and famine in Hong Kong.

1 Introduction

On average between 1981 and 2007, output per capita in Hong Kong grew at an annual rate of 3.2 percent and the unemployment rate averaged 3.7 percent. But economic performance in Hong Kong over the period was far from even. Between the fourth quarters of 1981 and 1986, output per capita in Hong Kong averaged 10 percent below its long run value. Over the next 11 years through the end of 1997, the picture was much brighter. Output per capita averaged

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9.7 percent above its long run average and the unemployment rate averaged 1.9 percent. Other measures tell a similarly bright story of the sub-period. For example, from 1987 through 1997 the real wage rate in Hong Kong averaged 4.5 percent above its long run value.

But toward the end of 1997, the feast ended and famine began. Over the next 43 quarters, the unemployment rate averaged 5.8 percent and output per capita, employment per capita, and the real wage averaged 5.2, 3.1, and 1.8 percent below their respective long run values.

This paper attempts to explain the feast-famine cycle in Hong Kong. In particular, it asks what caused the Hong Kong economy to change from a period of exceptional economic performance where the unemployment rate fell as low as 1.0 percent to one of weak performance where the unemployment rate rose as high as 8.5 percent. It is not simply the case that Hong Kong suffered a recession. The average unemployment rate between 2000 and 2005 was 6.3 percent. Whatever happened to cause the feast to end and the famine to begin had not only dire consequences for Hong Kong but long-lasting ones.

We use two types of analysis to explain what happened in Hong Kong. First, we fit a nine-variable Bayesian Vector Autoregression to Hong Kong data. The chief finding of our BVAR analysis is that Hong Kong economic activity is greatly affected by several types of foreign shocks. Second, we set out and estimate a dynamic, general equilibrium model for Hong Kong. The chief finding of our DGE analysis is that the model can account, qualitatively, for the response of Hong Kong to the shocks that it experienced. We also use the model to gauge the relative importance of the shocks experienced by Hong Kong in accounting for the onset and continuation of the its downturn.

We reach several findings of particular note. First, both our BVAR and structural model analysis indicate that the transition from feast to famine in Hong Kong that occurred in the late 1990's was the result of a "perfect storm" of negative shocks. Shocks to the risk premium associated with foreign borrowing and lending and shocks to export demand were two external factors that accounted for much of the big swing in Hong Kong economic performance. In addition, we find that shocks to nominal wages helped keep the unemployment rate low during the period of feast and also helped keep it high during the famine. Finally, we find that, in contrast with the standard real business cycle model, technology shocks played only a secondary role in the feast and famine cycle.

The paper is organized into five sections. We set out the DGE model in section two and derive the linear equations that govern movement of the model's variables in the vicinity of its steady state. In section three, we describe the data, explain our BVAR analysis, and infer from that analysis a set of stylized facts that describe economic performance in Hong Kong during the sample period. In section four, we explain how we calibrated some model parameters and estimated others, we report our model estimates, and explain the implications of those estimates with a forecast error variance accounting and impulse response functions. We argue that our model is able to account for many, if not all, of the stylized facts described in section 3. In Section 4, we use our model to explain what forces accounted for the dramatic change in economic fortune experienced by Hong Kong toward the end of the 1990's.

2 The Model

The model we use combines elements of Real Business Cycle (RBC) and New Keynesian models. It is a RBC model in the sense that no provision is made for holding money or for monetary policy–a reasonable approach given that Hong Kong pegs its currency to the U.S. dollar. The peg is the nominal anchor in the model which, given equilibrium conditions for real prices and quantities, determines the general level of prices. The model is New Keynesian in the sense that wages are sticky. Intermediate-goods firms and workers bargain over wages with the result that unemployment occurs in equilibrium.

Bargaining is costly and firms do not bargain each period. The resulting wage stickiness helps explain why shocks to the model's structural errors have lasting effects. Our model is a version of the model presented in Salemi [28] to which we add labor supply adjustment costs in order to account for the fact that Hong Kong labor force participation rates change only slightly during our sample period.

The equilibrium unemployment mechanism of this paper is different from the search-matching mechanism of Pissarides [26], Den Haan, Haefke, and Ramey [8], Den Haan, Ramey, and Watson [9] and others. In the search-matching mechanism, jobs are durable and workers and firms remain paired until either an exogenous shock or an endogenous decrease in the value of the pairing causes them to separate. Separated workers remain unemployed until a matching mechanism connects them to a new firm.

The mechanism of this paper is similar to that of Peretto [24]. Labor contracts last a single period and unemployment occurs because the wage bargaining process produces a wage higher than that which would clear the market. Unlike the households in Den Haan, Haefke, and Ramey [8] and Den Haan, Ramey, and Watson [9], households in our model derive utility both from consumption and leisure. In our framework, departures of the unemployment rate from its long run value persist because the wage rate is slow to adjust.

The model has four sectors: Households, Firms, Government, and International Trade. We begin with the household sector.

2.1 Household

The economy is made up of a continuum of households distributed along the unit interval. The representative household seeks to maximize

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t,\ J_t, \Lambda_t) \tag{1}$$

where C_t, J_t and Λ_t are consumption, leisure and household population respectively. The household population Λ_t grows at an exogenous rate g, so that

$\Lambda_t = g^t\Lambda_0$. Each household member is endowed with one unit of time. Leisure is defined as $J_t = \Lambda_t - L_t p_t^e - \Lambda_t\Omega(L_t, L_{t-1})$. L_t is labor supply, the number of household members participating in the labor market and p_t^e denotes the probability of finding employment. The product of these two variables, $L_t p_t^e$, is expected household employment.[1] The household takes p_t^e as exogenous when it solves its maximization problem.

We assume that the household faces coordination costs when it changes the level of labor it supplies to the market. We approximate these adjustment costs with the function, $\Omega(L_t, L_{t-1})$, given by

$$\Omega(L_t, L_{t-1}) \equiv \frac{\theta}{2}(\frac{L_t}{\Lambda_t} - \frac{L_{t-1}}{\Lambda_{t-1}})^2$$

By definition, steady-state labor supply is not affected by adjustment costs.

The period utility function has the form

$$U(C_t, L_t, \Lambda_t) = \Lambda_t \left\{ \ln \frac{C_t}{\Lambda_t} + \Psi \ln \left[\frac{\Lambda_t - L_t p_t^e}{\Lambda_t} - \frac{\theta}{2}\left(\frac{L_t}{\Lambda_t} - \frac{L_{t-1}}{\Lambda_{t-1}}\right)^2 \right] \right\}$$

which can be rewritten as

$$U(c_t, l_t, \Lambda_t) = \Lambda_t \left\{ \ln c_t + \Psi \ln \left[1 - l_t p_t^e - \frac{\theta}{2}\left(l_t - l_{t-1}\right)^2 \right] \right\} \tag{2}$$

where c_t and l_t represent per capita consumption and the fraction of the household participating in the labor market.[2]

Maximization of (1) is subject to a dynamic budget constraint given by

$$[W_t(1-\tau)]\Lambda_t l_t p_t^e + B_t\Lambda_t l_t(1-p_t^e) + D_t + S_t D_t^* + T_t + \Pi_t = P_t\Lambda_t c_t + \frac{D_{t+1}}{(1+R_t)} + \frac{S_t D_{t+1}^*}{(1+R_t^*)\kappa_t} \tag{3}$$

where W_t is the market nominal wage rate, B_t is nominal unemployment benefits, D_t is the family member's holding of one-period nominal domestic bonds and D_t^* is the family member's holding of one-period nominal foreign bonds, which are denominated in foreign currency. P_t is the domestic price level; S_t is the nominal exchange rate; T_t is a transfer from the government and Π_t is the flow of profits received by the household from intermediate-goods firms.

Domestic households can borrow and lend in domestic and foreign markets at gross nominal rates $1 + R_t$ and $(1 + R_t^*)\kappa_t$. The term κ_t represents the country risk premium associated with foreign loans to the domestic economy. In our empirical work we use the U.S. Treasury Bill rate as a measure of R_t^* and treat κ_t as an exogenous structural shock which is distributed independently of R_t^*.

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[1] If employed, a household member spends all his time working. If not employed, the household member preserves all his time for lesiure activities.

[2] Since the economy comprises a single household, l_t is the labor force participation rate of the economy.

Working household members earn wages at the nominal rate W_t and are taxed at rate τ. Household members choose whether or not to enter the labor market. Those who enter are employed with probability p_t^e and not employed with probability $1 - p_t^e$. Thus, unemployment is involuntary. Labor market entrants who are not employed receive an unemployment benefit B_t.

Solving the household's optimization problem yields three first order conditions

$$E_t\left[\frac{\beta c_t(1+R_t)P_t}{c_{t+1}P_{t+1}}\right] = 1 \tag{4}$$

$$E_t\left[\frac{\beta c_t(1+R_t^*)\kappa_t S_{t+1}P_t}{c_{t+1}S_tP_{t+1}}\right] = 1 \tag{5}$$

and

$$\frac{W_t^R}{P_tc_t} = \frac{\Psi}{j_t}(p_t^e + \theta(l_t - l_{t-1})) - E_t\frac{\beta\Psi\theta g}{j_{t+1}}(l_{t+1} - l_t) \tag{6}$$

where $W_t^R \equiv B_t(1-p_t^e) + W_t(1-\tau)p_t^e$ is the household member's reservation wage and $j_t \equiv 1 - l_tp_t^e - \frac{\theta}{2}\left(l_t - l_{t-1}\right)^2$ is per capita leisure.

Equations (4) and (5) are standard consumption Euler equations which together imply uncovered interest rate parity so that, given the exchange rate peg, the domestic interest rate is completely determined by the foreign interest rate and the risk premium.

Equation (6) shows that labor supply is directly related to the reservation wage. The probability of finding employment affects labor supply in two ways. A higher probability raises the reservation wage and causes the household to substitute labor for leisure.[3] But a higher probability also implies that the same labor supply decision leads to more employment and less leisure so that the optimal amount of labor decreases. The net effect of an increase in p_t^e on labor supply depends on the values of the parameters.

We assume there are no unfilled vacancies which implies that the probability of being unemployed equals the economy's unemployment rate: $U_t = 1 - p_t^e$. While the population growth rate, g, also affects labor supply, we assume for simplicity that g equals 1.0.[4]

2.2 Firms

There are two types of firms in the economy: a competitive final goods firm and a continuum of price-setting intermediate goods firms indexed by i, where $i \in [0,1]$. The competitive firm transforms intermediate goods into a final good with a production technology given by

$$Y_t = \left[\int_0^1 X_t(i)^{\left(\frac{\varepsilon-1}{\varepsilon}\right)}di\right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{7}$$

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[3] The reservation wage can be written as $W_t^R \equiv B_t + (W_t(1-\tau) - B_t)p_t^e$. We assume that the after-tax wage rate is larger than the unemployment benefit so that $W_t(1-\tau) - B_t > 0$.

[4] In fact, the average quarterly population growth rate of Hong Kong from 1981 to 2007 is 0.0027.

where Y_t is the final good and $X_t(i)$ is the ith intermediate good. The final good is either consumed by households or exported to the rest of the world.

The final goods firm maximizes profit

$$P_t Y_t - \int_0^1 P_t(i) X_t(i) di$$

subject to (7). The solution of the maximization problem yields the the final-goods firm demand equation for $X_t(i)$:

$$X_t(i) = Y_t \left(\frac{P_t(i)}{P_t} \right)^{-\varepsilon} \tag{8}$$

Substituting (8) into (7) provides the relationship between the aggregate price level and intermediate goods prices.

$$P_t = \left[\int_0^1 P_t(i)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}}$$

Each intermediate goods firm sets the price of its own good but all intermediate goods firms use the same McCallum-Nelson [21] production technology given by

$$X_t(i) = [\alpha(A_t N_t(i))^\nu + (1-\alpha) M_t(i)^\nu]^{1/\nu} \tag{9}$$

where A_t is a random labor productivity shock common to all firms, $N(i)$ is labor employment and $M(i)$ is employment of imported inputs. We assume that all imported goods are used as inputs by intermediate goods firms. None are consumed directly by households.

As in Salemi [28], workers and firms bargain over the nominal wage rate but not over levels of employment. Thus, the firm chooses the levels of labor and imported inputs that maximize profit while taking as given the wage rate and the price of imported inputs. Let Π_t denote the profits of the typical firm. Π_t is given by

$$\Pi_t = P_t Y_t^{1/\varepsilon} [\alpha(A_t N_t(i))^\nu + (1-\alpha)(M_t(i))^\nu]^\eta - W_t(i) N_t(i) - P_{M,t} M_t(i) \tag{10}$$

For each firm, optimal employment levels are the solutions to the following maximization problem:

$$\max_{N(i),M(i)} \{\Pi_t\}$$

The resulting demand for labor by the firm is given by

$$N_t(i) = (\eta\nu\alpha)^{1/(1-\nu)} A_t^{\nu/(1-\nu)} Y_t \left(\frac{W_t(i)}{P_t} \right)^{-1/(1-\nu)} \tag{11}$$

where $\eta = \frac{\varepsilon - 1}{\nu\varepsilon}$. The resulting demand for imported inputs is given by

$$M_t(i) = (\eta\nu(1-\alpha))^{1/(1-\nu)} Y_t \left(\frac{P_{M,t}}{P_t} \right)^{-1/(1-\nu)} \tag{12}$$

2.2.1 *Bargaining*

The wage rate is the outcome of a bargaining process and does not, in general, clear the labor market. We assume that the bargaining process results in the wage that maximizes the geometrically weighted sum of firm and worker the surpluses. The firm's surplus is its profit (10). The worker's surplus is defined as the product of employment and the difference between the worker's after-tax wage rate and his reservation wage.

Formally, we assume the wage bargain is the solution to the following maximization problem

$$\max_{W(i)} \left\{ \begin{array}{c} \gamma \log \left[P_t Y_t^{1/\varepsilon} [\alpha(A_t N_t(i))^\nu + (1-\alpha)(M_t(i))^\nu]^\eta - W_t(i) N_t(i) - P_{M,t} M_t(i) \right] \\ +(1-\gamma)\log[(W_t(i)(1-\tau) - W_t^R) N_t(i)] \end{array} \right\}$$

where employment of labor and imported inputs are governed by (11) and (12). The weights γ and $1-\gamma$ represent the power of the firm and workers in the bargaining process. During bargaining, both the firm and workers take W_t^R as given.

Combing the first order condition that describes the optimal wage bargain with equations (10), (11) and (12) yields our model's prediction about wages

$$W_t^*(i) = \frac{W_t^R}{1-\tau}(1+x_t) \tag{13}$$

where $W_t^*(i)$ is the outcome of the wage bargain and x_t is the wage markup given by

$$x_t = \left[\left(\frac{\gamma}{1-\gamma}\right) \frac{W_t^*(i) N_t(i)}{\Pi_t} + \frac{1}{1-\nu} - 1 \right]^{-1} \tag{14}$$

The optimal wage bargain is the product of the tax-adjusted reservation wage and a wage premium equal to one plus the wage markup x_t. When $\gamma = 1$, firms have all the bargaining power and the wage markup goes to zero. When $\gamma = 0$, workers have all the bargaining power and the wage markup goes to $(1-\nu)/\nu$. If $0 < \gamma < 1$, the markup depends on the ratio of the firm's wage bill to its profit. When γ and ν lie between zero and one, the markup is positive. Since every firm bargains with its workers and the bargaining process is the same for each firm, $W_t^*(i) = W_t^*, \forall i$, where W_t^* is the economy-wide wage bargain.

In a world without friction, bargaining would occur in each period and the wage would adjust instantaneously to the level predicted by (13). As we explain in the following sections, the data suggest that wages in Hong Kong adjust sluggishly to economic events. For that reason, we assume that W_t evolves according to

$$W_t = \lambda W_{t-1} + (1-\lambda) W_t^* \tag{15}$$

where larger values of λ imply slower adjustment. Salemi [28] and Hall [14] make similar assumptions.

2.3 Government sector

We assume that the government uses the proceeds of an income tax to finance unemployment benefits and distributes any residual income in a lump sum to households. The resulting budget constraint is:

$$T_t = \tau W_t N_t - B_t(L_t - N_t) \tag{16}$$

For simplicity, we assume that the unemployment benefit B_t is proportional to the nominal wage rate so that

$$B_t = \sigma W_t \tag{17}$$

where σ governs the generosity of the unemployment benefit.

2.4 International sector

The international sector plays an important role in our model since imports are used in the production of home-country intermediate goods and since exports account for a sizeable fraction of home-country aggregate demand. We assume that the rest of the world supplies imports to Hong Kong elastically at a foreign currency price P_t^* and a domestic currency price of $P_{M,t} = S_t P_t^*$ where S_t is the nominal exchange rate. We assume that the home economy faces the following standard demand schedule for its exports

$$EX_t = \phi(Q_t)^\mu Y_t^* \tag{18}$$

where Q_t is the real exchange rate given by

$$Q_t = \frac{S_t P_t^*}{P_t} \tag{19}$$

In (18), μ is the elasticity of export demand with respect to the real exchange rate, Y_t^* is exogenous foreign income and ϕ is a scale parameter. Given our definition of the real exchange rate, an increase in Q_t implies that a unit of foreign goods trades for a larger amount of Hong Kong goods. Thus, we expect that exports are directly related to Q_t, that is, that $\mu > 0$.

2.5 Equilibrium conditions

In this subsection, we describe what must be true in equilibrium. Because intermediate goods firms are identical, each charges the same price and employs the same amounts of labor and imported inputs and the relationship between aggregate production and aggregate input use is given by

$$Y_t = [\alpha(A_t N_t)^\nu + (1-\alpha)M_t^\nu]^{1/\nu} \tag{20}$$

where N_t and M_t are aggregate labor employment and imported input employment.[5] It follows that total nominal profit can be written as

$$\Pi_t = P_t Y_t - W_t N_t - P_{M,t} M_t$$

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[5] Since each intermediate good firm faces the same profit-maximization problem,

In equilibrium, final output is either consumed by households or exported to the rest of the world, so that

$$Y_t = C_t + EX_t \tag{21}$$

Under the assumption that all households are identical, net borrowing from domestic sources must be zero in equilibrium so that

$$D_t = 0 \tag{22}$$

However, D_t^* will not in general equal zero in equilibrium since domestic and foreign agents are not identical. Because the probability of being unemployed equals the unemployment rate, we have

$$1 - p_t^e = U_t \tag{23}$$

Because of the wage bargaining process, the labor market does not clear and the equilibrium level of unemployment is given by

$$U_t = \frac{L_t - N_t}{L_t} \tag{24}$$

Finally, combining the aggregate production function, the budget constraints for the household and government sectors yields the following condition:

$$S_t \left[\frac{D_{t+1}^*}{(1+R_t^*)\kappa_t} - D_t^* \right] = P_t[EX_t - Q_t M_t] \tag{25}$$

Equation (25) is the current account balance equation. The net additions to Hong Kong foreign bond holdings measured in domestic currency must equal the the Hong Kong trade surplus. We assume that the nominal exchange rate is fixed since Hong Kong pegs its currency to the U.S. dollar which implies that S_t is a constant.

For our model then, the endogenous variables are c_t, R_t, P_t, l_t, Y_t, N_t, M_t, W_t, W_t^*, Q_t, Π_t, T_t, D_t, D_t^*, p_t^e, U_t, B_t and EX_t.Given the exogenous variables, the endogenous variables are determined jointly by (4)-(6) and (11)-(25).

2.6 Log-linear Equations System

In this section, we set out the log-linear model that we take to the data in Section 4. We follow standard practice and linearize the model around its deterministic steady state. In Appendix B, we describe the model's steady state. In Appendix C, we explain in detail how we linearized the model.

Our short run model contains 11 variables: $\widehat{y}_t$, $\widehat{n}$, $\widehat{m}$, $\widehat{W}_t$, $\widehat{P}_t$, $\widehat{Q}_t$, $\widehat{l}_t$, $\widehat{W}_t^R$, $\widehat{c}_t^y$, $\widehat{U}_t$ and $\widehat{W}_t^*$ which denote output per capita, labor employment per capita, imported input employment per capita, the nominal wage rate, the domestic price

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$N_t = \int_o^1 N_t(i)di$ and $N_t = N_t(i)$. Likewise, $M_t = \int_o^1 M_t(i)di$.

level, the real exchange rate, the household's reservation wage, the consumption-output ratio, the unemployment rate and the optimal wage bargain.

Our model includes nine exogenous shocks: $\widehat{A}_t$, a technology shock; $\widehat{\epsilon}_{n,t}$, a shock to labor demand; $\widehat{\epsilon}_{m,t}$, a shock to the demand for imported inputs; $\widehat{\epsilon}_{l,t}$, a shock to labor supply; $\widehat{\epsilon}_{w,t}$, a shock to the nominal wage rate; $\widehat{\epsilon}_{x,t}$, a shock to foreign demand for Hong Kong exports; $\widehat{P^*_t}$, a shock to the level of foreign prices; $\widehat{R^*_t}$, a shock to the foreign interest rate; and $\widehat{\kappa}_t$, a shock to the risk premium received by Hong Kong citizens for holding foreign debt. Hatted variables are percentage deviations of non-hatted variables from their steady state values with two exceptions. $\widehat{U}_t$ and $\widehat{R^*_t}$ are absolute deviations of the unemployment rate and the foreign interest rate from their steady state values.

Because we do not have independent data on labor supply, we use equation 36 to substitute it from the system. Because Hong Kong fixes its exchange rate, equation 34 is an identity which we use to eliminate P_t from the system. We are thus left with a system of nine variables driven by nine stochastic shocks.

The log-linear model is:

$$\widehat{y}_t = \Gamma_{1,n}\widehat{n}_t + \Gamma_{1,m}\widehat{m}_t + \Gamma_{1,n}\widehat{A}_t \tag{26}$$

$$\widehat{y}_t - \widehat{n}_t = \Gamma_{2,w}(\widehat{W}_t - \widehat{P}_t) - \Gamma_{2,A}\widehat{A}_t + \widehat{\epsilon}_{n,t} \tag{27}$$

$$\widehat{y}_t - \widehat{m}_t = \Gamma_{3,Q}\widehat{Q}_t + \widehat{\epsilon}_{m,t} \tag{28}$$

$$\widehat{l}_t = \Gamma_{4,0}\left\{\widehat{W^R_t} - \widehat{P}_t - \widehat{c^y}_t - \widehat{y}_t + \Gamma_{4,-1}\widehat{l}_{t-1} + \Gamma_{4,1}\widehat{l}_{t+1} + \Gamma_{4,u}\widehat{U}_t\right\} + \widehat{\epsilon}_{l,t} \tag{29}$$

$$\widehat{W^R_t} = \widehat{W}_t + \Gamma_{5,u}\widehat{U}_t \tag{30}$$

$$\widehat{W^*_t} = \Gamma_{7,u}\widehat{U}_t + \Gamma_{7,y}(\widehat{y}_t - \widehat{Q}_t - \widehat{m}_t) + \widehat{P}_t + \widehat{A}_t \tag{31}$$

$$\widehat{W}_t = \lambda\widehat{W}_{t-1} + (1-\lambda)(\widehat{W^*_t}) + \widehat{\epsilon}_{w,t} \tag{32}$$

$$\widehat{c^y}_t = -\Gamma_{8,Q}(\mu\widehat{Q}_t + \widehat{\epsilon}_{x,t}) \tag{33}$$

$$\widehat{Q}_t + \widehat{P}_t = \widehat{P^*}_t \tag{34}$$

$$\widehat{c^y}_t + \widehat{y}_t = E_t(\widehat{c^y}_{t+1} + \widehat{y}_{t+1)} - (\widehat{R}^*_t - E_t(\widehat{P}_{t+1}) + \widehat{P}_t) - \widehat{\kappa}_t \tag{35}$$

$$\widehat{U}_t = \frac{\overline{n}}{\overline{l}}(\widehat{l}_t - \widehat{n}_t) \tag{36}$$

We define $\widehat{\varsigma}_t = \{\widehat{A}_t, \widehat{\epsilon}_{n,t}, \widehat{\epsilon}_{m,t}, \widehat{\epsilon}_{l,t}, \widehat{\epsilon}_{w,t}, \widehat{\epsilon}_{x,t}, \widehat{P}_t^*, \widehat{R}_t^*, \widehat{\kappa}_t\}$ to be the 9×1 vector of structural stochastic shocks that account for deviations in our model variables from their steady state values. We assume that each element of $\widehat{\varsigma}_t$ has the following univariate representation:

$$\widehat{\varsigma}_{i,t} = \rho_{\varsigma}(L)\widehat{\varsigma}_{i,t-1} + s_{i,t} \tag{37}$$

where $s_{i,t}$ is the innovation to $\widehat{\varsigma}_{i,t}$ and, as such, is serially uncorrelated.

We assume the labor productivity shock, $\widehat{A}_t$, follows an AR(4) process; the foreign price shock, $\widehat{P_t^*}$, follows an AR(3) process; the foreign interest rate shock, $\widehat{R}_t^*$, and risk premium shock, $\widehat{\kappa}_t$, follow AR(2) processes. We assume that the labor demand shock, $\widehat{\epsilon}_{n,t}$, the imported input demand shock, $\widehat{\epsilon}_{m,t}$, and the export demand shock, $\widehat{\epsilon}_{x,t}$, follow AR(1) processes. Finally, we assume that the labor supply shock, $\widehat{\epsilon}_{l,t}$, and the shock to the nominal wage rate are white noise. The number of lags in the time series representations of the shocks are selected to ensure that the structural innovations are white noise.[6]

We combine equations 26 through 37 into the model's companion form

$$A \begin{bmatrix} \widehat{X}_t \\ E_t(\widehat{Y}_{t+1}) \end{bmatrix} = B \begin{bmatrix} \widehat{X}_{t-1} \\ \widehat{Y}_t \end{bmatrix} + Cs_t \tag{38}$$

where s_t is the 9×1 vector with typical element $s_{i,t}$. For given parameter values, we solve the model using the method of Klein [16]. The solution of the model may be written as a first order autoregression

$$\begin{bmatrix} \widehat{X}_t \\ \widehat{Y}_t \end{bmatrix} = D \begin{bmatrix} \widehat{X}_{t-1} \\ \widehat{Y}_{t-1} \end{bmatrix} + Fs_t \tag{39}$$

where $\widehat{X}_t$ includes the model's predetermined variables, $\widehat{Y}_t$ includes the model's forward-looking variables and Fs_t is the vector of reduced form errors.

3 What The Data Show

In this section, we describe the data used in the empirical portion of our study and characterize interactions among the data series. We characterize interactions in two ways: by studying pairwise plots and by fitting a Bayesian VAR to the data. Although we defer estimation of our model until Section 4, we are guided by the model in our choice of series and VAR configuration. At the end of the section, we summarize our findings as a list of stylized facts. We report data sources and related information in Appendix A.

We use quarterly data for nine series beginning with the fourth quarter of 1981 and ending with the third quarter of 2007. Hong Kong fixed its currency

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[6] In an earlier work, we assumed most of the structural shocks follows an AR(1) process. However, the Ljung-Box test rejected the null hypothesis of no serial correlations in the structural innovations.

to the dollar in October of 1983. The starting point of our data set implies that, allowing for lags, we estimate our models for the period of the peg.

We pre-treat each series by extracting a constant and quarterly seasonal effects. We also extract the linear trends from series that display them, in particular output per capita, the nominal wage rate, and the price level. We consider the resulting series to be estimates of the departures of each series from its long run time path. The series are: the U.S. three month Treasury Bill rate ($\widehat{R_t^*}$), output per capita ($\widehat{y_t}$), labor employment per capita ($\widehat{n_t}$), employment of imported inputs per capita ($\widehat{m_t}$), the unemployment rate ($\widehat{U_t}$), the real exchange rate ($\widehat{Q_t}$), the nominal wage rate ($\widehat{W_t}$), the price level ($\widehat{P_t}$), and the consumption-output ratio ($\widehat{c_t^y}$). Table 1 provides sample statistics for these series and for others that will be described shortly.

Display Table 1 About Here

3.1 Pairwise Analysis of Selected Series

We display our data in Figure 1. Panel A displays output per capita and unemployment and shows clearly the dramatic reversal of fortune that occurred in Hong Kong after 1994. On closer inspection, the figure suggests that the sample period is composed of several episodes. Between 1981:IV and 1986:IV, output per capita is below its long run growth path but rising quickly toward it while unemployment begins near its long run value and then falls below it. After 1987, output per capita rises above its long run growth path and remains there while the unemployment rate remains very low creating a sustained period of economic prosperity. After the feast comes the famine. The Hong Kong economy reverses course beginning in 1995 when output per capita begins to fall. In 1998:I, output per capita crosses its long run growth path and begins a period of sustained sub-standard growth. In 1998, the unemployment rate rises above its long run value and remains above it for all but two quarters until the end of 2006. Between 1999 and 2007, output per capita and unemployment oscillate dramatically before returning toward their long run paths. The increase in the unemployment rate that occurs between 1989 and 2002 is a staggering 7 percent.

Panel A also clearly shows that output per capita and unemployment are negatively correlated and it is natural to ask whether a version of Okun's law provides a good description of these data. A simple regression of $\widehat{U_t}$ on $\widehat{y_t}$ implies that an increase in output per capita of 0.01 (one percent) implies a decrease in the unemployment rate of 0.0015 (15 basis points). However, the residuals from this regression are highly serially correlated suggesting that the effect on unemployment of an increase in output per capita is distributed through time–a conjecture that we check with our VAR analysis. Interestingly, it is the level of $\widehat{y_t}$ rather than the quarter-to-quarter change in $\widehat{y_t}$ which better explains the unemployment rate.

We next turn attention to prices and quantities in the labor market. During the sample period, the nominal wage grew at an annual rate of 7.7 percent and the price level grew at an annual rate of 3.0 percent implying that the real wage grew at an average annual rate of 4.7 percent. The real wage did not, however, grow steadily during the period. Panel B of Figure 1 shows that the real wage $(\widehat{W}_t - \widehat{P}_t)$ fell in the early 1980's and then rose steadily until 1998 when it began a steep decline–eventually falling by over 20 percent by the end of the sample.

Panel B also shows that labor employment per capita rose slightly and remained above its long run value until 1992, oscillated around that value until 1997, and then fell below it and remained there throughout the remainder of the sample. While Figure 3.2 indicates that $\widehat{n}_t$ and $\widehat{W}_t - \widehat{P}_t$ are negatively correlated, it suggests that turning points in the path of the real wage lag turning points in the path of employment by about a year. The figure thus suggests that Hong Kong wages may adjust slowly to economic conditions which motivates our decision to allow the wage rate in our model to adjust slowly to the value implied by current bargaining conditions.[7]

Our second input market is the market for imported goods which we treat as inputs to Hong Kong production. Panel C reveals that imported inputs per capita is strongly negatively correlated with the real exchange rate. The sample correlation is -.77. It also shows that $\widehat{m_t}$ rose and $\widehat{Q_t}$ fell steadily between the beginning of the sample and 1997. But, in 1997, $\widehat{m_t}$ changed course–falling dramatically in 1998 and 1999 and oscillating between 2000 and the end of the sample period. In a kind of mirror image, $\widehat{Q_t}$ fell steadily from the beginning of the sample period until it reached its sample minimum at the end of 1998 when it began a gradual increase toward a level a bit below the sample average.

Panels B and C both suggest that movements along (intensive) input demand schedules can explain the joint behavior of input use and input prices during the sample period. It will be interesting to see whether such a conclusion survives formal estimation of the model.

Taken together, the data for output per capita, the unemployment rate, the real exchange rate and the real wage rate suggest that the Hong Kong economy experienced several sizeable shocks that occurred at different times during the sample period. Something caused increases in output per capita to level off in the early 1990s. But it is likely that other shocks are responsible for the precipitous decline in output per capita that began in 1995. Still other shocks are needed to explain the leveling of the real exchange rate that began in 1998. Put another way, the data in Figure 1 make it unlikely that changes in Hong Kong production, employment and real factor prices can be explained as the result of a series of technology shocks which are typically assumed by real business cycle theorists to be the driving force behind cycles. Given our assumed production function, technology shocks will have difficulty accounting for the dramatic differences in the paths of labor and imported inputs.

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[7] To provide a further check, we compare wage adjustment in Hong Kong and in the U.S by fitting comparable VARs that include the growth rate of wages, the inflation rate and detrended output per capita. The estimated VARs imply that wage adjustment in Hong Kong is much slower. After one percent shocks to either wage growth, the inflation rate or output per capita, it takes about 25 quarters for the US wage to reach its new long run value. However, it takes at least 50 quarters for the Hong Kong wage to settle after similar shocks.

Panel D of Figure 1 reinforces the point that shocks to technology alone are unlikely to account for changes in $\widehat{y}_t$, $\widehat{n}_t$, and $\widehat{m_t}$ during the sample period. Panel D charts the Solow residuals implied by our preferred specification of the production function[8]. It shows a cluster of negative shocks to technology during 1994 through 1997 that lower output per capita from 20 percent above the sample average to 30 percent below it.[9] On the view that shocks to technology alone account for most of the variation in business cycles, we should see dramatic shifts in $\widehat{n}_t$, and $\widehat{m_t}$ at about the same time. We do not. Indeed it is hard to reconcile these technology shocks with continued growth in the use of imported inputs through 1998 and with continued growth in the real wage through 1997. In our view, it is likely that other shocks occurred and one of the goals of our research is to infer what these other shocks were.

Panel E displays the times series for departures of the foreign price level from its long run path. The fixed exchange rate regime maintained in Hong Kong throughout the sample period implies that values for foreign prices are a linear combination of the domestic price level and the real exchange rate ($\widehat{P_t^*} = \widehat{Q_t} + \widehat{P}_t$). Panel E shows that foreign prices grew during the first two years of the sample to a level about 15 percent above sample average, oscillated around that level until 1996, and then began to fall precipitously until 2003. In the following section, we will investigate the consequences of this dramatic fall in foreign prices on the Hong Kong economy.

Panel F of Figure 1 displays the estimate of shocks to foreign demand for Hong Kong exports that is implied by a standard estimate[10] of the elasticity of demand for exports with respect to their relative price ($\widehat{\varepsilon}_{x,t} = -\widehat{c_t^y} - 2.0 * \widehat{Q_t}$). The shock is defined so that positive values are increases in demand. The figure suggests that the demand schedule for Hong Kong exports shifted steadily upward from the beginning of the sample period through 1998 and remained relatively unchanged after that date. In what follows, we will examine the consequences of this apparent change in demand for Hong Kong exports through the lens of our model.

While we understand that our estimates of technology and export demand shocks are "generated regressors", we believe it is instructive to include these variables in our VAR analysis. Doing so allows us to construct a VAR with shocks that should mimic the structural shocks that our model says are important sources for variation in Hong Kong output and employment and important sources of the episodic behavior that the Hong Kong economy displays during the sample period.

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[8] We use the term "technology shock" to describe exogenous structural shocks to A_t in equation 9. We use the term "Solow residual" to describe estimates of those shocks derived by forming using estimates of the production function parameters to back out estimates of A_t.

[9] To check whether the large shift in the Solow residual was unique to Hong Kong, we estimated Solow residuals for South Korea, using a Cobb-Douglas production function with labor and imports as inputs. We find that the Solow residual in Korea moved from 10 percent below average to 20 percent above between late 1996 and early 1998.

[10] We use the estimate for μ reported by Abbott and De Vita [1]

3.2 Vector Autoregression Analysis

In this section we report what happens when we use a Bayesian VAR to characterize interrelationships among the data. The goal is to establish a set of stylized facts for Hong Kong that our structural model should account for.

We include nine series and six lags in our VAR which implies that we have 98 usable observations and potentially 55 coefficients to estimate in each equation. For that reason and to impose our prior view that certain variables in the VAR are very likely to be exogenous (in Granger's sense) relative to local Hong Kong variables, we use a Bayesian procedure to estimate the VAR coefficients.

Our prior is fairly standard with one exception. The prior means on all coefficients are zero except for the first lag of the dependent variable which has a prior mean of one. This feature of the prior implies that each variable is likely to follow a random walk. The standard deviations of the prior are smaller for other variables than for lagged dependent variables which implies that the prior favors a univariate autoregression for each variable. The standard deviations of the prior also grow smaller with lag length which implies that the prior favors shorter lag lengths over longer ones.

The non-standard feature of our prior is its asymmetry. We assume that Hong Kong is a small country in the sense that Hong Kong variables are far less likely to enter the equations for foreign variables than the other way around.

We are again guided by our model in selecting variables to include in our VAR system. Our "exogenous block" includes the foreign interest rate and our estimates of foreign price shocks, shocks in foreign demand for Hong Kong exports and technology shocks as estimated by the Solow residuals described in the previous section. We thus allow the VAR to gauge the relative importance for Hong Kong of shocks to the US interest rate, shocks to foreign prices, shocks to foreign demand for Hong Kong exports, and shocks to technology.

Our "endogenous block" includes the real exchange rate, real wage, labor employment per capita, imported inputs per capita and the unemployment rate. We drop output per capita from the analysis because our measure of technology shocks is a linear combination of $\widehat{y_t}$, $\widehat{n_t}$, and $\widehat{m_t}$. We thus allow our VAR to gauge the relative importance for Hong Kong of foreign shocks and shocks originating within the Hong Kong economy.

3.2.1 Forecast Error Variance Decomposition

We first turn our attention to the forecast-error-variance (FEV) decomposition implied by our estimated VAR. For each variable in the system, the decomposition provides a measure of the relative importance of all the variables for explaining variation in the variable in question. Table 2 contains our results for horizons of 1, 8 and 80 quarters.

Display Table 2 About Here

Table 2 supports the conclusion that foreign shocks are very important for explaining variation in Hong Kong employment and unemployment. For example, while over half of the one-quarter FEV in unemployment is accounted for by variation in unemployment's idiosyncratic part, that fraction falls to 42 percent at a horizon of 8 quarters, and 27 percent at a horizon of 80 quarters. At longer horizons, all the variables in the exogenous block become more important, accounting for about 30 percent of FEV at a horizon of 8 quarters and about 50 percent at a horizon of 80 quarters. It is interesting that while shocks to technology appear to be of some importance in the long run, they never account for as much as 20 percent of the forecast error variance of unemployment at any horizon.

A similar set of results holds for employment per capita. At a horizon of one-quarter, 89 percent of FEV is accounted for by idiosyncratic shocks to employment but that share falls to 74 percent at a horizon of 8 quarters and 43 percent at a horizon of 80 quarters. The exogenous block variables account for 36 percent of employment FEV at the 80 quarter horizon. Of this total, US interest rates account for a bit more and shocks to technology for a bit less than in the case of unemployment. It is interesting to note that surprises in the real wage rate and in the real exchange rate account for very little variation in either employment or unemployment.

A slightly different picture emerges for imported inputs per capita. Even at short horizons both shocks to export demand and technology account for a substantial fraction of FEV. As the horizon lengthens, US interest rates account for more and export and technology shocks account for less FEV but the total amount of FEV accounted for by exogenous block shocks remains large–45 percent. As was the case for $\widehat{n_t}$, surprises in the real wage and real exchange rate account for very little FEV of imported inputs at all horizons.

What does the VAR imply about the relative importance of foreign and domestic shocks for variation in the real wage rate and the real exchange rate? For the real wage rate, 85 percent of FEV is explained by own shocks at a one quarter horizon, 80 percent at a 8 quarter horizon, but only 9 percent at an 80 quarter horizon. As the horizon lengthens, foreign price shocks and exchange rate shocks grow in importance for the real wage eventually accounting for 79 percent of its FEV. Shocks to technology never account for more than more than 7 percent of the FEV of the real wage rate at any horizon. The picture that emerges is that real wages in Hong Kong respond slowly to domestic economic shocks and even more slowly to outside shocks.

A very different picture emerges for the real exchange rate. Even at the shortest horizon, foreign prices and export demand shocks account for almost 60 percent of $\widehat{Q_t}$ FEV while only 27 percent is accounted for by idiosyncratic shocks. The real exchange rate is the only variable in the system for which the importance of foreign shocks diminishes with forecast horizon. The three foreign-origin shocks account for 73 percent of FEV at a horizon of 1 quarter, 66 percent at a horizon of 8 quarters, but only 43 percent at a horizon of 80 quarters. Idiosyncratic shocks to imports increase in importance as the horizon lengthens.

Based on the FEV accounting, it is fair to draw several conclusions. First, foreign shocks are important for Hong Kong input markets and unemployment.

Second, shocks to technology are not the driving force behind the observed cycles in Hong Kong economic activity because they account for little variation in Hong Kong variables. Also, shocks to technology appear to be more important for employment of imports than for employment of labor–a fact that may be difficult for our model to explain. Third, shocks to the real exchange rate and the real wage account for very little variation in the Hong Kong "quantity variables," $\widehat{n_t}$, $\widehat{m_t}$, and $\widehat{U_t}$. This suggests, but falls short of formal evidence for, a model where prices are not an important mechanism through which shocks are transmitted to the real sector. We will look more closely at the responses of prices and quantities to shocks when we estimate our model.

3.2.2 Impulse Response Functions

We now turn our attention to the implications of our VAR for the propagation of shocks. Our results are summarized by several pairs of figures. In order to make comparisons easier, we have kept the vertical scale constant for each pair of figures.

Panel A of Figure 2 shows responses of unemployment to shocks in the exogenous block variables. Several conclusions are warranted. First a beneficial technology shock does lower the unemployment rate with an effect that does not wear out for about four years. Similarly, a positive shock to foreign prices is predicted to lower the unemployment rate and keep it low for many quarters. A shock to the US interest rate is predicted to first lower unemployment and then, after about two years, to raise it. Finally, a positive shock to export demand lowers the unemployment rate by a small amount initially. After one year, however, that shock is predicted to raise the unemployment rate for a sustained period.

Panel B shows the responses of unemployment to shocks in Hong Kong variables. Again, several conclusions are warranted. First, the response of unemployment to an idiosyncratic shock is predicted to be large and long lasting relative to the responses to other shocks. Second, as one would expect, a positive shock to labor employment causes a decline in the unemployment rate. It is also true that a positive shock to imported inputs per capita causes a decline in the unemployment rate as would be expected if firms tend to keep the input mix relatively constant throughout the business cycle. Finally, a positive shock to the real wage is predicted to slightly lower the unemployment rate at first but eventually to raise it.

Panels A and B of Figure 3 show responses for labor employment per capita. Several features of these figures stand out. First, a positive shock to export demand is predicted to have a short-lived positive effect on labor employment which jibes with the predicted effect of that shock on the unemployment rate. Similarly, a positive shock to foreign prices is predicted to raise employment and keep it high for a substantial period of time. This response too jibes with the predicted response of unemployment to a foreign price shock.

More puzzling is the effect on employment per capita of an interest rate shock. Panel A of Figure 3 implies that a positive shock to the US interest rate has a sustained positive effect on employment while Panel A of Figure 2 implies that the effect of such a shock on the unemployment rate is first negative and turns positive after two years. To reconcile these two findings, one would need a positive but delayed response of labor supply to the interest rate shock. Finally, Panel A shows that a positive technology shock does raise labor employment as the standard real business cycle model would predict.

Panel B of Figure 3 underscores the finding that the responses of employment to idiosyncratic shocks are large relative to all other employment responses. Coupled with the FEV accounting data presented in Table 2, these results suggest that, at least in the short run, employment per capita varied more due to idiosyncratic forces than due to shocks that were transmitted through standard demand and supply channels. On the other hand, the figure does show that employment responds negatively to an increase in the real wage.

Panels A and B of Figure 4 show responses of imported inputs per capita to exogenous block and domestic shocks. It is important to keep in mind that we treat all imports as inputs to a production process. Two shocks are predicted to have immediate and sizeable effects on imported inputs. A positive shock to export demand is predicted to raise $\widehat{m_t}$ immediately and keep it above its long run value for about five quarters. A positive shock to technology is predicted to first lower $\widehat{m_t}$ below its long run value and then, after four quarters, to raise it above its long run value. It will be interesting to see if our model can account for this sort of response by $\widehat{m_t}$ to a technology shock. Panel A also shows that an increase in the US interest rate causes a gradual but sustained decrease in $\widehat{m_t}$ which hits its lowest point after 12 quarters and then slowly returns to its long run value.

Panel B of Figure 4 shows that $\widehat{m_t}$ exhibits a long lasting response to an idiosyncratic shock. It also shows that $\widehat{m_t}$ responds only slightly to shocks in labor, the real exchange rate and unemployment. It is interesting that an increase in the real exchange rate is predicted to slightly lower $\widehat{m_t}$ as one would expect although it is well to keep in mind that the FEV accounting implies that little variation in $\widehat{m_t}$ is accounted for by variation in the real exchange rate.

Taken together, Figures 3 and 4 show that employment of resources in Hong Kong are affected in important ways by exogenous block shocks. They also show that labor employment and imported input use are slow to return to their long run values after departing from them. These results suggest that a good bit of stickiness must be allowed for in input markets if an economic model of these markets is to explain the data.

Panels A and B of Figure 5 show responses of the real exchange rate to exogenous block and domestic shocks. Panel A shows that the real exchange rate responds strongly to foreign shocks. An increase in foreign prices is predicted to have a sustained positive effect on the real exchange rate which, of course, is not surprising. An increase in the US interest rate is likewise predicted to have a sustained positive effect on the real exchange rate. A positive shock to technology is predicted to lower the real exchange rate but only after a delay of several quarters. A decrease in the real exchange rate implies that Hong Kong must give less Hong Kong goods to obtain a unit of foreign goods so it is also not surprising that a positive shock to export demand is predicted to lower the real exchange rate by a large amount and keep it below its long run value for a long time.

Panel B of Figure 5 shows that shocks to Hong Kong variables all have large and sustained effects on $\widehat{Q_t}$. A positive shock to imports is predicted to have a sustained negative effect on $\widehat{Q_t}$. It will be difficult for our model to explain this finding because one would expect an increase in demand for imported goods to raise the relative price of those goods rather than lower them. In the short run, an increase in the unemployment rate is predicted to have a sustained positive increase on $\widehat{Q_t}$, that is to require that Hong Kong give up more of its goods to obtain a unit of foreign goods.

Finally, Panels A and B of Figure 6 show responses of the real wage to shocks. Panel A supports the view that the real wage responds to exogenous-block shocks with a delay. For example, after a shock to foreign prices, the real wage first falls slightly but, after four quarters, rises and remains above its long run value for many periods. Similarly, a shock to export demand has little effect on the real wage rate for the first eight quarters and then is predicted to have a sizeable and sustained negative effect on it.

In sharp contrast to the results for the real exchange rate, the real wage rate appears to be little effected by shocks that originate in Hong Kong with the exception of an idiosyncratic shock to the real wage itself. Panel B of Figure 6 shows that an idiosyncratic shock has a long lasting effect but also shows that shocks to other domestic variables have very small effects.

Together, Figures 5 and 6 suggest that the markets for labor and for imports in Hong Kong are very different. The real exchange rate varies a lot in response to shocks while the real wage rate varies less and only with a greater delay. It will be interesting to see if a version of our model can account for this asymmetry of input markets.

3.3 Stylized Facts

We close this section of our paper with a summary of findings in the form of a list of stylized facts. First, shocks of foreign origin such as interest rate, foreign price and export demand shocks seem to be important sources of variation for Hong Kong employment and unemployment variables. It would be fair to say that we should expect these shocks to be able to account for a great deal of the predicted variation in $\widehat{y_t}$, $\widehat{n_t}$, $\widehat{m_t}$, and $\widehat{U_t}$.

Second, to the extent that Solow residuals accurately measure changes in labor productivity in Hong Kong, it does not appear that shocks to technology are an important source of variation in $\widehat{y_t}$, $\widehat{n_t}$, $\widehat{m_t}$, and $\widehat{U_t}$.

Third, the responses to shocks of labor, imported inputs and the unemployment rate are sustained and those of the real exchange rate and the real wage even more sustained. This finding presents a challenge to the model builder to either explain why shocks lead to sustained responses or to acknowledge that un-modeled features of the data account for some of its most important business cycle features.

Fourth, the responses of the real exchange rate and the real wage to shocks are very different suggesting that the markets for imports and labor may be very different.

Fifth, shocks to the real exchange rate and the real wage rate do not seem to be important sources of variation in employment of labor and imported inputs. It will be interesting to see whether a micro founded model such as ours can be reconciled with a data set that seems to embody the finding that surprises in relative prices are not very important sources of variation for movements in employment quantities.

Finally, it turns out that the key findings of our VAR analysis proved to be robust to variations in the variables that were included in the VAR system. For example, when we exclude from the system our estimates of technology shocks and shocks to export demand and include instead output per capita and the consumption output ratio, we obtain very similar results about the relative importance of foreign shocks for the evolution of Hong Kong variables. With this alternative specification innovations to the real exchange rate appear to be somewhat more important which is not surprising since our estimate of export demand shocks is a linear combination of $\widehat{Q_t}$ and $\widehat{c_t^y}$.

4 Estimation of the Model

In this section, we set out our procedure for estimating our model, report parameter estimates and ask how well our model can account for the stylized facts presented in the previous section. In what follows, we define η_t to be the $(9x1)$ vector the elements of which are the elements of Fs_t associated with the observable elements of $(\widehat{X_t}'\widehat{Y_t}')'$ in (equation 39).

4.1 Estimation Procedures and Parameter Estimates

To bring our model to the data requires values for four groups of parameters. The first group includes five parameters that we are not able to estimate with our data. For these, we chose values based on other sources. The first such parameter is ν,the production function parameter that governs the elasticity of substitution between labor and imported inputs. We set ν equal to -2 because that estimate provided more reasonable values for the Solow residuals. McCallum and Nelson [21] use the same value of ν. Our choice of ν implies that labor and imported inputs are not very good substitutes so that demand for each input is not very sensitive to its respective price.

We adopt values used by Salemi [28] for the tax rate, τ, and the ratio of unemployment benefits to the wage, σ. Salemi based these values on his analysis of the tax system and unemployment benefits system in Hong Kong. Estimating μ, the elasticity of foreign demand for Hong Kong exports with respect to the real exchange rate, is beyond the scope of the paper and we adopt the estimate of Abbott and De Vita [1]. Finally, since β, the household rate of time preference is not identified given our data, we use the standard value of 0.99. In sum, we assume values for five parameters as follows: $\nu = -2$, $\tau = 0.019$, $\sigma = 0.365$, $\mu = 2$, and $\beta = 0.99$.

The second group parameters are the steady state values of the model variables that appear in (26) through (36). We use "first moment" information to estimate these parameters in that we assume that each variable's steady state equals its sample mean. Table 3 reports our estimates.

Table 3:
Steady State Moments

Description	Variable	Value
Unemployment rate	$\overline{U}$	0.0371
Ratio of consumption to GDP	$\overline{c^y}$	0.5870
Ratio of employment to population	$\overline{n}$	0.5909
Real wage	$\overline{w}$	0.1255
Output per capita	$\overline{y}$	0.1978
Imported inputs per capita	$\overline{m}$	0.0769
Real exchange rate	$\overline{Q}$	1.1121

The third group of parameters consists of structural parameters that appear in the steady state equations of the model. We estimate these parameters with a calibration exercise. The equations that define the steady state of our model define a mapping from the steady state moments to the parameters of the third group. As explained in Appendix B, we use this mapping to find values for the steady state value of the wage markup, $\overline{x}$, the steady state supply of labor, $\bar{l}$, the steady state ratio of the wage bill to profits, $\overline{h}$, and the steady state value of technology shock, $\overline{A}$. We also use this mapping to identify γ, the relative bargaining power of firms, Ψ, the weight on leisure in the utility function, α, the weight on labor in the production function, and ε, the price elasticity of demand for the product of the typical intermediate firm and $\overline{\epsilon_x}$, the steady state value of the export-demand-function location parameter. Table 4 reports our estimates of the group three parameters.

Table 4:
Calibrated Parameter Values

Description	Parameter	Value
Steady state ratio of wage bill to profits	$\overline{h}$	1.9449
Steady state labor supply per capita	$\bar{l}$	0.6137
Steady state wage markup	$\overline{x}$	0.0239
Steady state value of technology shock	$\overline{A}$	0.4709
Export demand location parameter	$\overline{\epsilon_x}$	0.3339
Weight on leisure in the utility function	Ψ	0.4400
Weight on labor in the production function	α	0.9190
Relative bargaining power of firms	γ	0.9562
Intermediate Product Demand	ε	5.1880

The fourth group of parameters, denoted by ϑ, are those that govern the dynamics of the model but do not appear in the steady state equations. They include λ, the partial adjustment parameter from the wage equation, θ, the adjustment cost parameter from the labor supply equation, and a set of parameters that govern the serial correlation properties of the structural shocks. We estimate ϑ by maximum likelihood conditional on the values chosen for the parameters for groups one, two and three.

Because our model places no restrictions on the covariance matrix of reduced form innovations, we concentrate the likelihood function by replacing that covariance matrix with its maximum likelihood estimate, the typical element of which is the sample covariance between shock i and j. We then search for the values of the group four parameters that maximize

$$L(\vartheta) = -(Tn/2)\log(2\pi) - (Tn/2) - (T/2)\log(|\,\widehat{\Sigma}_\eta\,|) \tag{40}$$

where $\widehat{\Sigma}_\eta = (1/T)\sum_{t=1}^{T} \eta_t(\vartheta)\eta_t'(\vartheta)$, T is the number of observations, n is the number of series, and η_t is the $n \times 1$ vector of reduced form residuals implied by ϑ and the data. Appendix D provides additional detail about the derivation of our loglikelihood function[11].

Table 5:
Estimated Parameter Values

Description	Variable	Value	s.e.
Labor Supply Adjustment Cost Parameter	θ	729.98	0.0982
Partial Adjustment Parameter from Wage Equation	λ	0.9477	0.0005
Technology Shock			
First Lag	ρ_{a1}	0.8974	0.0032
Second Lag	ρ_{a2}	-0.0809	0.0030
Third Lag	ρ_{a3}	0.1100	0.0029
Fourth Lag	ρ_{a4}	0.0116	0.0026
Foreign Price Shock			
First Lag	ρ_{fp1}	1.2699	0.0105
Second Lag	ρ_{fp2}	-0.0749	0.0170
Third Lag	ρ_{fp3}	-0.1993	0.0099
Foreign Interest Rate Shock			
First Lag	ρ_{fr1}	1.3026	0.0062
Second Lag	ρ_{fr2}	-0.4385	0.0059
Risk Premium Shock			
First Lag	$\rho_{\kappa 1}$	0.0172	0.0028
Second Lag	$\rho_{\kappa 2}$	0.9763	0.0029
First Lag of *Labor Demand Shock*	ρ_n	0.8863	0.0013
First Lag of *Imported Inputs Demand Shock*	ρ_m	0.8824	0.0015
First Lag of *Export Demand Shock*	ρ_x	0.8970	0.0019

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[11] We use "fmincon" function in MATLAB to search for the parameter values that maximize the loglikelihood function.

Table 5 reports our maximum likelihood parameter estimates and our estimates of the standard errors for these parameters based on the Hessian formula.[12] All parameters are precisely estimated.[13]

Our estimate of the labor adjustment cost parameter θ is equal to 730. Holding other parameter values constant, $\theta = 0$ would imply that a one percent increase in the wage rate raises labor supply contemporaneously by seven-tenths of one percent. Our estimate, $\theta = 730$, implies that a one percent increase in the wage rate has a contemporaneous effect on labor supply that is near zero. Of course, our estimates imply that the wage rate increase raises labor supply as time passes. This result is not surprising since Hong Kong labor force participation rate is fairly stable over the sample period.

Our estimate of the wage adjustment parameter λ is 0.95, which implies that only 19% of the cumulative responses of wages to a one time shock in W_t^* occur within four quarters indicating that the Hong Kong wage rate is very sticky. This finding agrees with Genberg and Pauwels (2005) who argue that wage adjustment in Hong Kong is sluggish.

Our estimates of the parameters that govern the persistence of the model's structural shocks indicate that these shocks are highly persistent. For example, our estimates of ρ_{a1} through ρ_{a4} imply that the largest eigenvalue of $\rho_a(L)$ is 0.95 so that technology shocks wear out slowly. These estimates imply that persistence in the impulse responses that we will later report are substantially due to persistence in structural shock processes rather than to persistence accounted for by the structural equations per se.

4.2 Model Dynamics

In this section, we interpret our model estimates using the same tools we used in Section 3–decomposition of forecast-error-variance (FEV) and impulse response functions (IRF). We focus attention on those results that allow us to explain how well our model accounts for the stylized facts that characterize the data.

4.2.1 Forecast Error Variance Decomposition

We first explain what our model has to say about the relative importance of various shocks in accounting for variation in the variables of our model.[14] Table 6 reports the decomposition of FEV implied by our model estimates for six variables: $\widehat{y_t}$, $\widehat{U_t}$, $\widehat{n_t}$, $\widehat{m_t}$, $\widehat{Q_t}$, and $\widehat{w_t}$ at horizons of 1, 8 and 80 quarters.

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[12] Let $\widehat{\Upsilon}$ denote the estimate of the Hessian matrix we obtain from MATLAB. The standard errors are equal to the square roots of the diagonal elements of $T^{-1}\widehat{\Upsilon}^{-1}$, where T is the length of the data sample.

[13] To check on the sensitivity of our estimates to the value of ν, we reset ν to 0.5 and re-estimate the model. While our estimates do change, loglikelihood deteriorates substantially. We thus decided to maintain the assumption that $\nu = -2$.

[14] We use a Cholesky decomposition of the structural innovation covariance matrix to compute our FEV accounting. The innovation order we adopt is: $[s_{R^*,t}, s_{p^*,t}, s_{x,t}, s_{\kappa,t}, s_{w,t}, s_{m,t}, s_{n,t}, s_{A,t}, s_{l,t}]'$ where each of the $s_{j,t}$ is the innovation to a structural error. We assume that, within sample, innovations to foreign shocks are causally prior to innovations to shocks in domestic variables.

Display Table 6 About Here

Our estimates imply that risk premium shocks account for most of the FEV in output per capita–50 percent at a horizon of 1 quarter, 53 percent at 8 quarters, and 37 percent at 80 quarters. Technology shocks are also an important source of variation in $\widehat{y_t}$ accounting for 21 percent of FEV at one quarter and 10 percent at 80 quarters.[15] Shocks to the US interest rate and to export demand also account for some variation in output per capita. On the other hand, foreign price shocks, labor supply shocks, and employment shocks account for little variation in $\widehat{y_t}$. It is interesting that shocks to demand for imported inputs are unimportant in the short run but account for 27 percent of the FEV in $\widehat{y_t}$ in the long run.

Our estimates imply that variation in the unemployment rate is mostly due to labor demand, technology and wage shocks in the short run but to foreign interest rate and imported-input-demand shocks in the long run. Interestingly, our estimates imply that risk premium shocks are much less important for unemployment than for output per capita.

These results conflict somewhat with the FEV accounting for our BVAR (Table 2) which shows idiosyncratic shocks to the unemployment rate to be important in the short run and shocks to foreign interest rates, foreign prices, export demand, technology, and imported input demand to grow in importance with the horizon. Of course, our structural model does not have an idiosyncratic shock to the unemployment rate. Instead, it apportions contemporaneous variation in unemployment across the available structural shocks. Thus, the finding that labor demand shocks are important in the short run is not surprising. What is more surprising is the much larger role played by interest rate shocks in our model than in the BVAR. On the other hand, our estimated model and our BVAR both imply that foreign price and export demand shocks explain a small fraction of unemployment FEV.

According to our estimates, variation in the use of imported inputs is accounted for mostly by shocks to foreign interest rates, export demand, and demand for imported inputs in the short run. As the horizon lengthens, risk premium shocks become more important and foreign interest rate shocks become less important. Foreign price shocks, wage shocks, labor demand shocks and labor supply shocks are unimportant at all horizon. These results are mostly consistent with our BVAR findings. However, our model attributes a smaller fraction of the FEV of imported inputs to technology shocks than does our VAR. Our model also attributes a larger share of short run variation in imported input use to foreign interest rate shocks than does our BVAR.

For labor employment per capita, our model attributes 65 percent of FEV to idiosyncratic labor demand shocks. Our BVAR also attributes most short run variation in $\widehat{n_t}$ to idiosyncratic shocks. For longer horizons, our model attributes forecast error variation in employment to shocks in the foreign interest rate, the risk premium, and, to a lesser extent, to labor demand and supply shocks. Our

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[15] Note that productivity shock and technology shock are interchangeable in this paper.

model accounts for very little variation in labor employment with technology shocks–a finding that squarely agrees with our BVAR analysis. Both analyses attribute little variation in labor employment to shocks in foreign prices, demand for exports, or wages.

A different picture appears for the real wage. According to our model, more than half of the FEV of the real wage is accounted by wage shocks at the shortest horizon and by risk premium shocks at the longest horizon. Both our model and our BVAR show the importance of idiosyncratic shocks to the wage rate diminishing dramatically with the horizon. At longer horizons, our VAR implies that shocks to foreign prices and export demand account for the lion's share of real wage FEV. Our model, on the other hand, implies that shocks to foreign prices and export demand are not very important and that FEV of the real wage is accounted for at long horizons by variation in the foreign interest rate and the risk premium. Both analyses agree that technology shocks are not very important in accounting for variation in real wages which suggests that the wage process in Hong Kong is not closely connected to market forces of demand for and supply of labor.

According to our estimates, variation in the real exchange rate in the short run is accounted for by shocks to foreign interest rates, demand for Hong Kong exports, and the risk premium. Our model implies that as horizons lengthen, foreign interest rates and export demand shocks become less important and risk premium shocks become more important. These findings also agree closely with their BVAR counterparts although the BVAR accounts for more of the variation in the real exchange rate with foreign price shocks than does our model. Also, our model implies that foreign interest rate shocks become less important as the horizon lengthens while our BVAR analysis says the opposite.

In sum, our estimated model provides a forecast error variance accounting that agrees with that from our BVAR analysis in many but not all respects. In particular, both analyses attribute some but not much variation in Hong Kong economic variables to technology shocks. Both tend to explain a larger share of FEV to idiosyncratic shocks at short than at long horizons. Both imply that labor demand shocks are much more important for explaining variation in labor employment and unemployment than for explaining variation in other variables including wages. Both find that shocks to foreign demand for Hong Kong exports are an important source of variation in Hong Kong variables.

In Section 3, we observed that $\widehat{n_t}$, $\widehat{w_t}$, $\widehat{m_t}$, and $\widehat{Q_t}$ appeared to be generated by movements along input demand schedules rather than shifts in those schedule. It turns out that our model successfully captures these features of the data. Table 1 reports pairwise correlation among the predicted values of our model variables. The correlation between predicted labor employment and the predicted real wage rate is -0.20. The correlation between actual labor employment and the actual real wage is -0.15. The correlation between predicted employment of imported inputs and the real exchange rate is -0.76 while the correlation between the actual series is -0.77.

In Section 3, we also remarked that our estimated VAR implied that the real exchange rate was more endogenous than the real wage in the sense that a larger fraction of the short-horizon forecast error variance of $\widehat{Q_t}$ was accounted for by other shocks while a larger fraction of the short-horizon FEV of $\widehat{w_t}$ was accounted for by idiosyncratic shocks (Table 2). Our model is also able to account for this feature of the data. Table 6 shows that our model predicts that shocks to the US interest rate, export demand and the risk premium account for most of the short horizon FEV of the real exchange rate while most of the short-horizon FEV of the real wage is accounted for by shock to the wage rate itself.

On the other hand, our two analyses conflict in several ways. Our estimated model tends to attribute a larger share of FEV in Hong Kong variables to variation in foreign interest rates than does our VAR analysis. Our estimated model also attributes less variation in Hong Kong variables to foreign price shocks than does our VAR analysis. It is important to realize that our two analyses differ in some important respects. For example, we include no counterpart for the risk premium shocks in our BVAR analysis. Nevertheless, it is fair to say that our model appears capable of explaining many of the stylized facts about sources of variation.

4.2.2 Impulse Response Functions

We next explain what our model has to say about shock propagation. In this case, we compare the impulse responses implied by our estimated model with their BVAR counterparts.

Figure 7 shows the responses of the unemployment rates to several key shocks. A positive shock to labor productivity first lowers the unemployment rate and, after about 4 quarters, raises it. A positive shock to foreign prices also causes unemployment to fall, but the magnitude of the fall is smaller than that caused by the productivity shock. Both responses have similar shapes to their BVAR counterparts although the BVAR responses are more drawn out. Moreover, both analyses agree that a positive shock to foreign demand for Hong Kong exports lowers the unemployment rate in the short run. But the BVAR analysis implies that the stimulative effect of an export demand shock wears out after one year and is replaced by a rise in unemployment. A positive shock to the US interest rate is predicted to lower unemployment for about 20 quarters and then return it to trend. In contrast, our VAR implies that the stimulative effect wears out after 8 quarters.

Display Table 7 About Here

It might seems surprising that a positive US interest rate shock has stimulative effect. The reason for this unconventional result is due to our important departure from the standard practice. Much of the literature on real business cycles simply assumes that the structural shocks are orthogonal to each others. As mentioned, we do not impose any restrictions on the variance-covariance matrix of the structural innovations. In fact, we estimated the covariances between the structural shocks. We account for shock correlation in our analyses by assuming a within-period causal ordering for the shocks. In particular, we assume that contemporaneous correlation between two shocks is due to the response of the lower-ordered shock to the higher-ordered shock. The within-period causal ordering that we assume for structural shocks is: the US interest rate, foreign price, export demand, risk premium, domestic wage rate, demand for imported inputs, demand for labor, technology, and labor supply. The responses of unemployment to US interest rate shocks include the indirect effects of interest rate shocks on other shocks that are indicated by the correlations reported in Table 7. For example, a positive shock to the US interest rate raises the domestic interest rate and lowers consumption, which results in a higher unemployment rate. At the same time, the interest rate shock also affects other shocks. It serves as a foreign price shock and raises the foreign prices, which increases Hong Kong's exports and lowers unemployment. According to our impulse response function estimates, the net effect of a positive US interest rate shock is to lower the unemployment rate.[16]

Figure 8 displays the predicted responses of employment per capita to key shocks. Both a positive shock to foreign prices and a positive shock to export demand are predicted to have long-lasting positive effects on employment. Both of these findings jibe with their BVAR counterparts. Our model implies that a positive technology shock raises employment for 2 quarters then lowers it below trend. In contrast, our VAR predicts that a positive technology shock has little effect for two quarters and then has a sustained positive effect on employment. Finally, both our model and our VAR predict that a positive shock to the US interest rate raises employment for a substantial period of time. The model predicts that employment returns to trend after four years. The VAR predicts a more long lasting response.

Figure 9 shows the responses of imported input employment per capita. Both our model and our BVAR analysis predict that a positive shock to export demand causes a sustained increase in the use of imported inputs. Our model predicts that a positive technology shock causes $\widehat{m_t}$ to rise and then return slowly to trend. Our BVAR analysis predicts that the short run effect of a technology shock is negative but, after one year, positive. Our model predicts that a shock to foreign prices raises $\widehat{m_t}$ while our BVAR analysis shows little response. Finally, a positive shock to the US interest rate lowers imported inputs for about 10 quarters. The BVAR analysis agrees but predicts that the negative effect is delayed for three quarters.

Figure 10 displays responses of the real exchange rate. A positive shock to foreign prices is predicted by both our model and our BVAR analysis to have a long-lasting positive effect on the real exchange rate. A positive shock to export demand is predicted by both our model and our BVAR analysis to lower the real exchange rate for a long period of time. A positive shock to the US interest rate is predicted by both our model and BVAR analysis to raise the real exchange rate for a period of about two years. However, our model predicts that after two years the real exchange rate falls below trend while our BVAR analysis predicts

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[16] We find that a positive US interest rate shock without the "correlation effect" does raise the unemployment rate.

that the positive effect lasts much longer. Our model predicts that a positive technology shock raises the real exchange rate slightly above its long run value and keeps it there. In contrast, our BVAR analysis predicts that a positive technology shock has little effect on the real exchange rate in the short run and a negative effect in the long run.

Figure 11 shows responses of the real wage. In contrast with our BVAR analysis, our model predicts that the real wage responds quickly to shocks. Our model predicts that a positive technology shock has a sustained positive effect on the real wage–a result that is not surprising but also not consistent with our BVAR analysis. Our model predicts that a positive shock to the foreign interest rate lowers the real wage for about four quarters and then raises it. Our BVAR analysis says that a foreign interest rate shock has almost no effect on the real wage in Hong Kong. Surprisingly, both our model and our VAR predict that a positive shock to export demand has, if anything, a small negative effect on the real wage. Finally, our model implies that an increase in foreign prices has a sustained negative effect on the real wage. In contrast, our BVAR analysis implies that after a three quarter delay, a positive shock to foreign prices has a sustained positive effect on the real wage.

Figure 12 displays responses of output. Not surprisingly, positive technology shocks and export demand shocks have long lasting positive effects on output per capita. A positive foreign price shock initially raises $\widehat{y}_t$ but that effect wears out after six quarters. A positive shock to US interest rate lowers output for about 4 periods then raises it.

Finally, Panels A and B of Figure 13 show responses of model variables to a risk premium shock. We collect these results because risk premium shocks play such an important role in our estimated model and we want to understand them better. Panel A shows that an increase in the risk premium lowers employment by more than it lowers labor suppy so that the unemployment rate increases. Panel B shows that an increase in the risk premium generally de-stimulates the economy. It lowers use of imported inputs and output per capita. It lowers the real wage rate. It raises the real exchange rate so that Hong Kong must surrender more domestic goods to obtain a unit of foreign goods. Over all, a positive risk premium shock behaves like a negative shock to aggregate demand in a typical New Keynesian model. Of course, this makes sense. An increase in the risk premium, other factors unchanged, will lead the household to save more and consume less thereby decreasing aggregate demand. Panels A and B of Figure 13 also show that the effects of a risk premium shock are slow to wear off.

Overall, our model does a good job capturing the dynamics of the key variables. The responses of the key variables, especially employment, imports and the real exchange rate, to foreign price shock and export demand shock predicted by our theoretical model are consistent with those from the VAR. On the other hand, our model does less well in accounting for the apparent responses of variables to technology shocks and shocks in the US interest rate shock. Our model predicts larger responses to foreign interest rate shocks than those observed in the data. Introducing habit persistence in consumption might improve our model's ability to match the observed response of Hong Kong variables to interest rate shocks.

4.2.3 Model fit

In this section, we ask how well our model fits the data. First, we compare predicted and actual values of our variables. Second, we compare the second moment matrices for the predicted values and the data. These comparisons indicate that our model does a good job of tracking the data and accounting for the "second-moment" information imbedded in the data.

Figure 14 displays actual and predicted values for each of the nine series we employ. The model fits the data well–the predicted values track the actual values even when the actual series experience turning points. The model fits the unemployment rate less well than it fits the other series in that it overpredicts the unemployment rate between 1985 and 1995.

Table 1 reports pairwise correlations for the predicted values of our variables below the diagonal and the same correlations computed from the raw data above the diagonal. Comparison of the two parts of the table indicates that our model does a good job accounting for the second-moment information in the data. For example, correlations between the predicted values of output per capita and unemployment, employment and unemployment and the real exchange rate and imported inputs per capita are -0.61, -0.81, and -0.76. The data counterparts are -0.71, -0.82, and -0.77. On the other hand, our model predicts that the correlations between foreign interest rates and unemployment and foreign interest rates and output are -0.73 and -0.01 which are quite far from the data counterparts of -0.48 and -0.15. The standard deviations of most predicted variables in our model are close to those computed from the data.

5 Feast and Famine in Hong Kong

To close the paper, we return to the questions that interest us most: What caused the dramatic change in Hong Kong economic performance between 1981 and 2007? In particular, what caused Hong Kong to move from a period of weak economic performance between 1981 and 1986, to an economic feast between 1987 and 1997, and then to the famine that only recently subsided?

Our answers are based on a decomposition of the predicted values of output per capita and the unemployment rate implied by our model. Taking our model to the data provides us with estimates for the innovation process values for each our structural shocks. We obtain our decomposition by passing our estimates of the shock processes through our model one at a time. We depart from standard practice in one important way. As mentioned, we assume that contemporaneous correlation between two shocks is due to the response of the lower-ordered shock to the higher-ordered shock.[17] The responses of output per

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[17] It bears repeating that the within-period causal ordering for structural shocks is: the US interest rate, foreign price, export demand, risk premium, domestic wage rate, demand for

capita and unemployment to each structural shock includes the indirect effects of the structural shock on other shocks.

Figure 15 displays estimates of the time series for each structural shock. Panels A and B of Figures 16 and 17 display our decompositions for output per capita and the unemployment rate. Panels A and B of Figure 18 display the sum of the historical contributions of the foreign shocks, which include the US interest rate shock, the foreign price shock, the export demand shock and the risk premium shock, to the variations of output per capita and the unemployment rate.[18]

We first explain the period of weak economic performance that began at the end of 1981 and continued through the end of 1986. According to Figure 16, three economic factors account for the weak performance of this first sub-period: disadvantageous shocks to export demand, the risk premium attached to foreign interest rates, and, to a lesser extent, disadvantageous technology shocks. It bears repeating that, in our model, increases in the risk premium function like negative shocks to aggregate demand in that they raise the attractiveness of saving and lower desired household consumption. The disadvantageous technology shocks occur during the second half of the sub-period and are the only internal shocks that appear to explain the weak performance of the early period.

The second period was a time of economic feast in Hong Kong. But why did the feast begin and why was it sustained? Our estimates suggest several reasons–some external and some internal. First, a series of beneficial export demand shocks began in 1987 and continued throughout the period. Second, the risk premium shock series began to have a stimulative effect on Hong Kong output early in 1988. Our estimates imply that the risk-premium stimulus was small at first and became larger and more sustained after 1990. Third, shocks to the US interest rate had a stimulative effect. In fact, we estimate that US interest rate shocks began stimulating the Hong Kong economy in 1984 but the resulting stimulus was offset by the effects of contractionary shocks until early 1987. Fourth, Hong Kong benefited from three sources of domestic stimulus–beneficial technology shocks, positive shocks to demand for labor, and positive shocks to demand for imported inputs. All three of these contributed to the strong economic performance during the period.

While output per capita began falling back toward trend as early as 1994, it fell below trend at the beginning of 1997 and remained there until 2006. Famine followed the feast. But why? Genberg and Pauwels [10] argue that foreign shocks were the main drivers of the Hong Kong unemployment rate during this period. Peng et al. [23] argue that the sustained rise in Hong Kong unemployment rate after 1997 might have been caused by adverse demand shocks caused by the Asian financial crisis.

Our historical decompositions allow us to weigh in on the causes of the transition from feast to famine in Hong Kong. Figure 16 indicates that both external and internal forces were at work. After 1997, the effect of risk premium

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imported inputs, demand for labor, technology, and labor supply.

[18] We follow Adolfson et al. (2007) and consider the risk premium shock as a foreign shock.

shocks ceased being a source of stimulus and became a drag on Hong Kong output per capita. After 2000, a series of negative shocks to export demand placed additional downward pressure on output per capita. While the negative effects of the risk premium (aggregate demand) shocks began to abate after 2002, US interest rate shocks began to have negative effects that slowed the return of Hong Kong output per capita to its long run path. On the domestic side, one factor stands out. Beginning in 1996, import demand shocks had a sustained negative effect on output per capita which had not fully abated by the end of 2007.

Figure 17 reports our decompositions of the unemployment rate. It tells a similar story, but provides several new pieces of information. First, Figure 17 indicates that shocks to the nominal wage helped keep unemployment low between 1986 and 1995 and helped keep unemployment high between 1995 and 2003 and then helped return unemployment toward its long run value after 2003. Second, our estimates indicate that technology shocks play a very small role in accounting for movements in unemployment. Third, our estimates indicate that the spike in unemployment that occurred in Hong Kong after 2001 was due to US interest rate shocks.

Given the currency board arrangement in Hong Kong and the highly open nature of the economy, external factors should have significant influences on the development of the domestic variables in Hong Kong. To what degree had the foreign factors affected the Hong Kong economy from 1981 to 2007? Figure 18 displays the sum of the effects of all foreign shocks (i.e. the US interest rate shock, the foreign price shock, the export demand shock and the risk premium shock) on Hong Kong ouput per capita and unemployment. Together, foreign shocks account for most of the variations in Hong Kong output per capita throughout our sample period. However, it is a slightly different story for the unemployment rate. The fluctuations of the unemployment rate between 1982 and 1986 and, later, between 1991 and 1995 are largely explained by the domestic shocks. In sum, these findings jibe with those from our VAR analysis and further confirm the importance of foreign shocks on the evolution of the Hong Kong economy.

In mid-1997, Hong Kong underwent a financial crisis common to a number of East Asia economies, such as Thailand and Singapore. What does our model say about the impact of the Asia financial crisis on Hong Kong? The literature attributes financial market crises to both internal and external factors. Internal crisis theories stress the role of domestic market failures. Burnside et al. [5] shows that government loan guarantees can cause a currency mismatch between domestic banks' assets and liabilities. External crisis theories argue that the crisis is caused by imperfections in international capital markets that affect the borrowing ability of an emerging country. Arellano and Mendoza [3] argue that financial frictions are important in explaining the "Sudden Stop" phenomenon. Neumayer and Perri [22] argue specifically that shocks to the Argentine risk premium were an important driver of business cycle there.

It is beyond the scope of our paper to explain the causes of the Asian financial crisis. Instead, we follow Cook and Devereux [6] who argue that a financial crisis can be represented by an exogenous rise in a country's risk premium. Our decompositions indicate that our risk premium shock causes output per capita to fall significantly in Hong Kong after 1997. In fact, our decomposition indicates that more than half of the fall in Hong Kong output per capita after 1997 can be explained by shocks to the risk premium.

In closing, we point out once more that our model does a good job of capturing most of the imortant features of the data. From our model we learn that the transition from feast to famine in Hong Kong was due to several disadvantageous shocks. Increases in the risk premium (adverse demand shocks) led the way and were reinforced by increases in US interest rates and decreases in demand for Hong Kong exports. Nominal wage shocks also contributed to higher unemployment after 1997 and were slow to wear off. Finally, we note again that technology shocks, the chief cycle propogator in standard RBC models, appear to have played only a minor role in accounting for the big swings that Hong Kong experienced.

We realize that our model could do a better job of explaining the Hong Kong experience. We would prefer it if more model dynamics were accounted for by mechanisms in the model and less by serial correlation in exogenous shocks. In future work, we intend to investigate the implications of allowing for habit persistence in the household utility function. We also intend to include capital and investment in a future version of the model to determine whether doing so alters the importance of interest rate shocks.

A. Data

This appendix provides a description of the statistics and data series that we use in our empirical analysis of Hong Kong economy. The data, except where noted, are from the data archive of the Hong Kong Monetary Authority and were provided by the Hong Kong Institute of Monetary Research to the author. Some, but not all, of the data are available at www.info.gov.hk/hkma/eng/statistics.

The first step in the statistical analysis is to set out a definition of GDP that is compatible with the model. We define nominal GDP to be the sum of nominal consumption and nominal exports and real GDP as the sum of real consumption and real exports. The unit for the real series is millions of Year 2005 Hong Kong dollars. Because a substantial fraction of Hong Kong exports are re-exports, goods that enter Hong Kong's harbor only to be transferred from one ship to another and immediately sent on their way, we define exports to be the sum of exports of goods and exports of services minus re-exports and imports to be imports of goods and services minus re-exports. we likewise define real exports and real imports to be net of real re-exports. Nominal and real values for consumption, exports, imports and re-exports are compiled by the Census and Statistics Department of the Hong Kong Special Administrative Region (HKSAR).

Several of the statistics used in the calibration are per capita measures. To compute per capita measures, we divide the magnitude in question by the Hong Kong population of adults, individuals whose age is greater than 15. The population data are also compiled by the Census and Statistics Department of HKSAR.

Employment per capita, n, is computed as the ratio of employment to population. Employment is taken from the data set entitled "employed persons by hours of work during the seven days before enumeration and sex." The unemployment rate, U, is reported by the Census and Statistics Department of HKSAR. A person 15 years or older is considered unemployed if he: has not had a job and has not performed any work for pay in the prior seven days and has been available for work in the prior 7 days, and has sought work during the prior 30 days. Discouraged workers, people without a job and who have not been available for work due to temporary illness, people without a job and who have not been available for work due to anticipated employment are also considered unemployed. Per capita labor supply is computed as $l = \frac{n}{1-U}$.

Output per capita, y, is the sum of real consumption and real exports divided by the population of adults. Imports per capita, m, is real imports divided by the population of adults. The ratio of consumption to GDP, c, is the ratio of nominal consumption to the sum of nominal consumption and exports.

The real exchange rate is the ratio of the price of imports to the price of domestically produced goods. To compute this ratio requires three price indices, the price of consumption goods, the price of exports, and the price of imports. we compute each of these ratios by dividing nominal values by real values. We then compute the price of domestically produced goods by averaging the price of consumption goods and the price of exported goods using as weights the relative shares of consumption and exports in the total. Finally, we compute Q as the ratio of the price of imports to the price of domestically produced goods.

To compute the "wage bill" for Hong Kong, we use the series "Monthly Average Payroll for All Industry Groups". The series covers employees up to and including supervisory personnel and includes both salaries and bonuses that are typically paid in the first quarter of each year. To produce a series for annual average employee compensation, we add the monthly figures for each quarter and multiply the total by 4.0. To compute the "wage bill," we multiply average annual employee compensation and employment. The fraction of GDP accounted for by wages, g, is the ratio of the resulting wage bill to the sum of nominal consumption and nominal exports. The real wage rate is then computed as $w = \frac{gy}{n}$ and the ratio of the wage bill to profits, h, is computed as $h = \frac{w}{\frac{y}{n} - w - \frac{Qm}{n}}$.

Using the above definitions, data for U, n, l, m, y, c, w, q, g, and h were computed for each quarter from 1981:IV to 2007:III. The means, standard deviations, and ranges for each statistic over the period are reported in the following table.

Sample Moments of Hong Kong Data

1981:IV–2007:III

Series	Mean	Std. Deviation	Minimum	Maximum
Output per capita	0.198	0.039	0.115	0.278
Employment per capita	0.591	0.018	0.556	0.629
Real Imports per capita	0.077	0.016	0.043	0.109
Real Exchange Rate	1.112	0.153	0.907	1.402
Unemployment Rate	0.037	0.020	0.010	0.085
Consumption-Output Ratio	0.587	0.031	0.526	0.644
Nominal Wage Rate	0.120	0.062	0.026	0.210
Price Level	0.896	0.196	0.486	1.153
Real Wage	0.125	0.048	0.053	0.204

To calibrate the model also requires estimates of the fraction of compensation received by the typical worker when unemployed, σ, and the fraction of compensation paid in the form of salary tax, τ. Our estimate of σ is based on Lam (2001). In a reply to a question raised by members of Hong Kong's Finance Committee, Mrs. Carrie Lam reported that the average monthly assistance payable per unemployment case in Hong Kong in 1999 was 5470 HKD. Multiplying that figure by 12 and dividing by average payroll compensation for 1999 produces an estimate of σ that equals .365. As a check of the accuracy of this figure, we consulted the 2007 Revised Standard Payment Rates table which provides social assistance allowances as a function of family size and characteristics for able-bodied recipients. Assuming a household size of two adults and 1.1 children, which is the composition of the average family, the table implies a family compensation of 5002 HKD. This figure is .320 of the average payroll compensation for 2005, the most recent year for which those data are available. We conclude that 0.365 is a reasonable estimate of σ.

It is widely known that the maximum salary tax in Hong Kong is 0.16. However, τ is likely to be substantially smaller than 0.16 since the average family enjoys tax exemptions that equal a large portion of family income. To estimate τ, we consulted the table that provides government revenue from various sources produced by the Financial Services and the Treasury Bureau of HKSAR. For 2005, the salaries tax accounted for $11,938(10^6)$ HKD. The product of the average payroll and the average number of employed in Hong Kong for 2005 is $626,378(10^6)$ HKD. The ratio of the two numbers is .019, our estimate of τ.

Finally, to calibrate the model requires values for ϕ, the scale parameter of the rest-of-the-world demand for Hong Kong exports function and for $\overline{tb}$, the steady state trade balance expressed as a fraction of Hong Kong GDP. My estimate of ϕ implies that demand for exports equals supply of exports in the steady state: $\phi = \frac{1-\overline{c^y}}{\overline{Q}^2}$. My estimate of $\overline{tb}$ is taken directly from the data: $\overline{tb} = 1 - \overline{c^y} - \frac{\overline{Q}\overline{m}}{\overline{y}}$. Computing $\overline{tb}$ in this way amounts to the assumption that the average trade balance observed in the sample was a steady state equilibrium.

B The Steady State

This appendix describes the steady state of the model. We start by describing the optimal saving behavior in the steady state. From equation 4 , we know

$$\frac{1+\overline{R}}{1+\overline{\pi}} \approx 1 + \overline{R} - \overline{\pi} = \frac{1}{\beta} \tag{B1}$$

Thus, the steady state real rate of interest is determined solely by the discount factor of the representative households. The exchange rate peg and uncovered interest rate parity implies that the risk premium is the difference between domestic and foreign interest rates

$$\overline{\kappa} \approx 1 + \overline{R} - \overline{R}^* \tag{B2}$$

We next describe the steady state conditions of production and employment. Combining the definition of the reservation wage and wage markup, we obtain a steady state relationship between unemployment rate and wage markup,

$$\overline{U} = \frac{1-\tau}{1-\tau-\sigma} \frac{\overline{x}}{1+\overline{x}} \tag{B3}$$

The steady state labor supply equation, combined with the definition of reservation wage implies

$$\bar{l} = \frac{1}{1-\overline{U}} - \Psi \frac{\overline{c^y}\overline{y}}{\overline{w}(\sigma + (1-\overline{U})(1-\tau-\sigma))} \tag{B4}$$

The steady state conditions that describe the production function and the optimal employment of labor and imported inputs are

$$\overline{y} = [\alpha \left(\overline{An}\right)^{\nu} + (1-\alpha)\overline{m}^{\nu}]^{1/\nu} \tag{B5}$$

$$\frac{\overline{y}}{\overline{n}} = (\eta\nu\alpha)^{\frac{-1}{1-\nu}} \overline{A}^{\frac{-\nu}{1-\nu}} \overline{w}^{\frac{1}{1-\nu}} \tag{B6}$$

$$\frac{\overline{y}}{\overline{m}} = (\eta\nu(1-\alpha))^{\frac{-1}{1-\nu}}\overline{Q}^{\frac{1}{1-\nu}} \tag{B7}$$

The steady state wage markup is related to steady state wage-profit ratio according to

$$\overline{x} = \left[\frac{\gamma}{1-\gamma}\overline{h} + \frac{1}{1-\nu} - 1\right]^{-1} \tag{B8}$$

Steady state real profits equals $\overline{y} - \overline{wn} - \overline{Q}\overline{m}$. Thus, the steady state wage-profit ratio is

$$\overline{h} = \frac{\overline{w}}{\frac{\overline{y}}{\overline{n}} - \overline{w} - \overline{Q}\frac{\overline{m}}{\overline{n}}} \tag{B9}$$

The steady state value of $\overline{U}, \overline{l}$ and $\overline{n}$ must satisfy

$$\overline{U} = 1 - \frac{\overline{n}}{\overline{l}} \tag{B10}$$

We know the steady state of export-output ratio, $\frac{\overline{EX}}{\overline{Y}} = \phi\frac{\overline{Y^*}}{\overline{Y}}(\overline{Q})^{\mu}$.This implies the steady state values of $\overline{c^y}$ and $\overline{y}$ must satisfy

$$1 - \overline{c^y} = \phi\frac{\overline{Y^*}}{\overline{Y}}(\overline{Q})^{\mu} = \overline{\epsilon_x}\overline{Q}^{\mu} \tag{B11}$$

We now describe how to compute the values for the third group of parameters which includes: $\overline{x}$, $\overline{l}$, $\overline{h}$, $\overline{\epsilon_x}$, γ, Ψ, α, $\overline{A}$ and ϵ.. Given the values of $\nu, \mu, \tau, \sigma, \overline{U}, \overline{c^y}, \overline{n}, \overline{w}$, $\overline{y}$, $\overline{m}$ and $\overline{Q}$, the steady state value of wage markup, $\overline{x}$ can be computed from (B3). The values of $\overline{l}, \overline{h}$ and $\overline{\epsilon_x}$ can be found by using equations (B4), (B9) and (B11). Then, the values of γ and Ψ can be found by using (B8) and (B4). Finally, we use a numberical procedure to find the values of α, $\overline{A}$ and ϵ using the other steady state equations.

C Log-linear Model

In this section, we describe the full set of log-linear equations we use for the model. Each variable in the system represents a deviation of a variable from its steady state value. Deviations are defined in two ways. Variables $\widehat{y_t}, \widehat{n_t}, \widehat{m_t}, \widehat{W_t}, \widehat{P_t}, \widehat{Q_t}, \widehat{l_t}, \widehat{W_t^R}, \widehat{c_t^y}, \widehat{U_t}$ and $\widehat{W_t^*}$ represent the log deviation of the original variables from its steady state values, that is, $\widehat{z_t} = \ln z_t - \ln \overline{z}$. Variables, $\widehat{x_t}$ and $\widehat{U_t}$ represents the deviations, rather than percentage deviations, from their respective steady state, that is, $\widehat{x_t} = x_t - \overline{x}$ .The log-linear version of the model is given in 20 equations.

The firm's production function and first-order conditions are given by

$$Y_t = [\alpha(A_tN_t)^{\nu} + (1-\alpha)M_t^{\nu}]^{1/\nu}$$

$$N_t = (\eta\nu\alpha)^{1/(1-\nu)}A_t^{\nu/(1-\nu)}Y_t\left(\frac{W_t}{P_t}\right)^{-1/(1-\nu)}$$

and

$$M_t = (\eta\nu(1-\alpha))^{1/(1-\nu)} Y_t \left(\frac{P_{M,t}}{P_t}\right)^{-1/(1-\nu)}$$

In log-linear form, we have

$$\widehat{y}_t = \Gamma_{1,n}\widehat{n}_t + \Gamma_{1,m}\widehat{m}_t + \Gamma_{1,n}\widehat{A}_t \tag{C1}$$

$$\widehat{y}_t - \widehat{n}_t = \Gamma_{2,w}(\widehat{W}_t - \widehat{P}_t) - \Gamma_{2,A}\widehat{A}_t + \widehat{\epsilon}_{n,t} \tag{C2}$$

and

$$\widehat{y}_t - \widehat{m}_t = \Gamma_{3,Q}\widehat{Q}_t + \widehat{\epsilon}_{m,t} \tag{C3}$$

where $\Gamma_{1,n} = \frac{\alpha(\overline{An})^{\nu}}{\alpha(\overline{An})^{\nu}+(1-\alpha)\overline{m}^{\nu}}$, $\Gamma_{1,m} = \frac{(1-\alpha)(\overline{m})^{\nu}}{\alpha(\overline{An})^{\nu}+(1-\alpha)\overline{m}^{\nu}}$, $\Gamma_{2,A} = \frac{\nu}{1-\nu}$, $\Gamma_{2,w} = \frac{1}{1-\nu}$ and $\Gamma_{3,Q} = \frac{1}{1-\nu}$.

The household's first order conditions corresponding to labor supply is

$$\frac{W_t^R}{P_t c_t} = \frac{\Psi}{j_t}(p_t^e + \theta(l_t - l_{t-1})) - \frac{\beta\Psi\theta}{j_{t+1}}(l_{t+1} - l_t)$$

In log-linear form, we have

$$\widehat{l}_t = \Gamma_{4,0}\left\{\widehat{W_t^R} - \widehat{P}_t - \widehat{c^y}_t - \widehat{y}_t + \Gamma_{4,-1}\widehat{l}_{t-1} + \Gamma_{4,1}\widehat{l}_{t+1} + \Gamma_{4,u}\widehat{U}_t\right\} + \widehat{\epsilon}_{l,t} \tag{C4}$$

where $\Gamma_{4,0} = \frac{(1-\overline{U})\left[1-\bar{l}(1-\overline{U})\right]}{\theta\bar{l}(1+\beta)[1-\bar{l}(1-\overline{U})]+\bar{l}(1-\overline{U})^2}$, $\Gamma_{4,-1} = \frac{\theta\bar{l}}{1-\overline{U}}$, $\Gamma_{4,1} = \frac{\beta\theta\bar{l}}{1-\overline{U}}$, $\Gamma_{4,u} = \frac{1}{(1-\overline{U})(1-\bar{l}(1-\overline{U}))}$. The household reservation wage is given by

$$W_t^R \equiv B_t(1 - p_t^e) + W_t(1-\tau)p_t^e$$

Log-linearizing the reservation wage equation gives

$$\widehat{W_t^R} = \widehat{W}_t + \Gamma_{5,u}\widehat{U}_t \tag{C5}$$

where $\Gamma_{5,u} = \frac{\sigma+\tau-1}{u\sigma+(1-\tau)(1-u)}$. Log-linearizing the wage markup equation

$$x_t = \left[(\frac{\gamma}{1-\gamma})\frac{N_t W_t^*}{\Pi_t} + \frac{1}{1-\nu} - 1\right]^{-1}$$

and substituting the result into the wage equation

$$W_t^* = \frac{W_t^R}{1-\tau}(1 + x_t)$$

gives

$$\widehat{W_t^*} = \Gamma_{6,u}\widehat{U}_t + \Gamma_{6,y}(\widehat{y}_t - \widehat{Q}_t - \widehat{m}_t) + \widehat{P}_t + \widehat{A}_t \tag{C6}$$

where $\Gamma_{6,y} = \Gamma_{5,u}\left[\frac{(\nu-1)(1-\gamma)(\overline{y}-\overline{wn}-\overline{Qm})}{\nu\gamma\overline{h}\overline{x}^2(\overline{y}-\overline{Qm})}\right]$ and $\Gamma_{6,y} = \frac{\overline{Qm}(\nu-1)}{(\overline{y}-\overline{Qm})\nu}$

Log-linearizing the wage adjustment process

$$W_t = \lambda W_{t-1} + (1-\lambda)W_t^*$$

yields

$$\widehat{W_t} = \lambda\widehat{W}_{t-1} + (1-\lambda)\widehat{W_t^*} \tag{C7}$$

Combining the aggregate budget constraint, $Y_t = C_t + EX_t$, with the export equation

$$EX_t = \phi(Q_t)^{\mu}Y_t^*$$

yields

$$1 - c_t^y = \epsilon_{x,t}(Q_t)^{\mu}$$

where $c_t^y = C_t/Y_t$ is the consumption-output ratio, and $\epsilon_{x,t} = \phi Y_t^*/Y_t$ can be interpreted as the export demand shock. Log-linearizing this equation yields

$$\widehat{c^y}_t = -\Gamma_{8,Q}(\mu\widehat{Q}_t + \widehat{\epsilon}_{x,t}) \tag{C8}$$

where $\Gamma_{8,Q} = \frac{(\overline{\epsilon_x}\overline{Q}^{\mu})}{\overline{c^y}}$.

Log-linearize the real exchange rate equation yields

$$\widehat{Q}_t + \widehat{P}_t = \widehat{P_t^*} \tag{C9}$$

The Euler equations are

$$E_t\left[\frac{\beta c_t(1+R_t)P_t}{c_{t+1}P_{t+1}}\right] = 1$$

$$E_t\left[\frac{\beta c_t(1+R_t^*)\kappa_t S_{t+1}P_t}{c_{t+1}S_tP_{t+1}}\right] = 1$$

Given that S_t is a constant, we can combining the Euler equations and substituting the result in the first Euler equations yields

$$E_t\left[\frac{\beta c_t^y y_t(1+R_t^*)\kappa_t P_t}{c_{t+1}^y y_{t+1}P_{t+1}}\right] = 1$$

Log-linearizing the equation above gives

$$\widehat{c^y}_t + \widehat{y}_t = E_t(\widehat{c^y}_{t+1} + \widehat{y}_{t+1}) - (\widehat{R}_t^* - E_t(\widehat{P}_{t+1}) + \widehat{P}_t) - \widehat{\kappa}_t \tag{C10}$$

Log-linearizing the unemployment rate equation yields

$$\widehat{U}_t = \frac{n}{l}(\widehat{l}_t - \widehat{n}_t) \tag{C11}$$

The shock processes are

$$\widehat{R_t^*} = \rho_{fr1}\widehat{R}_{t-1}^* + \rho_{fr2}\widehat{R}_{t-2}^* + s_{R^*,t} \tag{C12}$$

$$\widehat{A}_t = \rho_{a1}\widehat{A}_{t-1} + \rho_{a2}\widehat{A}_{t-2} + \rho_{a3}\widehat{A}_{t-3} + \rho_{a4}\widehat{A}_{t-4} + s_{A,t} \tag{C13}$$

$$\widehat{\epsilon}_{x,t} = \rho_x\widehat{\epsilon}_{x,t-1} + s_{x,t} \tag{C14}$$

$$\widehat{P_t^*} = \rho_{fp1}\widehat{P}_{t-1}^* + \rho_{fp2}\widehat{P}_{t-2}^* + \rho_{fp3}\widehat{P}_{t-3}^* + s_{p^*,t} \tag{C15}$$

$$\widehat{\kappa}_t = \rho_{\kappa 1}\widehat{\kappa}_{t-1} + \rho_{\kappa 2}\widehat{\kappa}_{t-2} + s_{\kappa,t} \tag{C16}$$

$$\widehat{\epsilon_{w,t}} = s_{w,t} \tag{C17}$$

$$\widehat{\epsilon}_{n,t} = \rho_n\widehat{\epsilon}_{n,t-1} + s_{n,t} \tag{C18}$$

$$\widehat{\epsilon}_{m,t} = \rho_m\widehat{\epsilon}_{m,t-1} + s_{m,t} \tag{C19}$$

$$\widehat{\epsilon}_{l,t} = s_{l,t} \tag{C20}$$

D Loglikelihood Function

In this section, we provide the derivation of the likelihood function that we use in paper. We have a VAR(1) solution form

$$\begin{bmatrix} \widehat{X}_t \\ \widehat{Y}_t \end{bmatrix} = D \begin{bmatrix} \widehat{X}_{t-1} \\ \widehat{Y}_{t-1} \end{bmatrix} + Fs_t$$

where $\widehat{X}_t$ includes the predetermined variables and the driving forces in the model, $\widehat{Y}_t$ are the forward-looking variables and s_t is a vector of innovations to structural shocks. We assume $s_t \sim N(0, \Sigma_s), E(s_t s_w') = 0 \; \forall t, w$ such that $t \neq w$. We let $Z_t = [\widehat{X}_t \; \widehat{Y}_t]'$ denote a vector that contains all variables. Note that some of the variables in $\widehat{Z}_t$ are unobservables, thus we need to divide the variables in Z_t into two groups. We call the first group, uv_t,as it contains the unobservables. We call the second group ov_t, as it contains the observables. Since we use nine series in the estimation, ov_t must be a 9×1 vector. Thus, we can rearrange the order of the variables appearing in Z_t, and the corresponding elements in D. As a result, we transform the solution into the following form

$$\begin{bmatrix} uv_t \\ ov_t \end{bmatrix} = \begin{bmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{bmatrix} \begin{bmatrix} uv_{t-1} \\ ov_{t-1} \end{bmatrix} + \begin{bmatrix} H_1 \\ H_2 \end{bmatrix} s_t$$

We set uv_0 and ov_0 to their unconditional expected value of zero. At $t = 1$, we have $ov_1 = H_2 \; s_1$, which implies that $s_1 = (H_2)^{-1} ov_1$, where ov_1 is the first observation from the data. Given s_1, we know, $uv_1 = H_1 s_1$.At $t = 2$,

$ov_2 = G_{21}uv_1 + G_{22}ov_1 + H_2\ s_2$.Thus, $s_2 = (H_2)^{-1}[ov_2 - G_{21}uv_1 - G_{22}ov_1]$. and we know $uv_2 = G_{11}uv_1 + G_{12}ov_1 + H_1s_2$. Then $\eta_t = H_2s_t$ is the vector of innovations to the reduced form errors. The log likelihood function is:

$$-(Tn/2)\log(2\pi) - (T/2)\log(\mid \Sigma_\eta \mid) - (1/2)\sum_{t=1}^{T}\eta_t'\Sigma_\eta^{-1}\eta_t$$

Since we have the estimates of η_t, we know the MLE or the value of Σ_η that maximizes the likelihood is given by

$$\widehat{\Sigma}_\eta = (1/T)\sum_{t=1}^{T}\widehat{\eta}_t\widehat{\eta}_t'$$

We can replace the actual Σ_η in the likelihood function with the MLE. The last term in the log likelihood function becomes

$$\begin{aligned}
(1/2)\sum_{t=1}^{T}\widehat{\eta}_t'\widehat{\Sigma}_\eta^{-1}\widehat{\eta}_t &= (1/2)trace\left[\sum_{t=1}^{T}\widehat{\eta}_t'\widehat{\Sigma}_\eta^{-1}\widehat{\eta}_t\right] \\
&= (1/2)trace\left[\sum_{t=1}^{T}\widehat{\Sigma}_\eta^{-1}\widehat{\eta}_t\widehat{\eta}_t'\right] \\
&= (1/2)trace\left[\widehat{\Sigma}_\eta^{-1}(T\widehat{\Sigma}_\eta)\right] \\
&= (1/2)trace(TI) \\
&= Tn/2
\end{aligned}$$

The log likelihood function changes to $-(Tn/2)\log(2\pi) - (Tn/2) - (T/2)\log(\mid \widehat{\Sigma}_\eta \mid)$. Note that the estimates of η_t depends on the parameters in D and F. Let ϑ be a vector contains the elements of D and F that we want to estimate. Then, the loglikelihood function depends on ϑ, and it can be written as

$$L(\vartheta) = -(Tn/2)\log(2\pi) - (Tn/2) - (T/2)\log(\mid \widehat{\Sigma}_\eta \mid)$$

where $\widehat{\Sigma}_\eta = (1/T)\sum_{t=1}^{T}\widehat{\eta}_t(\vartheta)\widehat{\eta}_t'(\vartheta)$. This is the same function we present in the paper.

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