Online Appendix 1 to “The Borchardt hypothesis: a cliometric reassessment on Germany’s debt and crisis in 1930-32”

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Abstract

Online Appendix 1 reports the details of the analytical model, the derivation of the equilibrium conditions, and the solution method.

Online Appendix 1

Our analytical model is an extension of Céspedes, Chang, and Velasco (2003, 2004, 2005). We extend the original 2-period model to an infinite-period model to allow for quantitative simulation. We relax the assumption that price and wage are preset for one period, and we use the staggered price setting a la Calvo to model price and wage rigidities. We also add two stochastic shocks to the model economy: shocks to world real interest rate and to world demand for the country's exports. The model nests both fixed and flexible exchange rates, contains a clear mechanism for how foreign-currency debt affects the economy via entrepreneurs' balance sheet, and allows one to compare quantitatively the relative performance of alternative exchange rates under various scenarios.

There are infinite periods denoted by $t = 1, 2, 3, \ldots$. There are two distinct agents, workers and entrepreneurs. Workers supply labor and consume an aggregate of domestic and foreign goods; while entrepreneurs supply capital and own the firms. Entrepreneurs borrow from the world capital market in order to finance investment in excess of their own net worth.

Domestic production

The production of domestic goods is monopolistic competitive and firms have a Cobb-Douglas production technology given by:

$$Y_{jt} = AK_{jt}^{\alpha} L_{jt}^{1-\alpha}, \qquad 0 < \alpha < 1 \tag{1}$$

where j denotes firm (output of variety), t denotes time period, Y_{jt} denotes output of variety j in period t, K_{jt} denotes capital input, and L_{jt} denotes labor input. Since workers' labor services are heterogeneous, L_{jt} is an CES aggregate of the services (labor) of the different workers in the economy:

$$L_{jt} = \left[\int_0^1 L_{ijt}^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}}, \tag{2}$$

where workers are indexed by $i \in [0, 1]$, L_{ijt} denotes the services purchased from worker i by firm j, and $\sigma > 1$ is the elasticity of substitution among different labor types. The aggregate nominal wage, or the minimum cost of a unit of labor L_{jt}, is given by:

$$W_t = \left[\int_0^1 W_{it}^{1-\sigma} di \right]^{\frac{1}{1-\sigma}} \tag{3}$$

The j-th firm maximizes its profits, which are given by:

$$\Pi_{jt} = P_{jt} Y_{jt} - \int_0^1 W_{it} L_{ijt} di - R_t K_{jt}, \tag{4}$$

where R_t denotes return to capital, and the profits are expressed in terms of the domestic currency. Cost minimization of the firms implies that:

$$\frac{R_t K_{jt}}{W_t L_{jt}} = \frac{\alpha}{1-\alpha}, \tag{5}$$

so that all firms have the same capital to labor ratio K_t/L_t. The marginal cost of production is expressed as:

$$MC_t = \frac{1}{1-\alpha} W_t \frac{1}{A} \left(\frac{\alpha}{1-\alpha} \frac{W_t}{R_t} \right)^{-\alpha} \tag{6}$$

Following the staggered price setting a la Calvo (1983), the probability that the price of a given intermediate good can be changed in any particular period is $(1-\theta_p)$. The problem of the intermediate good producers is to choose price P_{jt} that maximizes discounted real profits:

$$\max_{P_{jt}} \nabla_t \sum_{\tau=0}^{\infty} (\theta_p)^{\tau} \rho_{t,t+\tau} \left\{ \left(\frac{P_{jt} - MC_{t+\tau}}{Q_{t+\tau}} \right) \left(\frac{P_{jt}}{P_{t+\tau}} \right)^{-\theta} C^H_{t+\tau} \right\} \tag{7}$$

As will become clear later, we use Q_t to denote the general consumption price level, P_t to denote the price of domestically produced goods and S_t to denote the price of imported goods. C^H_t denotes domestic consumption bundle to be further explained below. To avoid confusion with the real exchange rate, we use ∇ as the notation for expectation. The pricing kernel $\rho_{t,t+\tau}$ is assumed to be equal to the household's inter-temporal marginal rate of substitution in consumption:

$$\rho_{t,t+\tau} = \beta^{\tau} \frac{U_{C,t+\tau}}{U_{C,t}} \tag{8}$$

Define $\Xi_{t,t+\tau} \equiv \rho_{t,t+\tau} C^H_{t+\tau} \frac{(P_{t+\tau})^{\theta}}{Q_{t+\tau}}$. The first-order condition for optimal price setting is given by:

$$P^*_{jt} = \frac{\theta}{\theta-1} \frac{\nabla_t \sum_{\tau=0}^{\infty} (\theta_p)^{\tau} \Xi_{t,t+\tau} MC_{t+\tau}}{\nabla_t \sum_{\tau=0}^{\infty} (\theta_p)^{\tau} \Xi_{t,t+\tau}} \tag{9}$$

The equation implies that the price set at period t is equal to a weighted average of current and expected future marginal costs, multiplied by the markup factor $\frac{\theta}{\theta-1}$.[1] Assume symmetric solution for the firms so that $P^*_{jt} = P^*_t$, the price index for domestically produced goods evolves according to:

[1] This equation is analogous to Kollmann (2001, equation 9).

$$P_t = \left[\theta_p \left(P_{t-1}\right)^{1-\theta} + \left(1-\theta_p\right)\left(P_t^*\right)^{1-\theta}\right]^{\frac{1}{1-\theta}} \tag{10}$$

Workers

The representative worker has preferences over consumption C_t, labor supply L_t, and real money balances $\frac{M_t}{Q_t}$ given by:

$$\log C_t - \left(\frac{\sigma-1}{\sigma}\right)\frac{1}{\upsilon}L_t^{\upsilon} + \frac{1}{1-\varepsilon}\left(\frac{M_t}{Q_t}\right)^{1-\varepsilon}, \tag{11}$$

where $\upsilon > 1$, $\varepsilon > 0$, and Q_t is the consumer price index.

Consumption C_t is an aggregate of domestic and foreign goods:

$$C_t = \frac{1}{\gamma^{\gamma}\left(1-\gamma\right)^{1-\gamma}}\left(C_t^H\right)^{\gamma}\left(C_t^F\right)^{1-\gamma}, \tag{12}$$

where C_t^H is a basket of the varieties of domestically produced goods and C_t^F is a basket of imported goods. The basket of domestically produced goods, C_t^H, is aggregated through the CES function:

$$C_t^H = \left[\int_0^1 C_{jt}^{\frac{\theta-1}{\theta}}dj\right]^{\frac{\theta}{\theta-1}}, \qquad \theta > 1 \tag{13}$$

Using P_t to denote the domestic price of one unit of basket of domestically produced goods, P_t is expressed as:

$$P_t = \left[\int_0^1 P_{jt}^{1-\theta}dj\right]^{\frac{1}{1-\theta}} \tag{14}$$

The prices of imported goods are assumed to be fixed and are normalized to one in terms of foreign currency. The exchange rate is expressed as the price of a unit of foreign currency in terms of the domestic currency. Imports are freely traded and the law of one price holds, so that the domestic price of imported goods is equal to the nominal exchange rate S_t.

The cost of one unit of aggregate consumption Q_t (or CPI) is given by:

$$Q_t = P_t^{\gamma}S_t^{1-\gamma} \tag{15}$$

The i-th workers' budget constraint in period t is:[2]

$$P_tC_{it}^H + S_tC_{it}^F = W_{it}L_{it} + T_t - M_{it} + M_{it-1} \tag{16}$$

Use E_t to denote the real exchange rate; that is, $E_t \equiv S_t/P_t$. To minimize cost, the con-

[2] $Q_tC_{it} \equiv P_tC_{it}^H + S_tC_{it}^F$.

sumer will purchase domestic and foreign goods under the requirement that a proportion γ of consumption will be spent on domestic goods and a proportion $(1-\gamma)$ will be spent on foreign goods:

$$\frac{C_t^H P_t}{Q_t C_t} = \gamma \tag{17}$$

$$\frac{C_t^F S_t}{Q_t C_t} = 1-\gamma \tag{18}$$

The government follows a simple policy: it is assumed that revenues from an inflation tax are rebated to workers though lump-sum transfers.

$$M_t - M_{t-1} = T_t, \qquad M_t = \int_0^1 M_{it} di \tag{19}$$

The above fiscal policy setting and worker's budget constraint mean that in equilibrium, workers consume all their nominal income:

$$Q_t C_t = W_t L_t \tag{20}$$

We assume each household specializes in one type of labor, which it supplies monopolistically. Use θ_w to denote the degree of wage stickiness, assume a symmetric solution, and omit the household's index. Following Galí (2015), the household's wage setting problem is to find W_t^* which maximizes:

$$\nabla_t \sum_{\tau=0}^{\infty} (\beta\theta_w)^\tau U\left(C_{t+\tau}, L_{t+\tau|t}\right) \tag{21}$$

$$st. \qquad L_{t+\tau|t} = \left(\frac{W_t^*}{W_{t+\tau}}\right)^{-\sigma} L_{t+\tau} \tag{22}$$

$$st. \qquad Q_{t+\tau} C_{t+\tau} = W_t^* L_{t+\tau|t} + T_{t+\tau} - M_{t+\tau} + M_{t+\tau-1} \tag{23}$$

$L_{t+\tau|t}$ is the quantity of labor services provided in period $t+\tau$ by a household that last reset its wage in period t. Define $\Omega_{t+\tau} \equiv \frac{1-\alpha}{\alpha} K_{t+\tau} R_{t+\tau} \left(W_{t+\tau}\right)^{\sigma-1}$. The first-order condition, or the wage setting equation, is given by:[3]

$$W_t^* = -\frac{\sigma}{\sigma-1} \frac{\nabla_t \sum_{\tau=0}^{\infty} (\beta\theta_w)^\tau U_{L,t+\tau} \Omega_{t+\tau}}{\nabla_t \sum_{\tau=0}^{\infty} (\beta\theta_w)^\tau \frac{U_{C,t+\tau}}{Q_{t+\tau}} \Omega_{t+\tau}} \tag{24}$$

The wage index evolves according to:

$$W_t = \left[\theta_w \left(W_{t-1}\right)^{1-\sigma} + (1-\theta_w)\left(W_t^*\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{25}$$

[3]This optimal condition is similar to Kollmann (2001, equation 22).

In addition, the money demand is given by:

$$\nabla_t \left(\beta \frac{1}{C_{t+1}} \frac{Q_t}{Q_{t+1}}\right) = \frac{1}{C_t} - \left(\frac{M_t}{Q_t}\right)^{-\varepsilon} \tag{26}$$

Entrepreneurs

Entrepreneurs borrow from the world capital market in order to finance investment in excess of their net worth. Assume that all debt contracts are denominated in foreign currency. Entrepreneurs' budget constraint is given by:

$$P_t N_t + S_t D_{t+1} = Q_t I_t \tag{27}$$

$$I_t = K_{t+1}, \tag{28}$$

where N_t is net worth, D_{t+1} is the amount borrowed abroad in period t and to be repaid in period $t+1$, and $I_t = K_{t+1}$ is investment in period $t+1$ capital. Here, it is assumed that capital is produced in the same fashion as consumption, so that the cost of producing one unit of capital is also Q_t. Capital depreciates completely in production, and so there is no capital accumulation.

We use ρ_t to denote the world interest rate and η_{t+1} to denote risk premium. Here, ρ_t is a mean-reversion process with a mean value of ρ (the world safe interest rate). Assume that the risk premium is increasing in the ratio of the value of investment to net worth.

$$1 + \eta_{t+1} = \left(\frac{Q_t I_t}{P_t N_t}\right)^{\mu} = \left(1 + \frac{E_t D_{t+1}}{N_t}\right)^{\mu}, \qquad \mu \geq 0 \tag{29}$$

Entrepreneurs will borrow to finance investment so that the expected return is equal to the cost of borrowing.

$$\nabla_t \frac{R_{t+1}}{Q_t} = (1 + \rho_t)\left(1 + \eta_{t+1}\right) \nabla_t \left(\frac{S_{t+1}}{S_t}\right) \tag{30}$$

Entrepreneurs receive the profits of the firms as well as the rent on capital. Assume that capitalists consume a portion $(1 - \delta)$ of their net worth, and they only consume imported goods. Entrepreneurs' net worth therefore is:

$$\begin{aligned} P_t N_t &= \delta \left[R_t K_t + \Pi_t - \left(1 + \rho_{t-1}\right)(1 + \eta_t) S_t D_t\right] \\ &= \delta \left[P_t Y_t - W_t L_t - \left(1 + \rho_{t-1}\right)(1 + \eta_t) S_t D_t\right], \end{aligned} \tag{31}$$

where Π_t is firm profits in domestic currency, and D_t is dollar debt repayment in period t.

Market clearing conditions

The market clearing condition for home goods is given by:

$$Y_t = \gamma \left(\frac{Q_t}{P_t} \right) (I_t + C_t) + (E_t)^{\chi} X_t, \tag{32}$$

where E_t is the real exchange rate already mentioned above, $\chi > 0$, $(E_t)^{\chi} X_t$ denotes the domestic goods demanded by the rest of the world, and X is exogenous world demand for domestic goods.

Equilibrium conditions

Define $\Pi_{p,t} \equiv P_t/P_{t-1}$, $\tilde{P}_t \equiv P_t^*/P_t$, $\Pi_{w,t} \equiv W_t/W_{t-1}$, $\tilde{W}_t \equiv W_t^*/W_t$, $\Delta_{p,t} \equiv \int_0^1 \left(\frac{P_{jt}}{P_t} \right)^{-\theta} dj$, and $\Delta_{w,t} \equiv \int_0^1 \left(\frac{W_{it}}{W_t} \right)^{-\sigma} di$. We summarize the equilibrium conditions of the model as follows:

$$Y_t = \frac{1}{\Delta_{p,t}} \frac{1}{\Delta_{w,t}} A K_t^{\alpha} L_t^{1-\alpha} \tag{33}$$

$$\Delta_{p,t} = (1 - \theta_p) \left(\tilde{P}_t \right)^{-\theta} + \theta_p \left(\Pi_{p,t} \right)^{\theta} \Delta_{p,t-1} \tag{34}$$

$$\Delta_{w,t} = (1 - \theta_w) \left(\tilde{W}_t \right)^{-\sigma} + \theta_w \left(\Pi_{w,t} \right)^{\sigma} \Delta_{w,t-1} \tag{35}$$

$$\frac{R_t K_t}{W_t L_t} = \frac{\alpha}{1-\alpha} \tag{36}$$

$$\frac{MC_t}{P_t} = \frac{1}{1-\alpha} \frac{W_t}{P_t} \frac{1}{A} \left(\frac{\alpha}{1-\alpha} \frac{W_t}{R_t} \right)^{-\alpha} \tag{37}$$

$$P_t^* = \frac{\theta}{\theta - 1} \frac{\nabla_t \sum_{\tau=0}^{\infty} (\theta_p)^{\tau} \Xi_{t,t+\tau} MC_{t+\tau}}{\nabla_t \sum_{\tau=0}^{\infty} (\theta_p)^{\tau} \Xi_{t,t+\tau}} \tag{38}$$

$$1 = \left[\theta_p \left(\Pi_{p,t} \right)^{\theta-1} + (1 - \theta_p) \left(\tilde{P}_t \right)^{1-\theta} \right]^{\frac{1}{1-\theta}} \tag{39}$$

$$\frac{Q_t}{P_t} = \frac{P_t^{\gamma} S_t^{1-\gamma}}{P_t} = \left(\frac{S_t}{P_t} \right)^{1-\gamma} \tag{40}$$

$$\frac{S_t}{P_t} \equiv E_t \tag{41}$$

$$C_t = \frac{W_t}{Q_t} L_t \tag{42}$$

$$W_t^* = -\frac{\sigma}{\sigma - 1} \frac{\nabla_t \sum_{\tau=0}^{\infty} (\beta\theta_w)^{\tau} U_{L,t+\tau} \Omega_{t+\tau}}{\nabla_t \sum_{\tau=0}^{\infty} (\beta\theta_w)^{\tau} \frac{U_{C,t+\tau}}{Q_{t+\tau}} \Omega_{t+\tau}} \tag{43}$$

$$1 = \left[\theta_w \left(\Pi_{w,t}\right)^{\sigma-1} + (1-\theta_w) \left(\tilde{W}_t\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{44}$$

$$\nabla_t \left(\beta \frac{1}{C_{t+1}} \frac{Q_t}{Q_{t+1}}\right) = \frac{1}{C_t} - \left(\frac{M_t}{Q_t}\right)^{-\varepsilon} \tag{45}$$

$$N_t + \frac{S_t}{P_t} D_{t+1} = \frac{Q_t}{P_t} I_t \tag{46}$$

$$I_t = K_{t+1} \tag{47}$$

$$1 + \eta_{t+1} = \left(\frac{Q_t}{P_t} \frac{I_t}{N_t}\right)^{\mu} \tag{48}$$

$$\nabla_t \frac{R_{t+1}}{Q_t} = (1+\rho_t) \left(1+\eta_{t+1}\right) \nabla_t \left(\frac{S_{t+1}}{S_t}\right) \tag{49}$$

$$N_t = \delta \left[Y_t - \frac{W_t}{P_t} L_t - \left(1+\rho_{t-1}\right) (1+\eta_t) \frac{S_t}{P_t} D_t\right] \tag{50}$$

$$Y_t = \gamma \left(\frac{Q_t}{P_t}\right) (I_t + C_t) + (E_t)^{\chi} X_t \tag{51}$$

Steady state

The steady state of the model is the same regardless of the assumption about monetary policy (fixed or floating exchange rate regime), and regardless of the assumption about price and wage rigidity. We have imposed $P \equiv 1$. It follows that:

$$\Pi_p = \Pi_w = \Delta_p = \Delta_w = \tilde{P} = \tilde{W} = L = 1$$

The solution of other variables starts from solving η. Equation (52) solves for η.

$$1 - \delta \left[1 - \frac{\theta - 1}{\theta} (1-\alpha)\right] \frac{1}{\alpha} \frac{\theta}{\theta - 1} (1+\rho) (1+\eta) (1+\eta)^{\frac{1}{\mu}} + \delta (1+\rho) (1+\eta) \left((1+\eta)^{\frac{1}{\mu}} - 1\right) = 0 \tag{52}$$

In the special case that $\theta = \infty$ (perfect competition):

$$\eta = \frac{1}{\delta\left(1+\rho\right)} - 1$$

For a compact notational expression, we define coefficients λ_1 and λ_2 as:

$$\lambda_1 \equiv \left[1 - \frac{\theta-1}{\theta}\gamma\left(1-\alpha\right) - \frac{\theta-1}{\theta}\frac{\alpha\gamma}{\left(1+\rho\right)\left(1+\eta\right)}\right]$$

$$\lambda_2 \equiv \frac{\theta-1}{\theta}\alpha\frac{A^{\frac{1}{\alpha}}}{\left(1+\rho\right)\left(1+\eta\right)}$$

The steady states of other variables are solved in the following sequence.

$$S = \left[\lambda_2\left(\frac{X}{\lambda_1}\right)^{\frac{\alpha-1}{\alpha}}\right]^{\frac{1}{1-\gamma+\chi\frac{1-\alpha}{\alpha}}}$$

$$Y = \frac{\left(S\right)^{\chi}X}{\lambda_1}$$

$$K = \left(\frac{Y}{A}\right)^{\frac{1}{\alpha}}$$

$$Q = S^{1-\gamma}$$

$$C = \frac{\theta-1}{\theta}\left(1-\alpha\right)\frac{Y}{Q}$$

$$N = QK\left(1+\eta\right)^{-\frac{1}{\mu}}$$

$$D = \frac{QK-N}{S}$$

$$M = Q\left(\frac{1-\beta}{C}\right)^{\frac{-1}{\varepsilon}}$$

$$E = S$$

$$I = K$$

$$R = \alpha\frac{\theta-1}{\theta}\frac{Y}{K}$$

$$W=(1-\alpha)\frac{\theta-1}{\theta}\frac{Y}{L}$$

Log-linearization

We use a linear method to solve the model. The log-linearized equilibrium conditions are expressed below (when i_t is replaced by k_{t+1}). With the exception of η_t ($\hat{\eta}_t$) and ρ_t ($\hat{\rho}_t$), we use lower case to denote the linearized variables. All variables are expressed as log-deviation from their steady states, and only ρ_t is expressed as deviation from the steady state.

$$y_t=\alpha k_t+(1-\alpha)\,l_t \tag{53}$$

$$r_t+k_t=w_t+l_t \tag{54}$$

$$(mc_t-p_t)=(w_t-p_t)-\alpha\,(w_t-r_t) \tag{55}$$

$$\pi_{p,t}=\frac{(1-\theta_p)\,(1-\theta_p\beta)}{\theta_p}\,(mc_t-p_t)+\beta\pi_{p,t+1} \tag{56}$$

$$(q_t-p_t)=(1-\gamma)\,(s_t-p_t) \tag{57}$$

$$c_t+q_t=w_t+l_t \tag{58}$$

$$\pi_{w,t}=\frac{(1-\beta\theta_w)\,(1-\theta_w)}{\theta_w}\,[(\upsilon-1)\,l_t+c_t+q_t-w_t]+\beta\pi_{w,t+1} \tag{59}$$

$$\left(\beta\frac{1}{C}\right)(-c_{t+1}+q_t-q_{t+1})=\frac{-1}{C}c_t+\varepsilon\left(\frac{M}{Q}\right)^{-\varepsilon}(m_t-q_t) \tag{60}$$

$$n_t+\frac{SD}{NP}\,(s_t-p_t+d_{t+1})=\frac{QI}{NP}\,(q_t-p_t+k_{t+1}) \tag{61}$$

$$\hat{\eta}_{t+1}=\left(\frac{Q}{P}\frac{I}{N}\right)^{\mu}\frac{\mu}{\eta}\,(q_t+k_{t+1}-p_t-n_t) \tag{62}$$

$$(r_{t+1}-q_t)=(s_{t+1}-s_t)+(1+\rho)\,\frac{Q}{R}\,(\eta\hat{\eta}_{t+1})+(1+\eta)\,\frac{Q}{R}\,(\hat{\rho}_t) \tag{63}$$

$$Nn_t = \delta \left[Yy_t - \frac{WL}{P}(w_t - p_t + l_t) - (1+\rho)(1+\eta)\frac{SD}{P}\left(s_t - p_t + d_t + \frac{\eta}{1+\eta}\hat{\eta}_t + \frac{1}{1+\rho}\hat{\rho}_{t-1} \right) \right] \tag{64}$$

$$y_t = \gamma \frac{Q}{P}\frac{I}{Y}(k_{t+1} + q_t - p_t) + \gamma \frac{Q}{P}\frac{C}{Y}(c_t + q_t - p_t) + \frac{(E)^\chi X}{Y}(x_t + \chi e_t) \tag{65}$$

$$s_t - p_t = e_t \tag{66}$$

$$\pi_{p,t} = p_t - p_{t-1} \tag{67}$$

$$\pi_{w,t} = w_t - w_{t-1} \tag{68}$$

Recovering shocks

The model contains two structural shocks X_t and ρ_t. Given the model parameters and two observables, the exogenous shocks can be extracted recursively by inverting the observation equation (Guerrieri and Iacoviello, 2017; Kollmann, 2017).

More specifically, the model solution takes the form:

$$X_t^m = P \cdot X_{t-1}^m + Q \cdot u_t, \tag{69}$$

where X_t^m include both state and control variables of the model, P and Q are coefficient matrices, and u_t denotes exogenous shocks. Let H be a selection matrix and $Y_t = H \cdot X_t^m$ is the vector of observed series. Multiply both sides of equation (69) by H and we obtain:

$$Y_t = H \cdot X_t^m = H \cdot P \cdot X_{t-1}^m + H \cdot Q \cdot u_t. \tag{70}$$

Given X_{t-1}^m and the current realization of Y_t, equation (70) represents a system of non-linear equations that allow us to solve for u_t recursively. A necessary condition for the inversion filter is that matrix $H \cdot Q$ is invertible. To initiate the inversion filter, we also assume that X_0^m coincide with the model's steady state.

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