Online Appendix to: "Oil Prices and the Dynamics of Output and Real Exchange Rate"

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This appendix contains more details on (I) our two-sector energy real business cycle (ERBC) model showing the complete model listing, (II) the calibration of the parameter values used to initialise the Simulated Annealing (SA) search algorithm, (III) the description of the driving processes, and (IV) our data sources and construction.

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I. Complete Log-linearised Model Used for Simulation

Having substituted out λ_t, R_t^e, and R_t^n, the log-linearised equations we are interested in are:

$$c_t = \frac{1}{1+\iota}c_{t+1} + \frac{\iota}{1+\iota}c_{t-1} + \frac{1-\iota}{\epsilon(1+\iota)}\left(\tau_t - \tau_{t+1} - \beta rr_t\right) \tag{1}$$

$$hh_t = h^e h_t^e + h^n h_t^n \tag{2}$$

$$h_t^e = p_t^e + y_t^e - \frac{w}{1+w}w_t - \frac{1}{1+w}\xi_t^e \tag{3}$$

$$h_t^n = p_t^n + y_t^n - \frac{w}{1+w}w_t - \frac{1}{1+w}\xi_t^n \tag{4}$$

$$f_t = \left(1 + \mathsf{r}_{t-1}^f\right) f_{t-1} + ex/y\left(p_t + ex_t\right) - (im/y)im_t - e/y\left(\mathsf{q}_t + e_t\right) \tag{5}$$

$$ii_t = i^e i_t^e + i^n i_t^n \tag{6}$$

$$i^e i_t^e = k^e k_t^e - \left(1 - \delta u^e\right) k^e k_{t-1}^e + \delta_{e1} u^{\mu_e} k^e u_t^e - i^e \mathsf{z}_t^e \tag{7}$$

$$i^n i_t^n = k^n k_t^n - \left(1 - \delta u^n\right) k^n k_{t-1}^n + \delta_{n1} u^{\mu_n} k^n u_t^n - i^n \mathsf{z}_t^n \tag{8}$$

$$\begin{aligned}\left(\frac{1}{1+\frac{1}{\delta_{e1}u^{\mu_e}}}\left(\mu_e - 1\right) + \nu_e + 1 - \frac{\nu_e}{1 + \frac{1-\theta_e}{\theta_e}\left(\frac{e^e}{k^e}\right)^{-\nu_e}}\right) u_t^e = p_t^e + y_t^e + \frac{\mathsf{z}_t^e}{1+\frac{1}{\delta_{e1}u^{\mu_e}}} \\ - \frac{\vartheta_t^e}{1+\delta_{e1}u^{\mu_e}} + \left(\frac{\nu_e}{1 + \frac{1-\theta_e}{\theta_e}\left(\frac{e^e}{k^e}\right)^{-\nu_e}} - \nu_e - 1\right) k_{t-1}^e + \frac{\nu_e}{1 + \frac{\theta_e}{1-\theta_e}\left(\frac{e^e}{k^e}\right)^{\nu_e}}\left(\mathsf{o}_t^e + e_t^e\right)\end{aligned} \tag{9}$$

$$\begin{aligned}\left(\frac{1}{1+\frac{1}{\delta_{n1}u^{\mu_n}}}\left(\mu_n - 1\right) + \nu_n + 1 - \frac{\nu_n}{1 + \frac{1-\theta_n}{\theta_n}\left(\frac{e^n}{k^n}\right)^{-\nu_n}}\right) u_t^n = p_t^n + y_t^n + \frac{\mathsf{z}_t^n}{1+\frac{1}{\delta_{n1}u^{\mu_n}}} \\ - \frac{\vartheta_t^n}{1+\delta_{n1}u^{\mu_n}} + \left(\frac{\nu_n}{1 + \frac{1-\theta_n}{\theta_n}\left(\frac{e^n}{k^n}\right)^{-\nu_n}} - \nu_n - 1\right) k_{t-1}^n + \frac{\nu_n}{1 + \frac{\theta_n}{1-\theta_n}\left(\frac{e^n}{k^n}\right)^{\nu_n}}\left(\mathsf{o}_t^n + e_t^n\right)\end{aligned} \tag{10}$$

$$\begin{aligned}\psi_e\left(1+\beta\right)k_t^e &= \frac{\epsilon}{1-\iota}\left(c_t - \iota c_{t-1}\right) - \frac{\epsilon}{1-\iota}\left(c_{t+1} - \iota c_t\right) + \tau_{t+1} - \tau_t \\ &\quad + \beta\delta_{e1}u^{\mu_e}\left(\mu_e - 1\right)u_{t+1}^e - \mathsf{z}_{t+1}^e + \mathsf{z}_t^e + \psi_e\left(\beta k_{t+1}^e + k_{t-1}^e\right)\end{aligned} \tag{11}$$

$$\begin{aligned}\psi_n\left(1+\beta\right)k_t^n &= \frac{\epsilon}{1-\iota}\left(c_t - \iota c_{t-1}\right) - \frac{\epsilon}{1-\iota}\left(c_{t+1} - \iota c_t\right) + \tau_{t+1} - \tau_t \\ &\quad + \beta\delta_{n1}u^{\mu_n}\left(\mu_n - 1\right)u_{t+1}^n - \mathsf{z}_{t+1}^n + \mathsf{z}_t^n + \psi_n\left(\beta k_{t+1}^n + k_{t-1}^n\right)\end{aligned} \tag{12}$$

$$yy_t = y^e y_t^e + y^n y_t^n \tag{13}$$

$$y_t^e = \mathsf{a}_t^e + (1-\alpha_e)\, h_t^e + \frac{\alpha_e}{1+\frac{1-\theta_e}{\theta_e}\left(\frac{e^e}{k^e}\right)^{-\nu_e}}\left(u_t^e + k_{t-1}^e\right) + \frac{\alpha_e}{1+\frac{\theta_e}{1-\theta_e}\left(\frac{e^e}{k^e}\right)^{\nu_e}}\left(\mathsf{o}_t^e + e_t^e\right) \tag{14}$$

$$y_t^n = \mathsf{a}_t^n + (1-\alpha_n)\, h_t^n + \frac{\alpha_n}{1+\frac{1-\theta_n}{\theta_n}\left(\frac{e^n}{k^n}\right)^{-\nu_n}}\left(u_t^n + k_{t-1}^n\right) + \frac{\alpha_n}{1+\frac{\theta_n}{1-\theta_n}\left(\frac{e^n}{k^n}\right)^{\nu_n}}\left(\mathsf{o}_t^n + e_t^n\right) \tag{15}$$

$$e_t = \frac{e^e}{e} e_t^e + \frac{e^n}{e} e_t^n \tag{16}$$

$$\left(\nu_e + 1 - \frac{\nu_e}{1+\frac{\theta_e}{1-\theta_e}\left(\frac{e^e}{k^e}\right)^{\nu_e}}\right) e_t^e = p_t^e + y_t^e - \mathsf{q}_t + \frac{\nu_e}{1+\frac{1-\theta_e}{\theta_e}\left(\frac{e^e}{k^e}\right)^{-\nu_e}}\left(u_t^e + k_{t-1}^e\right) + \left(\frac{\nu_e}{1+\frac{\theta_e}{1-\theta_e}\left(\frac{e^e}{k^e}\right)^{\nu_e}} - \nu_e\right)\mathsf{o}_t^e \tag{17}$$

$$\left(\nu_n + 1 - \frac{\nu_n}{1+\frac{\theta_n}{1-\theta_n}\left(\frac{e^n}{k^n}\right)^{\nu_n}}\right) e_t^n = p_t^n + y_t^n - \mathsf{q}_t + \frac{\nu_n}{1+\frac{1-\theta_n}{\theta_n}\left(\frac{e^n}{k^n}\right)^{-\nu_n}}\left(u_t^n + k_{t-1}^n\right) + \left(\frac{\nu_n}{1+\frac{\theta_n}{1-\theta_n}\left(\frac{e^n}{k^n}\right)^{\nu_n}} - \nu_n\right)\mathsf{o}_t^n \tag{18}$$

$$dd_t = cc_t + ii_t + \mathsf{gg}_t \tag{19}$$

$$d_t^e = \varsigma\gamma_t + \varsigma\left(p_t - p_t^e\right) + d_t \tag{20}$$

$$imim_t = cc_t + ii_t + \mathsf{gg}_t + exex_t - e\left(\mathsf{q}_t + e_t\right) - yy_t \tag{21}$$

$$im_t^e = \eta\varphi_t - \eta \mathsf{p}_{e,t}^{im} + im_t \tag{22}$$

$$ex_t = \phi_w \varpi_t^w - \phi_w p_t + \mathsf{d}_t^w \tag{23}$$

$$ex^e ex_t^e = y^e y_t^e - d^e d_t^e + im^e im_t^e \tag{24}$$

$$w_t = \omega h_t + \zeta_t + \frac{\epsilon}{1-\iota}\left(c_t - \iota c_{t-1}\right) \tag{25}$$

$$r_t = \mathsf{r}_t^f + p_t - p_{t+1} - \psi_f ff_t \tag{26}$$

$$\phi p_t = im_t - d_t - \phi\varpi_t \tag{27}$$

$$\eta_w p_t^e = \eta_w\left(\varphi_t^w + p_t\right) + ex_t - ex_t^e \tag{28}$$

$$(1-\sigma)\left(\frac{p^n}{p}\right)^{1-\varsigma} p_t^n = p_t - \sigma\left(\frac{p^e}{p}\right)^{1-\varsigma}\left(\varsigma\gamma_t + p_t^e\right) \tag{29}$$

solving for the following endogenous stochastic processes: c_t, h_t, h_t^e, h_t^n, b_t^f, i_t, i_t^e, i_t^n, u_t^e, u_t^n, k_t^e, k_t^n, y_t, y_t^e, y_t^n, e_t, e_t^e, e_t^n, d_t, d_t^e, im_t, im_t^e, ex_t, ex_t^e, w_t, r_t, p_t, p_t^e, and p_t^n.

II. Initialisation of the Simulated Annealing Algorithm

A vector of the parameters defined by $\Gamma_{2a} = \{\omega,\, \varepsilon,\, \iota,\, \alpha_e,\, \alpha_n,\, \nu_e,\, \nu_n,\, \delta_{e1}u^{\mu_e},\, \delta_{n1}u^{\mu_n},\, \mu_e,\, \mu_n,\, \psi_e,\, \psi_n,\, \psi_f,\, \phi,\, \phi_w,\, \eta,\, \eta_w,\, \sigma,\, \varsigma\}$ in the main text is estimated using the indirect inference econometric approach. In doing this, we use the Simulated Annealing (SA) search algorithm to find a more optimal vector of values. The SA algorithm requires starting values to be suggested, however. Here, we discuss how these are calibrated.

We set the elasticity of labour supply as equal to 5, fix consumption elasticity at 2, and preserve the CES form of the production functions by setting the respective sector's elasticity of substitution between capital services and efficient energy use, ν_e and ν_n, as equal to 0.7.[1] Elasticities of labour hours in the energy and non-energy intensive sectors, $1-\alpha_e$ and $1-\alpha_n$, are calibrated to be 0.57 and 0.72, respectively. We also suppose that there is some degree of habit formation for agents in this model, setting the initial parameter value to 0.7.

Next, we turn to calibrate the component parameters of the two depreciation functions. In the steady state, these are given by $\delta u^j = \delta_{j0} + \delta_{j1}\left(\mu_j\right)^{-1}\left(u^j\right)^{\mu_j}$ for $j = e,\, n$, for which we note that only four of the six parameters needed identifying, namely δ_{e0}, δ_{n0}, μ_e and μ_n. Thus, with no loss of generality, we fix the values for δ_{e1} and δ_{n1} at unity.[2] The idea is that u^j are admitted into the model only jointly as $\delta_{j1}\left(u^j\right)^{\mu_j}$ such that $\delta_{j1} = 1$ has a trivial implication that $\delta_{j1}\left(u^j\right)^{\mu_j} = \left(u^j\right)^{\mu_j}$. Then, using household optimality conditions with regards to capital utilisation rates conditioned on the values for the respective sector's real rental rate of capital in the steady state, we have that $\delta_{j1}\left(u^j\right)^{\mu_j} = R^j = 1/\beta - \left(1 - \delta\left(u^j\right)\right)$, where we have already calibrated $\delta\left(u^j\right)$. The previous expression then simplifies to give the initial values for $\delta_{e1}u^{\mu_e}$ and $\delta_{n1}u^{\mu_n}$ of 0.132 and 0.102, respectively.

Conditional on the values of the discount factor and the real rental rates, we calibrate the parameters governing the elasticities of marginal depreciations with respect to capital utilisation rates as $\mu_e = \frac{\delta_{e1}(u^e)^{\mu_e}}{1+\delta_{e1}(u^e)^{\mu_e}-1/\beta} = 1.463$ and $\mu_n = \frac{\delta_{n1}(U^n)^{\mu_n}}{1+\delta_{n1}(U^n)^{\mu_n}-1/\beta} = 1.694$, which are reasonably located in the range found in the literature.[3] For us, the point of adding adjustment costs is

1. Kim and Loungani (Table 2, p. 180) provide a justification for using this value. They also considered a value of 0.001 suggesting a Cobb-Douglas form and high elasticity of substitution between capital services and energy use. We, however, stick to the parameter value that preserves the general form of specification while leaving the optimal choice of parameter value to be estimated.

2. See, for example, Burnside and Eichenbaum (1996), Boileau and Normandin (1999), King and Rebelo (1999), and Leduc and Sill (2004).

3. Basu and Kimball (1997) suggested the upper bound of 2 based on a 95% confidence band. Further, to calibrate this parameter, we have gone for the more restricted form of the depreciation function by setting $\delta_{e0} = \delta_{n0} = 0$. Basu and Kimball (1997) though, used the more general form in their empirical work and concluded that there is no statistical evidence in support of the non-zero value for the fixed component of the depreciation function, as is assumed by many other authors in the literature [see, for example, Greenwood et al. (1988) and Burnside and Eichenbaum (1996)]. We 'conclude' that this value of 2 is not far (not a statistical conclusion) from that usually employed in the literature [see, for example, Greenwood et al., who used a value of 1.42, and Burnside and Eichenbaum who, using their factor-hoarding model and data on output and capital, calibrated μ to be 1.56 ($\Delta = 0.56$)]. We note that the specification for time-varying depreciation is less general in these other studies. Statistically, however, both values are not rejected by the data. This is done noting one of the concerns of Basu and Kimball (1997) that "...our method makes clear that Δ is a parameter that needs to be estimated, and in fact is not pinned down very precisely by the data because it has to be estimated as the reciprocal of a fairly small number. Thus, even the small standard error of the reduced-form parameter necessarily implies that there is large uncertainty about the structural parameter Δ. Consequently, economic modellers should conduct sensitivity analysis of their results using a wide range of values for this parameter." It should also be noted that "variable depreciation does not seem a significant source of error in the capital stock figures reported by the BEA." Specifically, they concluded that this issue "strikes us as second-order."

mainly technical rather than for imposing a prori a very high friction into the model. This we have set the parameters that relate to the adjustment costs of capital and foreign bonds, ψ_e, ψ_n, and ψ_f to a very small value of 0.001 to follow a standard practice in the literature. This way we are permitting the model to inform me when it has been estimated whether there is more or less real rigidity in the system. The values chosen for the shares and elasticities of substitution parameters in the aggregator functions are all standard in the literature.

III. Driving Processes

There are five observed exogenous variables in the model, (d_t^w, g_t, $\mathsf{p}_{e,t}^{im}$, q_t, r_t^f), and seventeen behavioural errors, (a_t^e, a_t^n, φ_t, φ_t^w, γ_t, ζ_t, o_t^e, o_t^n, τ_t, ϑ_t^e, ϑ_t^n, ϖ_t, ϖ_t^w, ξ_t^e, ξ_t^n, z_t^e, z_t^n). We take the actual data for the first group and part-sequentially use the model to derive the series for the second group given the estimated model parameter values. Particularly, because τ_t, ξ_t^e, ξ_t^n, γ_t, φ_t, ϖ_t^w, ζ_t, ϖ_t, and φ_t^w are exactly identified in the equilibrium conditions (1), (2), (3), (20), (22), (23), (25), (27), and (28), respectively, we can simply re-write these expressions for each of the shock variables in any order we wanted. We can then sequentially derive o_t^e from (17), o_t^n from (18), a_t^e from (14), a_t^n from (15), z_t^e from (11), z_t^n from (12), ϑ_t^e from (9), and ϑ_t^n from (10). The unit root tests for the resulting series are reported in Table I.

Hence, we estimate the parameters of the shock processes by specifying that they follow:

$$\ln \Delta \mathsf{a}_t^e = \rho_{\mathsf{a}^e} \ln \Delta \mathsf{a}_{t-1}^e + \epsilon_{\mathsf{a}^e,t},\ \epsilon_{\mathsf{a}^e,t} \backsim N\left(0, \sigma_{\mathsf{a}^e}\right) \tag{30}$$

$$\ln \Delta \mathsf{a}_t^n = \rho_{\mathsf{a}^n} \ln \Delta \mathsf{a}_{t-1}^n + \epsilon_{\mathsf{a}^n,t},\ \epsilon_{\mathsf{a}^n,t} \backsim N\left(0, \sigma_{\mathsf{a}^n}\right) \tag{31}$$

$$\ln \Delta \mathsf{d}_t^w = \rho_{\mathsf{d}^w} \ln \Delta \mathsf{d}_{t-1}^w + \epsilon_{\mathsf{d}^w,t},\ \epsilon_{\mathsf{d}^w,t} \backsim N\left(0, \sigma_{\mathsf{d}^w}\right) \tag{32}$$

$$\ln \Delta \varphi_t = \rho_{\varphi} \ln \Delta \varphi_{t-1} + \epsilon_{\varphi,t},\ \epsilon_{\varphi,t} \backsim N\left(0, \sigma_{\varphi}\right) \tag{33}$$

$$\ln \Delta \varphi_t^w = \rho_{\varphi^w} \ln \Delta \varphi_{t-1}^w + \epsilon_{\varphi^w,t},\ \epsilon_{\varphi^w,t} \backsim N\left(0, \sigma_{\varphi^w}\right) \tag{34}$$

$$\ln \Delta \gamma_t = \rho_{\gamma} \ln \Delta \gamma_{t-1} + \epsilon_{\gamma,t},\ \epsilon_{\gamma,t} \backsim N\left(0, \sigma_{\gamma}\right) \tag{35}$$

$$\ln \Delta \mathsf{g}_t = \rho_{\mathsf{g}} \ln \Delta \mathsf{g}_{t-1} + \epsilon_{\mathsf{g},t},\ \epsilon_{\mathsf{g},t} \backsim N\left(0, \sigma_{\mathsf{g}}\right) \tag{36}$$

$$\ln \zeta_t = \rho_{\zeta} \ln \zeta_{t-1} + \epsilon_{\zeta,t},\ \epsilon_{\zeta,t} \backsim N\left(0, \sigma_{\zeta}\right) \tag{37}$$

$$\ln \mathsf{o}_t^e = \rho_{\mathsf{o}^e} \ln \mathsf{o}_{t-1}^e + \epsilon_{\mathsf{o}^e,t},\ \epsilon_{\mathsf{o}^e,t} \backsim N\left(0, \sigma_{\mathsf{o}^e}\right) \tag{38}$$

$$\ln \mathsf{o}_t^n = \rho_{\mathsf{o}^n} \ln \mathsf{o}_{t-1}^n + \epsilon_{\mathsf{o}^n,t},\ \epsilon_{\mathsf{o}^n,t} \backsim N\left(0, \sigma_{\mathsf{o}^n}\right) \tag{39}$$

$$\ln \Delta \mathsf{p}_{e,t}^{im} = \rho_{\mathsf{p}_e^{im}} \ln \Delta \mathsf{p}_{e,t-1}^{im} + \epsilon_{\mathsf{p}_e^{im},t},\ \epsilon_{\mathsf{p}_e^{im},t} \backsim N\left(0, \sigma_{\mathsf{p}_e^{im}}\right) \tag{40}$$

$$\ln \Delta \mathsf{q}_t = \rho_{\mathsf{q}} \ln \Delta \mathsf{q}_{t-1} + \epsilon_{\mathsf{q},t},\ \epsilon_{\mathsf{q},t} \backsim N\left(0, \sigma_{\mathsf{q}}\right) \tag{41}$$

$$\ln \mathsf{r}_t^f = \rho_{\mathsf{r}^f} \ln \mathsf{r}_{t-1}^f + \epsilon_{\mathsf{r}^f,t},\ \epsilon_{\mathsf{r}^f,t} \backsim N\left(0, \sigma_{\mathsf{r}^f}\right) \tag{42}$$

$$\ln \tau_t = \rho_{\tau} \ln \tau_{t-1} + \epsilon_{\tau,t},\ \epsilon_{\tau,t} \backsim N\left(0, \sigma_{\tau}\right) \tag{43}$$

$$\ln \vartheta_t^e = \rho_{\vartheta^e} \ln \vartheta_{t-1}^e + \epsilon_{\vartheta^e,t},\ \epsilon_{\vartheta^e,t} \backsim N\left(0, \sigma_{\vartheta^e}\right) \tag{44}$$

$$\ln \vartheta_t^n = \rho_{\vartheta^n} \ln \vartheta_{t-1}^n + \epsilon_{\vartheta^n,t},\ \epsilon_{\vartheta^n,t} \backsim N\left(0, \sigma_{\vartheta^n}\right) \tag{45}$$

$$\ln \varpi_t = \rho_{\varpi} \ln \varpi_{t-1} + \epsilon_{\varpi,t},\ \epsilon_{\varpi,t} \backsim N\left(0, \sigma_{\varpi}\right) \tag{46}$$

This, therefore, raises the issue of sensitivity analysis regarding our results in response to various values that could be used for μ (Δ). To this end, we impose a wider boundary of $[0, 10]$ in the estimation exercise.

$$\ln \varpi_t^w = \rho_{\varpi^w} \ln \varpi_{t-1}^w + \epsilon_{\varpi^w,t},\ \epsilon_{\varpi^w,t} \backsim N(0, \sigma_{\varpi^w}) \tag{47}$$

$$\ln \Delta\xi_t^e = \rho_{\xi^e} \ln \Delta\xi_{t-1}^e + \epsilon_{\xi^e,t},\ \epsilon_{\xi^e,t} \backsim N(0, \sigma_{\xi^e}) \tag{48}$$

$$\ln \Delta\xi_t^n = \rho_{\xi^n} \ln \Delta\xi_{t-1}^n + \epsilon_{\xi^n,t},\ \epsilon_{\xi^n,t} \backsim N(0, \sigma_{\xi^n}) \tag{49}$$

$$\ln \mathsf{z}_t^e = \rho_{\mathsf{z}^e} \ln \mathsf{z}_{t-1}^e + \epsilon_{\mathsf{z}^e,t},\ \epsilon_{\mathsf{z}^e,t} \backsim N(0, \sigma_{\mathsf{z}^e}) \tag{50}$$

$$\ln \mathsf{z}_t^n = \rho_{\mathsf{z}^n} \ln \mathsf{z}_{t-1}^n + \epsilon_{\mathsf{z}^n,t},\ \epsilon_{\mathsf{z}^n,t} \backsim N(0, \sigma_{\mathsf{z}^n}) \tag{51}$$

IV. Data construction

Output

Model variables: Y_t, Y_t^e, Y_t^n.

Data: Aggregate output, Y_t, is measured as the sum of the two sectoral outputs, $Y_t^e + Y_t^n$. We construct the two sectoral gross domestic products from the value added by industry data. More specifically, aggregate output is defined as the total value added of all industries where the energy intensive sector output, Y_t^e, is defined as the sum of the value added from agriculture, mining, utilities, construction, manufacturing and transportation, and non-energy intensive sector output, Y_t^n, is defined as the sum of the value added from wholesale and retail trade, information, finance, professional and business services, educational services, arts, and other services except government. Lastly, due to the lack of sufficient disaggregation of government output, we split the output of the public sector into two and added half each to Y_t^e and Y_t^n. Source: GDP by Industry, BEA.

Consumption

Model variable: C_t.

Data: This is defined as personal consumption expenditures less durable goods. Source: Table 1.1.5. Gross Domestic Product, BEA.

Investment

Model variables: I_t, I_t^n, I_t^n.

Data: The measure of gross investment is taken to be the sum of personal consumption expenditure on durable goods and private fixed investments. This was applied to defining the two types of investment variables, noting that aggregate investment is given as $I_t = I_t^e + I_t^n$. For the investment series, we combined Table 2.7: Investment in Private Fixed Assets, Equipment, Structures, and Intellectual Property Products by Type and the series for consumer durables from Table 2.4.5: Personal Consumption Expenditures by Type of Product. Beginning with the consumption of durable goods in Table 2.4.5, the following are assigned investments that are non-energy intensive, denoted by I_{dg}^n: furnishings and durable household equipment, recreational goods and vehicles, and other durable goods, such that investment in energy intensive durable goods is given by I_{dg}^e = Durable goods - I_{dg}^n. Further, investment in energy intensive goods is deemed to be given by the sum of equipment and structures less residential equipment and improvements. Investment in non-energy intensive type goods is, therefore, the sum of residential equipment, improvements and intellectual property products. Source: BEA.

Capital

Model variables: K_t^e, K_t^n.

Data: We construct the capital stock of energy intensive goods as the sum of non-residential equipment and structures, while the capital stock of non-energy intensive goods is calculated as the sum of residential equipment and structures and intellectual property products. As in the investment series above, non-energy intensive capital stocks is taken as the sum of furnishings and durable household equipment, recreational goods and vehicles, and other durable goods, such that the capital stock in the energy intensive consumption of durable goods is given by motor vehicles and parts. Source: Table 8.1. Current-Cost Net Stock of Consumer Durable Goods and Table 2.1. Current-Cost Net Stock of Private Fixed Assets, Equipment, Structures, and Intellectual Property Products by Type, BEA.

Labour hours

Model variables: H_t, H_t^e, H_t^n.

Data: Aggregate labour hours, H_t, is defined as the hours worked by all persons engaged in production and the hours worked per sector, H_t^e and H_t^n. These are calculated by following the procedure of Herrendorf et al. (2013), involving combining GDP-by-Industry data reported using NAICS classification with the Income-and-Employment-by-Industry data reported with three different classifications over the sample period (SIC72 for pre-1987, SIC87 between 1987-2000, and NAICS since 2001). This is necessary because, while the former data source follows the classification we would prefer, Herrendorf et al. show that the latter provides us with the kind of detailed industry level information we require for assignment into the two sectors. In order to effect this assignment, therefore, we follow the definitions of other sectoral variables already shown above as closely as feasibly permitted by the level of data disaggregation. Specifically, for each of the series, employment and hours in agriculture, mining, utilities, construction, manufacturing and transportation are classed as related to the energy intensive sector, while employment and hours in wholesale, retail trade, information, finance, professional services, education, arts, and other services are non-energy intensive. Formally, the sectoral labour hours are obtained using:

$$H^j = NAICS_{FT}^H + \frac{NAICS_{FT}^H}{NAICS_{FT}^E} \times NAICS_{SE}$$

with

$$NAICS_{FT}^H = SIC_{FT}^H \times \frac{NAICS_{FT}^E}{SIC_{FT}^E}$$

$$NAICS_{FT}^E = SIC_{FT}^E \times \frac{NAICS_{FTPT}^E}{SIC_{FTPT}^E}$$

$$NAICS_{SE} = SIC_{SE} \times \frac{NAICS_{FTPT}^E}{SIC_{FTPT}^E}$$

where superscripts H and E denote hours employed and number of employees, respectively, and subscripts FT, SE, and $FTPT$ denote full-time, self-employed, and full-time part-time, respectively. Source: BEA.

Capital utilisation rate

Model variables: U_t^e, U_t^n.

Data: Following the assignment of industries into the two sectors, we deemed it fit to have two definitions of capital utilisation rate. Thus, capacity utilisation rate for total manufacturing industry and capacity utilisation rate for motor vehicles and parts are used as proxies for the measures of capital utilisation rates in the energy and non-energy intensive sectors, respectively. Source: BLS.

Energy use

Model variables: E_t, E_t^e, E_t^n.

Data: We take the total energy consumption in the economy, E_t, to be the aggregate consumption of primary energy or the consumption of fossil fuels comprising of petroleum, coal, and natural gas measured in trillions of British thermal units (BTUs) in the private sector excluding the electric power sector.[4] Energy consumption is provided for four end-use sectors, namely, the industrial, transportation, residential and commercial sectors. Given a lack of further disaggregation, we use the primary energy consumption in both the industrial and transportation sectors as a proxy energy use in the energy intensive sector, and primary energy consumption in both the residential and commercial sectors as a proxy energy use in the non-energy intensive sector. Hence, aggregate energy consumption in this economy is formally given by $E_t = E_t^e + E_t^n$ = dollar value of total primary energy use = $q_t \frac{(E_t \times 1\ trillion/\varkappa \times 1\ million)}{1\ billion}$, where $\varkappa = 5.78$, representing the conversion factor assumed for relating BTUs to barrels of oil, which is similar to the figure employed by the industry. Source: EIA.

Domestic absorption

Model variable: D_t.

Data: $D_t = C_t + I_t + \mathsf{G}_t$. Source: Table 1.1.5. Gross Domestic Product.

Domestic demand for energy intensive goods

Model variable: D_t^e.

Data: This is constructed as D_t^e = private consumption of energy intensive goods + private investment in energy intensive goods + government consumption of energy intensive goods + government investment in energy intensive goods. Note that given the lack of disaggregated data on government consumption expenditure, we assume that the share of government consumption in energy intensive goods is the same as for government investment in energy intensive goods, and apply this share to the consumption data. Source: Table 2.4.5: Personal Consumption Expenditures by Type of Product, Table 2.7: Investment in Private Fixed Assets, Equipment, Structures, and Intellectual Property Products by Type, Table 3.9.5: Government Consumption Expenditures and Gross Investment, Tables 7.5A-7.5B: Investment in Government Fixed Assets, BEA.

Aggregate imports

Model variable: IM_t.

Data: This is taken to be the aggregate imports. Source: Table 1.1.5. Gross Domestic Product, BEA.

Import of energy intensive goods

Model variable: IM_t^e.

Data: This is taken to be the import of goods Source: Table 1.1.5. Gross Domestic Product, BEA.

Aggregate exports

Model variable: EX_t.

Data: This is taken to be the aggregate exports. Source: Table 1.1.5. Gross Domestic Product, BEA.

Export of energy intensive goods

Model variable: EX_t^e.

Data: This is taken to be the export of goods. Source: Table 1.1.5. Gross Domestic Product, BEA.

Wage rate

Model variable: W_t.

4. We do not include the consumption of renewables (geothermal, solar/ PV, and biomass) and electricity for both theory and data reasons. On the data, if one chooses to use, for instance, total primary energy consumption data, there is no data for biomass consumption until 1981. Also, we excluded the electric power generating sector, which would have been classed as a highly energy intensive sector, given that close to 70% of all primary energy is used, or lost, because this sector provides electricity to the final consumers. We have, however, not included it because we have not modelled an energy producing sector, which would have to be the case if we incorporate electricity into our total for energy consumption.

Data: This is a real index of hourly compensation. Source: Series ID: PRS85006063, Nonfarm Business Sector: Compensation.

Interest rate

Model variable: R_t.

Data: This is the three-month Treasury bill rate for 1949-1954 where we have converted their quarterly data into annual data by averaging; we use the federal funds rate for 1955-2013. Source: Smets and Wouters (2007).

Real exchange rate

Model variable: P_t.

Data: General price level in the domestic country, which is taken to be the consumer price index (CPI) for all urban consumers, relative to world CPI. Source: BLS.

Price of energy intensive goods

Model variable: P_t^e.

Data: Calculated as the weighted average of the chain-type price indexes for value added from agriculture, mining, utilities, construction, manufacturing, and transportation. Source: GDP by Industry, BEA.

Price of non-energy intensive goods

Model variable: P_t^n.

Data: Calculated as the weighted average of the chain-type price indexes for value added from wholesale and retail trade, information, finance, professional and business services, educational services, arts and other services except government. Source: GDP by Industry, BEA.

Government spending

Model variable: G_t.

Data: This is government consumption expenditures and gross investment. Source: Table 1.1.5. Gross Domestic Product, BEA.

Real price of energy

Model variable: Q_t.

Data: Q_t is the nominal dollar price per barrel of crude oil proxied by the crude oil domestic first purchase price divided by the consumer price index. Source: Table 9.1: Crude Oil Price Summary, EIA; CPI, BLS.

Foreign bonds

Model variable: F_t.

Data: This is taken to be the ratio of nominal net foreign assets (NNFA) to nominal GDP (NGDP), $F_t = \frac{NNFA}{NGDP}$, where NNFA = Total assets - Total liabilities.

Foreign interest rate

Model variable: r_t^f.

Data: Calculated as the weighted average of the interest rate for the G7 countries (excluding the U.S.). Source: International Financial Statistics (IFS).

World demand

Model variable: D_t^w.

Data: This is measured as world trade less U.S. imports . Source: the International Financial Statistics (IFS).

Price of imported energy intensive goods

Model: $\mathsf{P}_{e,t}^{im}$.

Data: This is the price of U.S. imported manufactures from the rest of the world. Source: the International Financial Statistics (IFS).

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TABLE I: Test for Stationarity of Shocks

Shocks	*ADF* Test Statistics			*PP* Test Statistics			*KPSS* Test Statistics			Conclusion
	LL	*WT*	*FD*	*LL*	*WT*	*FD*	*LL*	*WT*	*FD*	
a_t^e	−1.48 (0.54)	−2.04 (0.57)	−6.86 (0.00)	−1.48 (0.54)	−1.99 (0.60)	−6.80 (0.00)	0.8340	0.1387	0.1666	Non-stationary†
a_t^n	−2.48 (0.13)	−3.07 (0.12)	−6.77 (0.00)	−3.09 (0.03)	−2.97 (0.15)	−9.35 (0.00)	0.9517	0.1728	0.4504	Non-stationary‡
d_t^w	−2.13 (0.23)	−2.67 (0.25)	−7.66 (0.00)	−2.16 (0.22)	−2.66 (0.26)	−7.66 (0.00)	0.9461	0.1489	0.2304	Non-stationary‡
φ_t	−0.42 (0.90)	−1.57 (0.79)	−6.20 (0.00)	−0.64 (0.85)	−1.45 (0.84)	−6.42 (0.00)	0.8700	0.1550	0.1542	Non-stationary‡
φ_t^w	−0.51 (0.88)	−2.05 (0.57)	−8.04 (0.00)	−0.47 (0.89)	−2.08 (0.55)	−8.07 (0.00)	0.9616	0.1543	0.0858	Non-stationary‡
γ_t	0.11 (0.96)	−1.95 (0.62)	−7.25 (0.00)	0.08 (0.96)	−1.95 (0.62)	−7.25 (0.00)	0.9898	0.1733	0.1742	Non-stationary‡
g_t	−1.22 (0.66)	−1.35 (0.87)	−6.30 (0.00)	−3.30 (0.02)	−2.75 (0.22)	−6.30 (0.00)	0.9732	0.1687	0.4662	Non-stationary‡
ζ_t	−2.07 (0.26)	−2.04 (0.57)	−7.71 (0.00)	−2.02 (0.28)	−2.00 (0.59)	−7.84 (0.00)	0.1586	0.1705	0.1120	Stationary*
o_t^e	−1.86 (0.35)	−1.86 (0.66)	−7.98 (0.00)	−1.86 (0.35)	−1.89 (0.65)	−8.01 (0.00)	0.0915	0.0939	0.1560	Stationary*
o_t^n	−1.92 (0.32)	−1.76 (0.71)	−7.55 (0.00)	−1.97 (0.30)	−1.78 (0.71)	−7.55 (0.00)	0.4441	0.0902	0.1202	Stationary*
$\mathsf{p}_{e,t}^{im}$	−0.93 (0.77)	−1.43 (0.84)	−4.92 (0.00)	−0.66 (0.85)	−1.44 (0.84)	−4.93 (0.00)	0.8792	0.1526	0.1468	Non-stationary‡
q_t	−0.99 (0.75)	−1.84 (0.67)	−7.74 (0.00)	−1.03 (0.74)	−1.86 (0.67)	−7.74 (0.00)	0.4758	0.0793	0.1159	Non-stationary†
r_t^f	−1.47 (0.54)	−1.91 (0.64)	−5.58 (0.00)	−0.84 (0.80)	−1.17 (0.91)	−5.29 (0.00)	0.3284	0.2477	0.4658	Stationary*
τ_t	−2.27 (0.19)	−2.14 (0.51)	−8.95 (0.00)	−2.05 (0.27)	−1.85 (0.67)	−9.53 (0.00)	0.2566	0.2525	0.3534	Stationary*
ϑ_t^e	−0.10 (0.95)	−2.03 (0.58)	−7.63 (0.00)	−0.15 (0.94)	−2.19 (0.49)	−7.66 (0.00)	0.9145	0.1150	0.1406	Trend stationary*
ϑ_t^n	−1.27 (0.64)	−3.67 (0.03)	−6.55 (0.00)	−1.25 (0.65)	−3.67 (0.03)	−13.6 (0.00)	0.9949	0.1309	0.3379	Trend stationary*
ϖ_t	−0.53 (0.88)	−1.37 (0.86)	−7.58 (0.00)	−0.53 (0.88)	−1.50 (0.82)	−7.58 (0.00)	0.9714	0.1198	0.1553	Trend stationary*
ϖ_t^w	−0.40 (0.90)	−2.64 (0.26)	−6.35 (0.00)	−0.48 (0.89)	−1.99 (0.60)	−6.37 (0.00)	0.8085	0.1161	0.1842	Trend stationary*
ξ_t^e	−0.50 (0.88)	−1.69 (0.74)	−3.80 (0.01)	−0.56 (0.87)	−1.58 (0.79)	−6.90 (0.00)	0.9647	0.1645	0.1131	Non-stationary‡
ξ_t^n	−2.03 (0.28)	−0.15 (0.99)	−6.77 (0.00)	−1.84 (0.36)	−0.30 (0.99)	−6.54 (0.00)	0.9983	0.2075	0.4352	Non-stationary‡
z_t^e	−5.67 (0.00)	−5.62 (0.00)	−9.68 (0.00)	−5.34 (0.00)	−5.26 (0.00)	−23.6 (0.00)	0.0523	0.0362	0.3187	Stationary‡
z_t^n	−5.61 (0.00)	−5.55 (0.00)	−9.57 (0.00)	−5.26 (0.00)	−5.17 (0.00)	−23.7 (0.00)	0.0437	0.0361	0.3390	Stationary‡

Note: a_t^e: energy intensive sector productivity, a_t^n: non-energy intensive sector productivity, d_t^w: world demand, φ_t: preference for imported energy intensive goods, φ_t^w: preference for exported energy intensive goods, γ_t: preference for energy intensive goods, g_t: government-spending, ζ_t: labour supply, o_t^e: energy intensive sector energy efficiency, o_t^n: non-energy intensive sector energy efficiency, $\mathsf{p}_{e,t}^{im}$: price of imported energy intensive goods, q_t: energy price, r_t^f: foreign interest rate, τ_t: intertemporal preference, ϑ_t^e: energy intensive sector capital cost shifter, ϑ_t^n: non-energy intensive sector capital cost shifter, ϖ_t: preference for aggregate imported goods, ϖ_t^w: preference for aggregate exported goods, ξ_t^e: energy intensive sector wage bill shifter, ξ_t^n: non-energy intensive sector wage bill shifter, z_t^e: energy intensive investment-specific technology, and z_t^n: non-energy intensive investment-specific technology; *ADF*: Augmented Dickey-Fuller, *PP*: Phillips-Perron, *KPSS*: Kwiatkowski, Phillips, Schmidt, and Shin, *LL*: levels, *WT*: with trend, and *FD*: first difference. †We made a judgement supporting ADF and PP tests; *we made a judgement supporting KPSS test; ‡all three methods agree on the conclusion we reached; conclusions are based on 5% critical value.