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Energy Price Shocks and External Balances

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Abstract

This paper studies the impact of a wide set of energy price shocks on external balances using a two-country framework comprising multiple sectors and endogenous energy production with convex costs. The paper disentangles different demand and supply shocks in the energy market through their distinct impact on external balances. It provides a theoretical confirmation of Kilian et al. (2009) and a theoretical foundation to the determining role of the non-energy trade balance in the transmission of energy price shocks. The presence of durables also highlights the immediate channel through which energy prices impact the non-energy trade balance.

JEL classifications: E32, F32, F41, Q43

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1 Introduction

There is a growing consensus in the literature that oil price shocks are not the same as oil supply shocks. As noted by Kilian (2008, 2009), to assess the macroeconomic conse-

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quences of oil price increases, it is necessary to disentangle different underlying supply and demand shocks in the energy market because the effects of energy price increases on the economy crucially depend on the source of the energy price increase (also see, e.g., Kilian and Murphy 2012, 2013; Baumeister and Peersman 2013a). In the international economics literature, Kilian et al. (2009) re-affirmed that view with a comprehensive empirical investigation of the responses of the oil and non-oil trade balances of oil-exporting and oil-importing countries to various oil price shocks. That paper demonstrated the distinct effects on external balances of the different shocks considered and the crucial role played by the non-oil trade balance in determining the overall effect on the trade balance. Theoretically, however, this body of literature has not moved towards endogenous energy production to explain different sources of energy price increases. There have been several important studies on the impact of oil price shocks on external balances, such as Backus and Crucini (2000) and Bodenstein et al. (2011). Yet, in Bodenstein et al. (2011), the oil supply is an exogenous endowment, which represents the extreme case of a perfectly inelastic oil supply and does not capture the dynamics of energy production (similarly observed in Bodenstein and Guerrieri 2011; Bodenstein et al. 2012). Backus and Crucini (2000) also employed an exogenous process for OPEC oil production. Moreover, Backus and Crucini (2000) has no restriction on the endogenous component of the oil supply, which allows oil production to expand freely. This feature does not capture the inelastic nature of energy supply[1]. Therefore, for demand-driven energy price disturbances, these frameworks might not provide satisfactory descriptions of energy price and production dynamics, and thus, of energy and non-energy trade balances. Furthermore, little attention has been paid to the decomposition of the non-energy trade balance. An understanding of how goods with varying degrees of energy dependence influence trade patterns might provide additional policy tools to address energy price shocks.

This paper attempts to fill the gap with a richer setup of multiple sectors and a

[1]Krichene (2005) provided a range of estimates for the short-run price elasticity of the oil and natural gas supplies and found them to be highly inelastic, with the highest estimate not exceeding 0.1. Estimates from Baumeister and Peersman (2013b) show that, since the late eighties, the median value of the short-run oil supply elasticities falls between 0.02 and 0.25. Kim and Loungani (1992) calculated the relative volatility of energy price to output at 6.02 using U.S. annual data from 1949 to 1987.

more generalized specification of energy production. The contribution is two-fold. First, we disentangle and establish the theoretical underpinnings of how different sources of energy price shocks impact external balances, which Kilian et al. (2009) have established empirically. The analysis considers to a wider set of shocks than either Backus and Crucini (2000) or Bodenstein et al. (2011), mirroring those analyzed in Kilian et al. (2009). An additional motivation is the prospect that the U.S. will become a net energy exporter over the next 15 to 20 years thanks to its shale gas boom. Within this framework, it is possible to make predictions about how this shift might impact the U.S. economy. Second, we look deeper into the composition of the non-energy trade balance to investigate the dynamics of goods with varying degrees of energy dependence, an angle not yet explored in previous research.

Our setup consists of two large economies, Home and Foreign, each with three production sectors: durables, nondurables and energy. These two countries can freely trade all three types of goods with each other. Energy is considered a homogeneous good worldwide, while some degree of differentiation is assumed between the two countries' durables (and non-durables). Energy is needed for durables and capital usage. By modeling the consumption and production of goods with different degrees of energy dependence, this model introduces a new dimension to the household consumption decision and creates heterogeneity in the way energy price increases impact these different sectors[2]. Energy production itself is energy-consuming and is subject to convex costs. The convex costs of energy production reduce the energy price elasticity of energy supply and bring it closer to the data. This feature makes the analysis of demand shocks to the energy market more meaningful. The model can also be flexibly calibrated to reflect varying degrees of energy dependence for the Home country, reflecting not only the U.S. but also a range of large economies with different levels of energy importation.

For the analyses in this paper, we calibrate the Home country to broadly match the U.S. using its readily available macro data. Home thus plays the role of a major energy importer, while the Foreign country plays the role of the rest of the world (an

[2]Dhawan and Jeske (2008) considered consumption of durables and non-durables but not in an international context.

energy exporter). We investigate the dynamics of the two countries' external balances in response to a number of supply and demand shocks. We examine the standard case of an adverse energy supply shock to the rest of the world. We then look at a shock to the overall demand for energy resulting from expansions in the business cycle. A demand shock that is specific to the energy market is also analyzed. This shock is given a specific interpretation in our model and is implemented differently than in Bodenstein et al. (2011). These three shocks broadly correspond to the three supply and demand shocks analyzed in Kilian et al. (2009). In addition, we introduce a new type of demand shock: a preference shock coming from households' increased taste for durables. This shock has direct relevance for the case of a large growing economy whose citizens increasingly consume durables. Finally, we pose the question of what would happen if the energy importing country became a more productive energy producer.

Our results confirm the empirical findings of Kilian et al. (2009) that the responses of external balances vary in response to different energy price shocks, principally due to the diverse responses of the non-energy trade balance. The distinction of a broad, indirect shock to energy demand is especially pertinent, while the specific demand shocks exacerbate the usual impact of high energy prices. Our analysis connects these differences to the sources of the energy price increases and distinguishes the roles played by goods with different degrees of energy dependence. We show that the time path of the energy price increases is not the only factor influencing the trade responses of the Home country, as different shocks affect the Foreign economy differently and thus have different impacts on Home exports. Another main result of our analysis is that the response of trade in durables is highly volatile and is the determining component in the diverse responses of the non-energy trade balance. This result implies a more immediate channel through which energy price influences the non-energy trade balance: the energy dependent nature of durables. This channel leads to movements in the non-energy trade balance beyond the usual influence of the terms of trade. As such, each shock's impact on external balances is mostly determined by how it affects durables trade in both countries.

Finally, our model also predicts beneficial effects to the energy importing country if it becomes more productive in energy. Cheaper, more readily available energy leads to an increase in Home output, expansion in its durables sector and improvement in its energy trade balance.

This paper is organized as follows: section 2 presents the theoretical framework, section 3 details the calibration of the model parameters and outlines its solution method, section 4 presents the cyclical properties of the model, section 5 examines the dynamics of the external balances in response to various shocks, section 6 answers the question of how an energy boom in the home country would benefit its economy, section 7 provides a sensitivity analysis, and section 8 concludes.

2 Model

This model comprises two large, symmetrical economies representative of the U.S. and the rest of the world. Each country has three sectors, durables, non-durables and energy. Additionally, they trade all three goods freely. The consumer in each country is a representative household, and both households consume a bundle of durables and non-durables, which are composites of the relevant domestically and foreign produced goods. The manner in which energy is consumed is identical in both countries; the representative household needs energy to use its stock of durables, and all sectors need energy to operate their capital stocks. For the sake of brevity, only the setup of the home country is described here as the foreign country has a symmetric setup.

2.1 Household

The household consumes a CES aggregation of durables and non-durables as follows

$$c_t = [\alpha^{1-\rho}(u_t d_t)^\rho + (1-\alpha)^{1-\rho} {n_t}^\rho]^{1/\rho}$$

where n_t is household consumption of non-durables, d_t is the stock of durables and u_t the utilization rate of this durables stock. The elasticity of substitution between durables and non-durables is represented by $\frac{1}{1-\rho}$, while α represents the share of durables usage in the household's consumption bundle. Together, $u_t d_t$ defines the service the household derives from its existing stock of durables during period t.

The representative household's problem is to maximize its expected lifetime utility

$$E_0 \sum_{t=0}^{\infty} \beta^t (\varphi \log c_t + (1-\varphi)\log(1-h_t)) \tag{1}$$

subject to the following budget constraint:

$$p_{e,t}e_{h,t} + p_{n,t}n_t + p_{d,t}i_{d,t} + p_{d,t}i_{k,t} + i_{B,t} = w_t h_t + r_t k_t + r_B B_t \tag{2}$$

where $i_{d,t}$, $i_{k,t}$ and $i_{B,t}$ denote investments in durables, capital and foreign bonds, respectively, r_t is the return on capital, w_t the wage and r_B the return on foreign bonds. k_t and B_t are the household's capital stock and foreign bond holdings, respectively, and h_t the hours worked. $e_{h,t}$ denotes the energy needed by the household to utilize its durables stock. $p_{e,t}$ and $p_{n,t}$ are the prices of energy and non-durables, respectively, while the price of durables and capital is $p_{d,t}$. The household earns its income from the rental of its capital stock to firms, its labor service and returns on its foreign bonds. The investments in capital and durables have the following adjustment costs:

$$i_{d,t} = d_{t+1} - (1-\delta_{d,t})d_t + \frac{\omega_{d1}}{1+\omega_{d2}}\left(\frac{d_{t+1}-d_t}{d_t}\right)^{1+\omega_{d2}} \tag{3}$$

$$i_{k,t} = k_{t+1} - (1-\delta_k)k_t + \frac{\omega_{k1}}{1+\omega_{k2}}\left(\frac{k_{t+1}-k_t}{k_t}\right)^{1+\omega_{k2}} \tag{4}$$

where $\delta_{d,t}$ and δ_k denote the depreciation rates of durables and of capital, respectively, and ω_{d1}, ω_{d2}, ω_{k1}, and ω_{k2} represent the parameters of the cost functions. The rate of durables depreciation varies positively with the utilization rate. Here, we use the following power function form for the depreciation rate following Finn (2000):

$$\delta_{d,t} = \frac{a_1}{a_2+1}{u_t}^{a_2+1} \tag{5}$$

To render the model stationary, the household's foreign bond holdings are subject to a portfolio adjustment cost (PAC) following Schmitt-Grohe and Uribe (2002). This is a technical solution to the problem encountered by a Small Open Economy (SOE) with incomplete asset markets. Investment in foreign bonds during each period by the home country's household is given by:

$$i_{B,t} = B_{t+1} - B_t + \frac{\omega_{B1}}{1+\omega_{B2}}\left(B_{t+1} - \bar{B}\right)^{1+\omega_{B2}} \tag{6}$$

The household's choice of $\{n_t, u_t, h_t, d_{t+1}, k_{t+1}, B_{t+1}\}$ to maximize (1) subject to (2), (3), (4), (5), and (6) results in the usual first order conditions detailed in appendix A.

Household energy use

Household use of durables requires a variable amount of energy ($e_{h,t}$) each period that is directly dependent on the utilization rate and stock of durables. Energy consumption does not enter the utility function directly. Instead, its cost enters into the household budget constraint. In this specification, the model makes use of the specification in Finn (2000) and extends it to the household. Household use of energy during each period can be described as a function of the stock of durables multiplied by its utilization rate $e_{h,t} = f(u_t d_t)$. In all analyses conducted in this paper, the amount of energy needed to sustain a utilization rate u_t of a stock of durables d_t is assumed to be linearly dependent on their product $u_t d_t$, that is, $e_{h,t} = a u_t d_t$, where a is a constant to be calibrated. This linear relationship assumes that aggregate durables have constant energy intensity.

In addition, to model an energy market specific demand shock originating from the household, we add the following exogenous shock to the household energy demand function:

$$e_{h,t} = \mu_{a,t} a u_t d_t \tag{7}$$

where $\mu_{a,t}$ is an AR(1) process with mean 1 and subject to i.i.d innovations

$$\mu_{a,t} - 1 = \rho_a(\mu_{a,t-1} - 1) + \epsilon_{a,t}, \epsilon_{a,t} \sim^{i.i.d} N(0, \sigma^2_{e,a}) \tag{8}$$

2.2 Producers

Each country has three sectors: durables, non-durables, and energy. The energy sector provides energy to these sectors (including itself) and to the household.

Energy Usage in Production

This framework assumes that each sector j's use of energy is tied directly to its use of capital, i.e. $e_{j,t} = g(k_{j,t})$, where g is a function to be determined. Similarly to the household case, g is calibrated to be a simple linear function; that is, a sector j's energy consumption is given by $e_{j,t} = bk_{j,t}$, where b is a constant. The parameter b can thus be interpreted as the energy intensity of capital. For the overall analysis in this paper, it suffices to assume that b is the same for all three sectors. One implication of this setup is that the energy sector also needs energy for its own production. In other words, energy is needed to produce energy. This factor introduces to the energy sector's production plan considerations about the opportunity cost of energy. When energy price increases, it also raises the cost of producing energy. Again, it should be noted that energy does not enter the production function directly. Its cost shows up in the first-order conditions of the three producers, where it adds to the cost of capital. The relationship $e_{j,t} = bk_{j,t}$ implies a very high degree of complementarity between capital and energy. With this specification, we emphasize the fundamental importance of energy in the operation of capital.

Again, we can model an energy market specific demand shock originating from the producers by introducing an exogenous shock to the producers' energy demand function such that for each producer

$$e_{j,t} = \mu_{b,t} bk_{j,t} \tag{9}$$

where $\mu_{b,t}$ is an AR(1) process with mean 1 and subject to i.i.d innovations

$$\mu_{b,t} - 1 = \rho_b(\mu_{b,t-1} - 1) + \epsilon_{b,t}, \epsilon_{b,t} \sim^{i.i.d} N(0, \sigma^2_{e,b}) \tag{10}$$

Energy Producer

The model implements energy production with convex costs to produce a low price elasticity of energy supply. The production function of the energy sector takes the following form:

$$y_{e,t} = \exp(A_{e,t})(1 - \lambda_{e,t})k_{e,t}^{\gamma_e} h_{e,t}^{1-\gamma_e} \tag{11}$$

where $y_{e,t}$, $h_{e,t}$ and $k_{e,t}$ denote output, labor and capital of the sector, respectively, and

$$A_{e,t} = \rho_e A_{e,t-1} + \epsilon_t, \epsilon_t \sim^{i.i.d} N(0, \sigma_e^2) \tag{12}$$

$\lambda_{e,t}$ represents the fraction of energy output that is lost, and has the following power function form:

$$\lambda_{e,t} = \frac{\omega_{e1}}{(1 + \omega_{e2})}(k_{e,t}^{\gamma_e} h_{e,t}^{1-\gamma_e})^{1+\omega_{e2}} \tag{13}$$

This functional form for $\lambda_{e,t}$ implies that with higher outputs of energy production, an increasingly higher fraction of that is lost through waste or inefficiency in the production process. This implementation creates a mechanism whereby when a demand shock hits the energy market, the energy sector cannot simply expand its output by a large percentage quickly. This constraint makes energy price more volatile, while energy supply itself is relatively less responsive to shocks.

Non-energy Producers

The durables and non-durables sectors are assumed to have Cobb-Douglas production functions but with different capital share parameters. They also share the same productivity process. The two sectors' production functions are given as:

$$y_{i,t} = \exp(A_t)k_{i,t}^{\gamma_i} h_{i,t}^{1-\gamma_i} \tag{14}$$

where $y_{i,t}$, $k_{i,t}$, and $h_{i,t}$ denote output, capital and labor, respectively, of sector i, where $i = d, n$, and

$$A_t = \rho_A A_{t-1} + \epsilon_{u,t}, \epsilon_{u,t} \sim^{i.i.d} N(0, \sigma_u^2) \tag{15}$$

Each sector solves the following profit-maximization problem:

$$\max_{\{k_{j,t},h_{j,t}\}} \{p_{j,t}y_{j,t} - w_t h_{j,t} - r_t k_{j,t} - p_{e,t}e_{j,t}\} \tag{16}$$

where $j = d, n, e$. Wages and returns of capital are assumed equal across sectors.

2.3 External Sector

This model assumes that energy is a homogenous good across countries and can be traded without friction. Durables and non-durables, although also traded without friction, are differentiated across the two countries. The household in each country therefore consumes durables/non-durables that are a composite of domestically produced and foreign produced durables/non-durables. For each country, there exists a packager who assembles domestic and foreign goods into composites for consumption within that country. For durables, the assembled supply for use in the country comes from the domestically produced durables and the imported durables defined as follows:

$$I_{D,t} = \left[\alpha_d^{1-\rho_d} I_{DD,t}^{\rho_d} + (1-\alpha_d)^{1-\rho_d} I_{DM,t}^{\rho_d}\right]^{1/\rho_d} \tag{17}$$

where α_d denotes the share of domestic durables in the durables bundle, and $\rho_d = 1-1/\epsilon_d$ where ϵ_d is the elasticity of substitution between domestic and foreign durables. The resulting quantity $I_{D,t}$ is used for investments in durables and capital

$$I_{D,t} = i_{d,t} + i_{k,t} \tag{18}$$

Similarly, for nondurables,

$$N_t = \left[\alpha_n^{1-\rho_n} N_{D,t}^{\rho_n} + (1-\alpha_n)^{1-\rho_n} N_{M,t}^{\rho_n}\right]^{1/\rho_n} \tag{19}$$

$$N_t = n_t \tag{20}$$

2.4 Prices

With the assumption that the packager minimizes production costs and enjoys zero profits, we arrive at the following prices for durables and non-durables in the home country:

$$p_{d,t} = \left[\alpha_d \left(p_{d,d,t}\right)^{\frac{\rho_d}{\rho_d-1}} + (1-\alpha_d)(ER_t p^*_{d,d,t})^{\frac{\rho_d}{\rho_d-1}}\right]^{\frac{\rho_d-1}{\rho_d}} \tag{21}$$

$$p_{n,t} = \left[\alpha_n \left(p_{n,d,t}\right)^{\frac{\rho_n}{\rho_n-1}} + (1-\alpha_n)(ER_t p^*_{n,d,t})^{\frac{\rho_n}{\rho_n-1}}\right]^{\frac{\rho_n-1}{\rho_n}} \tag{22}$$

where $p_{d,d,t}$ and $p_{n,d,t}$ are the prices of domestically produced durables and nondurables, respectively, and $p^*_{d,d,t}$ and $p^*_{n,d,t}$ their foreign counterparts, while ER_t is the real exchange rate. The CPI index for the home country is defined as follows:

$$p_t = \left[\alpha \left(p_{d,t} + ap_{e,t}\right)^{\frac{\rho}{\rho-1}} + (1-\alpha) p_{n,t}^{\frac{\rho}{\rho-1}}\right]^{\frac{\rho-1}{\rho}} \tag{23}$$

The real exchange rate is defined as the price (CPI index) of the foreign bundle of goods relative to the price (CPI index) of the goods bundle at home as follows:

$$ER_t = \frac{p^*_t}{p_t} \tag{24}$$

The terms of trade for the home country are defined as the relative price of its exports and its imports, where the price of exports is defined as the CPI index of wholly domestically produced goods and the price of imports is defined as the CPI index of wholly foreign produced goods.

2.5 Aggregation and Equilibrium

In this model, it is assumed that all energy produced worldwide is completely consumed during each period. The market clearing condition for energy is global and is automatically satisfied by both countries' household budget constraints and the market clearing conditions of the other two goods. Home's durable and nondurable outputs are used for domestic consumption, investments and exports

$$y_{d,t} = I_{DD,t} + I^*_{DM,t} \tag{25}$$

$$y_{n,t} = N_{D,t} + N^*_{M,t} \tag{26}$$

The factor markets also clear as follows:

$$k_t = k_{d,t} + k_{n,t} + k_{e,t} \tag{27}$$

$$h_t = h_{d,t} + h_{n,t} + h_{e,t} \tag{28}$$

Aggregate output y_t (value added) is defined as follows (excluding energy used in production):

$$p_t y_t = p_{d,t} y_{d,t} + p_{n,t} y_{n,t} + p_{e,t} a u_t d_t \tag{29}$$

2.6 Exogenous driving processes

The model is driven by four main shocks: a conventional TFP shock ($\epsilon_{u,t}$) that is common to both the durables and non-durables sectors, a productivity shock that affects the energy sector alone (ϵ_t), a shock to household energy consumption ($\epsilon_{a,t}$), and a shock to producer energy needs ($\epsilon_{b,t}$).

3 Model Calibration and Solution

Certain parameters are calibrated following conventions in the literature and Dhawan and Jeske (2008). The discount factor β is set at 0.99; the share of consumption in the household utility function φ is set at 0.34. The share of durables α in consumption is set at 0.2. Empirical research estimates the elasticity of substitution between durables and non-durables to be close to 1. In our model, the elasticity is set at 0.99 for the main analyses, and the CES parameter of the household utility function ρ is therefore $1 - 1/0.99$, which is negative and indicates that durables and non-durables are somewhat complementary. Other parameters are calibrated to produce theoretical moments of model aggregates that reproduce in the best possible way the empirical moments calculated from aggregate U.S. data (Table 1). Quarterly capital depreciation is calibrated at 2.5%, while the parameters of the durables depreciation function, a_1 and a_2, are chosen to produce a steady-state quarterly depreciation rate of 3.37% and a utilization rate of 78% for durables. The calibration of the parameters a and b, representing the energy intensities of durables and capital, respectively, is based directly on the empirical ratios E_h/Y and E_f/Y in Table 1.

The functional forms of capital and durables adjustment costs are given in the form of a general power function governed by two parameters, ω_1 and ω_2. In this paper, we assume a quadratic form for both stocks, thus $\omega_2 = 1$. The remaining choice of ω_1 does not affect the steady state of the model; therefore, it must be chosen using the volatilities of capital and durables in the data as a guide. The parameters of the three sectors' production functions are also calibrated using the ratios in Table 1 as a guide as well as additional ratios, such as the ratio of durables consumption to total real personal consumption. Based on NIPA tables of real GDP and real personal consumption expenditures, these parameters are calibrated for the Home country to give household durables consumption of 14% of total household consumption expenditures and 10% of Home's output. The capital share of the energy sector is also calibrated to be higher than the average value of 0.36 usually found in the literature, meaning that the energy sector is more capital intensive. Additionally, the calibration of these parameters depends to a great extent on the equilibrium dynamics of the system, and they are chosen so that the model produces a stable equilibrium.

The parameters for the convex cost function of the energy sector, ω_{e1} and ω_{e2}, are calibrated to produce low price elasticities of energy supply for both Home and Foreign. However, their choices are constrained by the volatility of various energy-related variables, such as household and producer energy consumption and energy output, and by the equilibrium dynamics of the model. Parameter values that yield a very low price elasticity of energy supply result in excess volatility of these variables and often cause the model to have no stable equilibrium. We choose a quadratic function for the convex cost, where

$\omega_{e2} = 1$ for both Home and Foreign, and $\omega_{e1} = 23$ for Home and 2.8 for Foreign.

The elasticity of substitution between domestic and imported goods (for both durables and non-durables, $\frac{1}{1-\rho_{d/n}}$) is set at 1.5, following Bodenstein et al. (2011) and standard literature, and is identical for both Home and Foreign countries. The shares of domestic goods in the composite durables (α_d) and non-durables (α_n) are set to produce an export share of approximately 14% of output, an import share of 17 - 18% of output, and an overall trade deficit of 3 - 4% of output for the Home country (following U.S. trade data obtained from the U.S. Census Bureau, Foreign Trade Division). The Home country is also calibrated to produce half of its total energy consumption, which corresponds to the current energy situation of the U.S.

The model is solved for its steady-state, and an approximate solution to the model is found by linearizing the equilibrium conditions around the steady-state using the first-order perturbation method of Schmitt-Grohe and Uribe (2004).

4 Cyclical Properties

Table 1 compares the relative volatility of various aggregates to output of the model and U.S. data. The empirical ratios were calculated from Dhawan and Jeske (2008), which was also used initially for reference and calibration, except for the trade ratio, which was taken from Backus and Crucini (2000).

Variables	**Model**	**U.S. data**
Output	1	1
Consumption	0.66	0.80
Nondurables consumption	0.56	0.52
Investment	3.13	3.06
Hours	0.50	0.96
Household's energy consumption	1.36	1.34
Trade ratio	4.48	3.96

Table 1: The relative volatility of aggregates to output.

These relative volatilities illustrate the cyclical properties of the model that broadly reflect the cyclical patterns of the U.S. economy. Both consumption and consumption of non-durables are less volatile than output, though consumption is slightly less volatile in the model than in the data. Household energy consumption and investment are more volatile than output, and these come close to matching their empirical values. The model does less well reflecting hours worked, as the relative volatility of hours worked in the model is substantially lower. A possible source of this low volatility concerns the frictionless movement of labor among the three sectors in the model. By making the relocation of labor more difficulty/costly, labor movements might be made more realistic, which might help bring up the volatility of total labor. The model also captures a trade aspect of the business cycle in that the trade ratio (value of exports over imports) is more volatile than output, even though in the model this ratio is slightly more volatile than in the data.

The presence of an energy sector produces an energy price that is endogenous, and the model produces energy price dynamics that come quite close to that found in the data. Table 2 shows the relative volatility of energy price to output and energy price-output correlation. For comparison, we present the same quantities calculated from Kim and Loungani (1992) in column 3. From the data it is found that energy price is highly volatile, its percent standard deviation is several times that of output, and that its correlation with output is negative. We can see that the model captures reasonably well these features of energy price dynamics. Kim and Loungani (1992) calculated the ratio of percent standard deviation of energy price to that of output to be 6, and their correlation to be -0.44 using annual data. This model puts these two values at 6.76 and -0.48, respectively, calibrated at quarterly frequency.

	Model	**Kim and Loungani (1992)**
Energy price-output	6.76	6.02
Energy Price-Output Corr	-0.48	-0.44

Table 2: Energy Price Dynamics: row 1 shows the relative standard deviation of energy price to output, row 2 displays the correlation between energy price and output.

5 Shocks to the Energy Market and External Balances

5.1 Adverse Foreign Energy Supply Shock

While this shock has been mostly modeled as a direct shock to energy/oil price, here we can model a more realistic energy supply shock with a negative shock to the productivity of the Foreign energy sector, scaled to induce a 10% increase in energy price.

This shock has a recessionary impact on Home. The increase in energy price causes an input cost shock to the producers and a negative income effect on the household, leading to a contraction in the business cycle. Though the figures are not shown here, Home's output shrinks by 1%, consumptions, investments, and factor prices all decrease. Because energy is needed to consume durables, a higher energy price pushes up the effective price of durables, causing demand for durables to decline more than that for non-durables. Home's durables sector is thus the hardest hit among the three sectors.

As energy is highly complementary with durables/capital, Home's energy use is very price inelastic. As a result, the higher energy price leads to only a small decline in Home's energy use (0.8%, figure 1a), similarly to Bodenstein et al. (2011) in the near Leontief case (0.6%). Home's energy import declines more than twice as much as energy use in percentage terms (2%), because Home's energy supply is also very price inelastic (Home's energy output increases by just 0.3%) and Home's energy import is half of its energy demand.

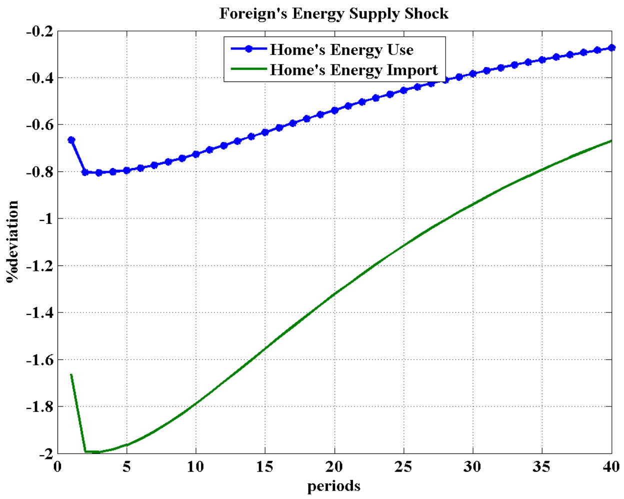
Concerning the external sector, given the price inelasticity of Home's energy import, Home's energy trade balance deteriorates by approximately 8% (figure 1b), which translates to 1% of output for a 50% increase in energy price, which is a similar result to that observed in Bodenstein et al. (2011). However, in contrast to Bodenstein et al. (2011), the non-energy trade balance improves by nearly 15%, causing the overall trade balance to improve by nearly 3%. Translating to a 50% price increase, this means an improvement in the overall trade balance of close to 0.16% of GDP, while Bodenstein et al. (2011) observe a significant overall trade balance deterioration of over 1.5% of GDP. However, it can be observed that the deterioration in the energy trade balance is more persistent than the non-energy trade balance, which deteriorates after 10 quarters. This causes the gain in the total trade balance to last only for the first 5 quarters. The responses are in line with those in Kilian et al. (2009), which reported a small and short-lived oil trade deficit and a non-oil trade surplus. Even though the responses are either small or not significant in Kilian et al. (2009), it should be noted that the estimated oil supply shock in the study is small and leads to a smaller oil price increase, while in this paper, we induce a 10% increase in energy price.

The large non-energy trade surplus is spurred in part by a decline in Home's terms of trade, which makes Home's imports more costly. Even though this also causes a decrease in the value of Home's exports, the decline in Home's imports more than compensates. In Bodenstein et al. (2011), a 50% increase in energy prices leads to a 6% deterioration in Home's terms of trade under the Leontief case, while in our framework, Home's terms of trade deteriorate by 3% following the same price increase. The contrast with Bodenstein et al. (2011) in terms of the response of the non-energy trade balance is due to the fact that in Bodenstein et al. (2011), the Home country's non-oil trade responds much more slowly to the declining terms of trade due to the presence of adjustment costs that cause non-oil goods demand to respond gradually to changes in the relative price of imports.

The composition of Home's non-energy trades further explains the improvement in Home's non-energy trade balance. Figure 1c shows that the response of Home's durables imports is a lot more volatile than that of Home's non-durables imports: Home's durables imports decrease by more than 5% in the 2^{nd} quarter, while non-durables imports decline by a little more than 1%. Much of the improvement in Home's non-energy trade balance, therefore, comes from this sharp fall in durables imports. And yet, because the relative price of durables imports increases by approximately the same percentage as the relative price of non-durables imports (figure not shown), the increasing price of foreign durables cannot explain the sharp decrease in Home's durables imports. The decline in Home's terms of trade thus does not adequately explain the response of Home's non-energy trade balance. Rather, the explanation lies in the energy dependent nature of durables and direct influence of energy price. A higher energy price causes a greater contraction in

Home's durables demand, and this, rather than the declining terms of trade, leads to a large decrease in Home's durables imports. Consequently, energy price plays a significant role in influencing the flow of durables trade, and the impact of this energy price shock on Home's non-energy trade balance extends beyond the usual channel of the terms of trade.

For the Foreign country, as it is the energy exporter, the responses of its external balances mirror those of the Home country.



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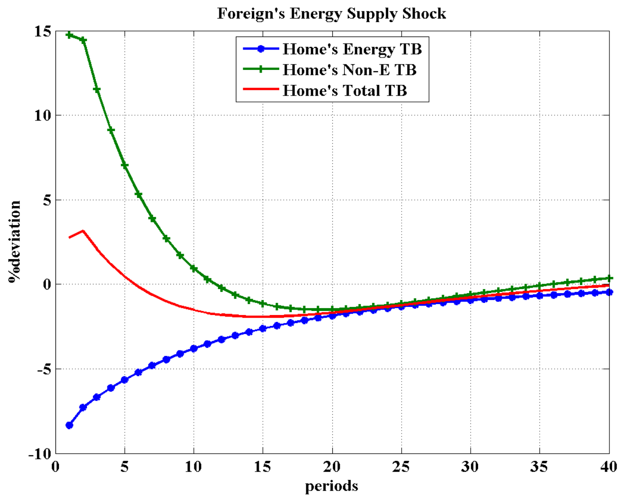

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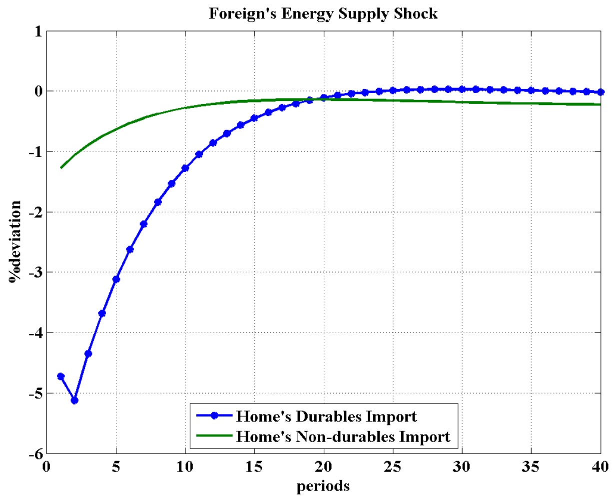

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Figure 1: Impulse responses to a negative shock to the Foreign's energy productivity, scaled to produce a 10% increase in energy price.

5.2 Productivity Booms

We now turn to the case where an energy price increase is demand-driven. As Kilian (2008) has noted, demand shocks to the energy market might have very different effects from energy supply shocks as they might affect the economy through channels other than energy price alone. The time paths of energy price increases might exhibit different characteristics from the case of a simple supply shock. In an example cited by Kilian et al. (2009), a rise in global demand for commodities brought about by a productivity shock might have a stimulating effect on the energy importing country even though the shock also raises the price of energy. In this case, the negative income effects produced by higher energy prices might be considerably or entirely offset by the underlying expanding business cycle. Our framework allows for this type of energy price shock to be investigated by causing a positive innovation to the productivity of the non-energy sectors. Through this productivity boom, the world economy goes through an expansion and the demand for energy rises. This shock can thus be compared to the case of an aggregate demand shock, such as in Kilian et al. (2009), in terms of external balances.

Here we compared two cases: a productivity boom in the Home country, and a boom of similar magnitude in the Foreign country. In both cases, energy price increases, but the overall effects of these shocks on the two economies are very different from the case of an energy supply shock. Focusing on Home, the effects are beneficial despite the higher energy price: output, consumption, investments, and factor prices increase. Higher energy prices here are a response to higher demand for energy throughout the economy. Producers employ more capital for their production, and the household utilizes and consumes more durables. This result is clearly observed in Figure 2a for the Home productivity boom, where Home's energy use rises by 0.4% and Home's energy import increases by nearly 1% at its peak during the 10^{th} quarter. The case of a Foreign productivity expansion displays slightly different dynamics for Home's energy use (and energy import). The initial impact of the higher energy price causes Home's energy use to decrease. However, as the positive spillovers from the Foreign expansion take hold, Home's energy use eventually rises above its steady-state value after the 10^{th} quarter. Energy import follows the pattern of energy use and displays a stronger response in percentage terms.

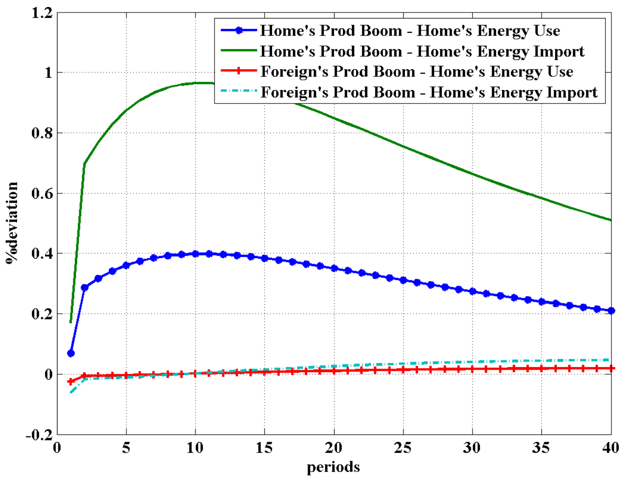
Figure 2e shows the contrast in the time paths of energy price responses for these two productivity booms and the energy supply shock described in Section 5.1. The energy supply shock in Section 5.1 produces an energy price increase that is less persistent than either energy price increase caused by the productivity booms in this section. This is because when there is an energy supply shock, the higher energy price and contraction in the business cycle reinforce each other and quickly depress energy demand thereby easing the pressure on energy price. Conversely, the productivity expansions in this section overcome the demand-slowing effect of higher energy prices not only causing energy demand to rise but also sustaining it. As a result, the increases in energy price display higher persistence in response to productivity-led expansions in the business cycle.

Turning to Home's external sector, the increases in energy price in response to these two productivity booms are more persistent, and Home experiences higher energy import. Therefore, the energy balance registers a larger (in terms of energy price elasticity) and more persistent deterioration than in the case of an energy supply shock (Figures 2b and c). In response to economy-wide productivity expansions, therefore, the behavior of the energy trade balance is rather different in both the magnitude and persistence of the deterioration compared to an energy supply shock.

The responses of Home's non-energy and total trade balances are also quite different from those described in Section 5.1. Home productivity boom causes a sharp, relatively short-lived deterioration in the total trade balance lasting approximately 6 - 7 quarters, while Foreign productivity expansion produces a large, persistent improvement. By comparison, Kilian et al. (2009) reported a marginally significant trade deficit. These differences are largely determined by the response of the non-energy trade balance. Home productivity expansion causes its non-energy trade balance to deteriorates by nearly 8% during the 2^{nd} quarter. Foreign productivity expansion, however, causes Home's non-energy trade balance to improve by nearly 4.5% by the 2^{nd} quarter.

Trade in durables and nondurables in turn provides insight into the responses of Home's non-energy trade balance. When productivity expands in the Home economy, even though it experiences a decline in the terms of trade, Home's durables imports still rise sharply (peaking at 3.5%) due to the higher demand for capital and durables investments (Figure 2d). Home's imports of non-durables decrease, but by a much smaller percentage, as do Home's exports (not shown). The result is that Home's durables imports dominate the non-energy trades and Home's non-energy trade balance deteriorates. When the productivity expansion occurs abroad, Home's terms of trade improve. This causes Home's imports to rise; however, Home also exports more durables because the Foreign economy demands more durables. This sharp increase in Home's durables exports dominates, and we see a large improvement in Home's non-energy trade balance.

The main distinction with Section 5.1 stems from the fact that with these two shocks, the direct channel of energy price is offset by the greater momentum of the expanding business cycle, so that the influence of energy price on durables trade is muted (shown by the increases in Home's durables imports despite the higher energy price). In Section 5.1, conversely, the larger increase in the price of energy relative to durables and non-durables indicates a much larger influence of energy price on both the durables trade and non-energy trade balance.



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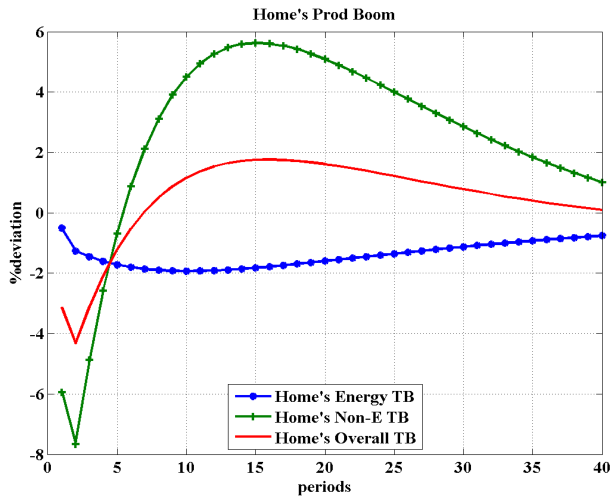

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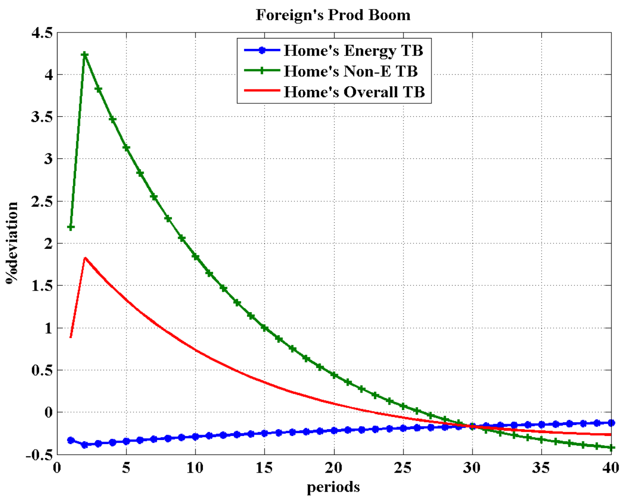

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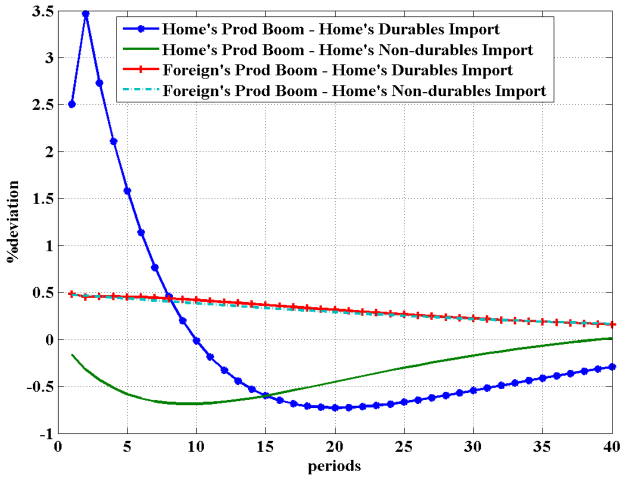
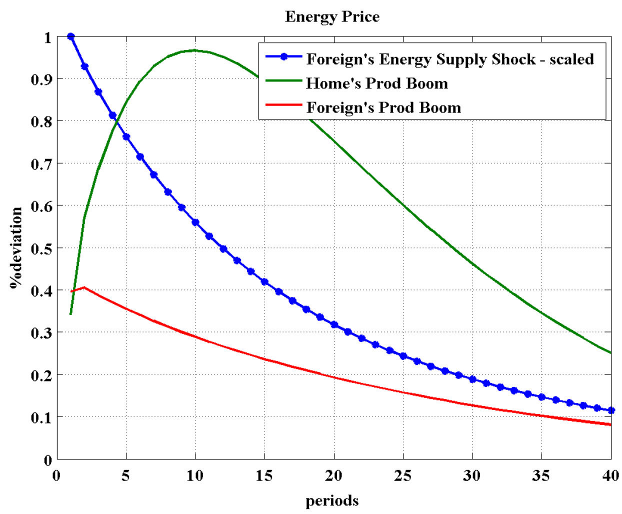




(e)

Figure 2: Impulse responses to Home's and Foreign's productivity boom.

5.3 Energy Market Specific Demand Shocks

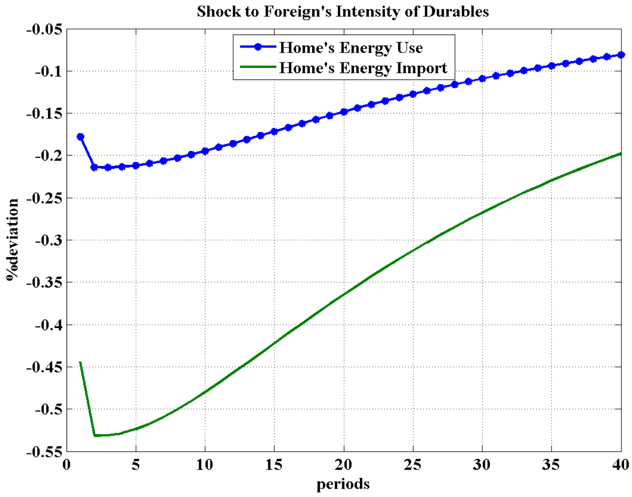
5.3.1 Shock to Foreign's energy intensity of durables

This section addresses a demand shock specific to the energy market, mirroring the oil-market specific demand shock analyzed in Kilian et al. (2009) and in Bodenstein et al. (2011). In Bodenstein et al. (2011), a preference shock increases the marginal productivity of oil in the Foreign household utility function, causing the Foreign household to need more oil. Here, we model this shock in the form of an exogenous shock to the Foreign household energy demand function (according to equation 7), which raises the effective energy intensity of durables for the Foreign household. This shock causes the Foreign household to need more energy for a given stock of durables thus representing a demand shock specific to the energy market.

This shock has a direct negative income effect on the Foreign household, because it is now more costly to operate its stock of durables. The immediate effect is that the Foreign household tries to reduce its durables stock as well as its durables utilization rate. However, given the inelastic nature of energy use, the reduction in utilized durables cannot offset the rise in the energy intensity of durables. The result is a higher demand for energy from the Foreign household and a higher energy price. For Home, this higher demand for energy from abroad has an adverse impact on its economy that is qualitatively similar to the energy supply shock considered in Section 5.1. The convex cost of energy production is important here as it ensures that Home cannot freely expand its energy sector to meet the higher demand. For a 20% increase in the Foreign household's energy demand, energy price rises by 2.7% and Home's output decreases by 0.28% (not shown). Compared to an energy supply shock, this demand shock has a similar effect on Home's output in terms of output-energy price elasticity. Home's energy use and import also decline, with similar elasticities to Section 5.1 (figure 3a).

The responses of Home's external balances show slight qualitative differences from the case of an energy supply shock (figure 3b). The energy trade balance still deteriorates with similar persistence and magnitude (in terms of energy price elasticity), but the non-energy trade balance does not improve upon impact, only reaching its peak in the 2nd quarter. Moreover, peak improvement in the non-energy trade balance is only one and a half times the largest deterioration of the energy trade balance in percentage terms compared to almost two times in Section 5.1. This delayed and smaller response of the non-energy trade balance means that there is an initial sharp worsening of the total trade balance. Subsequently, during the 2nd quarter, the overall trade situation for Home improves but it also quickly worsens for the rest of the 10-year horizon. Qualitatively, the results are similar to Kilian et al. (2009) and Bodenstein et al. (2011) in that an overall trade deficit was recorded, and the energy balance shows a similarly persistent and significant deficit. The model, however, gives a response of the non-energy trade balance that is closer to the estimated response in Kilian et al. (2009), which reported a statistically insignificant non-oil trade surplus, while Bodenstein et al. (2011) showed a non-oil trade deficit. Again, the non-oil deficit reported in Bodenstein et al. (2011) comes from the slower adjustment of non-oil trades to changes in the terms of trade.

The decomposition of Home's non-energy trades emphasizes the essential role of trade in durables in determining the response of the non-energy trade balance. From the perspective of Home, this shock's impact is similar to that of an energy supply shock, reflected in Home's similar responses in energy usage and import as well as non-energy imports (Figure 3a and c). However, this shock impacts the Foreign economy in different ways than an energy supply shock. It causes a greater increase in the effective energy cost of durables consumption for the Foreign household than the energy supply shock does. The explanation is as follows. An energy supply shock causes the energy cost of durables usage to increase by the amount of the resultant energy price increase alone. This shock, however, causes the energy cost of durables usage to increase by the combined amount of the energy price increase *and* the higher energy intensity of durables. Consequently, Foreign's durables demand is more severely affected by this shock in terms of energy price elasticity. The greater impact of this shock on Foreign's durables demand directly influences its non-energy trade response. Figure 3d, which compares Foreign's responses in non-energy imports between this shock and the energy supply shock, shows that Foreign's durables imports suffer a larger decrease in response to this shock (in terms of energy price elasticity) despite the fact that Home's terms of trade deteriorate more in response to this shock than to the energy supply shock (not shown). This pattern demonstrates the larger decrease in Foreign's demand for durables in response to this shock. Therefore, for Home, its exports suffer more, despite the fact that its goods are cheaper. The result is a smaller improvement in Home's non-energy trade balance than in the case of an energy supply shock.



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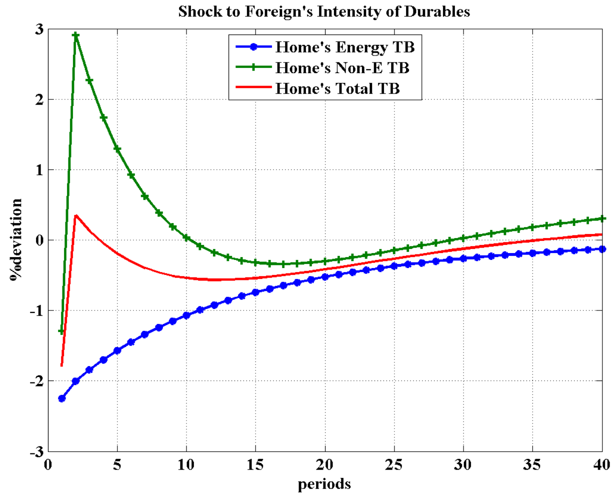

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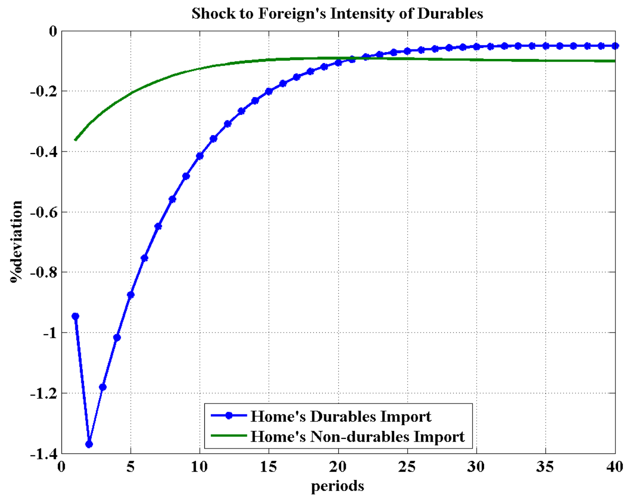

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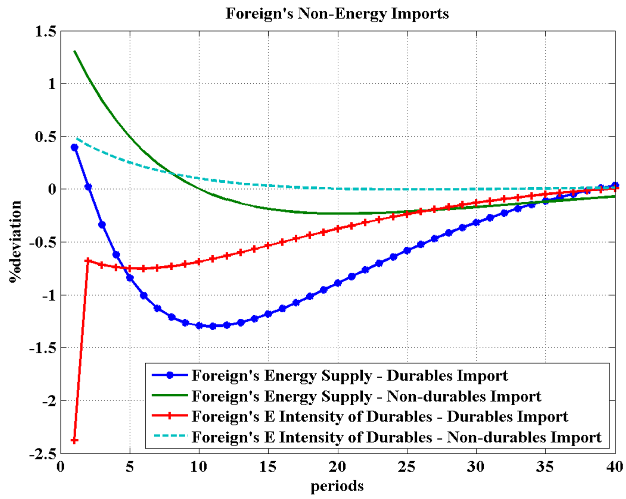


(d)

Figure 3: Impulse responses to a 20% innovation to Foreign's energy intensity of durables.

5.3.2 Preference Shock

Another interpretation of an energy market specific demand shock comes in the form of a preference shock to durables consumption. Whether this is strictly an energy market specific shock is debatable because this shock to energy demand comes from a shock to demand for energy-dependent goods. The example cited in Kilian et al. (2009) of a shift in Chinese tastes from bicycles to motorcycles and cars illustrates this debate, because clearly, the demand for more energy comes about as a result of a preference shift towards consumption of more durables or durables of higher value (cars vs. bicycles). Here, we consider what happens when the tastes of Foreign households shift towards durables through the following preference shock to the consumption of the Foreign household:

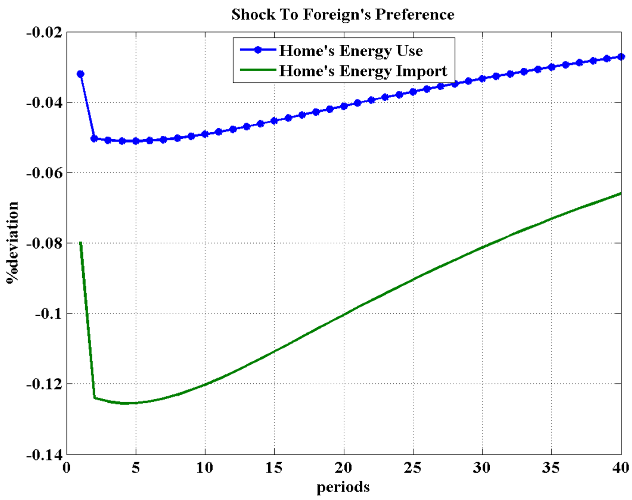
$$c_t = [\alpha^{1-\rho}(u_t \frac{d_t}{\mu_{p,t}})^\rho + (1-\alpha)^{1-\rho} {n_t}^\rho]^{1/\rho}$$

where $\mu_{p,t}$ is an AR(1) process with mean 1. When there is a positive innovation to $\mu_{p,t}$, this raises the marginal productivity of durables for the Foreign household such that Foreign's demand for durables increases.

Given the energy dependence of durables, this change represents a shock to energy demand. The price of energy increases due to higher demand for energy from the Foreign household but through a slightly different mechanism. This higher energy demand is coupled with a higher level of durables stock in the Foreign household. The Foreign household responds by reducing the utilization rate of its durables, but because the response is energy price inelastic, the result is still a higher utilized durables stock and higher household energy consumption. The main difference from the shock in Section 5.3.1 is the way the Foreign household rebalances its portfolio of capital and durables stocks: this preference shock causes the household to augment its durables stock while reducing its capital stock. The opposite pattern is observed in Section 5.3.1.

This preference shock has similarly adverse effects on Home as a shock to Foreign's energy intensity of durables: energy price rises, and Home's output drops. The higher energy price leads to lower energy usage and energy import, which again exhibits a larger decrease in percentage terms (Figure 4a). The responses of the trade balances also come close to Kilian et al. (2009) in this shock (Figure 4b). The energy trade balance registers a similarly persistent deterioration as in Section 5.3.1, and the total trade balance shows an overall deterioration. The distinction with Section 5.3.1 is determined by the response of the non-energy trade balance and originates in the more volatile response of trade in durables, as expected. In response to this preference shock, Foreign's non-energy prices increase more dramatically relative to Home's non-energy prices as the shift in Foreign's durables demand amplifies the increase in Foreign's durables prices. This has two effects. The first is a larger deterioration in Home's terms of trade (not shown). The second is that the income effect on the Foreign household is also more severe. The result is that, compared to the shock in Section 5.3.1, even though Home's imports decline more (Fig 4c), Foreign's durables imports also decline considerably more after the 1st quarter in terms of energy price elasticity (Fig 4d). Consequently, Home's non-energy trade balance registers a persistent deterioration after the 1st quarter.

The implication of the results of these two specific demand shocks is that even though these shocks cause energy price increases that are mostly identical to the increase caused by an energy supply shock, the non-energy trade balance for the Home country responds differently. The reason is that these shocks affect the Foreign country differently, especially in terms of durables demand, and have a different impact on Home's durables exports. We show thus that the time path of the energy price increase is not the only factor in determining the responses of the trade balances in contrast to the conclusion of Bodenstein et al. (2011) that only the time path of the energy price increase matters for the trade balances of the energy importing country. These two shocks also show again the more immediate influence of energy price on the non-energy trade balance, which is observed through the volatile nature of trade in durables. Energy price shocks are thus transmitted to non-energy trade responses by more than the usual terms of trade channel.



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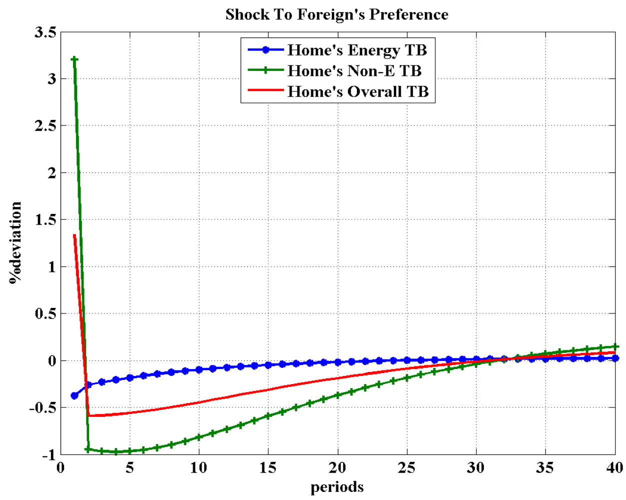

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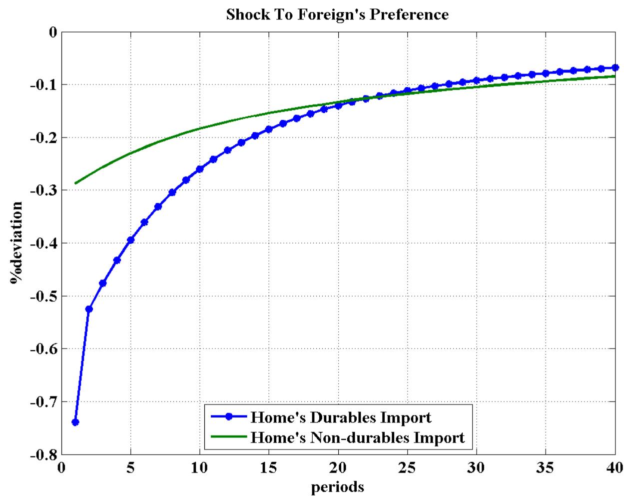

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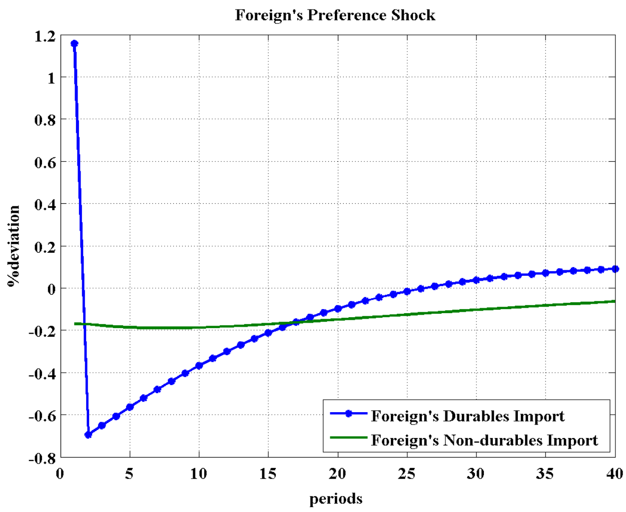

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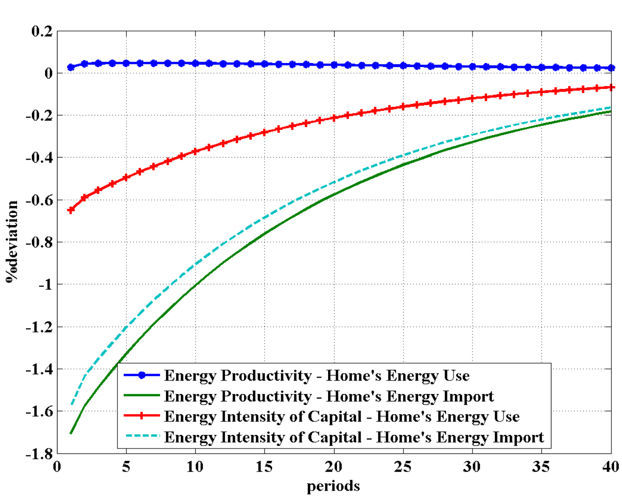
Figure 4: Impulse responses to a shock to Foreign's preference.

6 Energy Boom in the Home Country

The U.S. is widely anticipated to become a net energy exporter over the next 15 to 20 years thanks to its shale gas boom. What would the effects of progress in energy extracting or processing technology on the Home country be? In this framework, we could address this question by implementing a positive shock to Home's energy sector and analyzing its effects. There are two ways to model this shock: an exogenous increase in the productivity of Home's energy sector or an exogenous, persistent shock to the energy demand of Home's energy sector (according to equation 9). The former is a straightforward supply shock to energy output, while the latter is a demand shock to the energy market, but since it affects the effective energy intensity of capital in the energy sector, this shock could affect energy supply. We introduce an innovation to the energy demand function of Home's energy sector in one case (case 6.a), so that the effective energy intensity of capital in Home's energy sector decreases by 20%, and an increase in the productivity of Home's energy sector in the other (case 6.b). The increase in productivity of Home's energy sector is calibrated so that both cases produce a reduction in energy prices of the same magnitude. Both shocks are modeled as temporary but persistent shocks.

Though the nature of each shock differs somewhat, their impacts on Home's internal sector are similar. In both cases, a lower energy price stimulates Home's economy. Home's durables sector benefits from the lower energy price and expands. The lower energy price lowers the cost of using durables and capital, producing a positive income effect on the household and a lower total marginal cost of capital. This reduction stimulates investment in energy-dependent goods (durables and capital) and results in a higher utilization rate of the household's durables stock (figures not shown). The result is higher household energy usage and a higher stock of capital. The durables sector benefits the most from this shock, and contributes the most to Home's economic expansion as a lower energy price boosts the sector's supply as well as demand for its goods.

What we have then is a difference in how Home's energy usage is realized in response to the two shocks, as Figure 5a shows. In case 6.a, Home's energy usage decreases; the lower energy demand coming from the energy sector offsets the higher energy use from the household and the other sectors. In case 6.b, since there is no shift in energy demand from the energy sector, Home's overall energy demand rises. In both cases, a large decrease in Home's energy import occurs. What this means for Home's energy balance is that both cases produce a similar significant improvement (Figures 5b and c) due to both a lower energy price and a reduction in energy import. The non-energy balance deteriorates by a similar amount in both cases due to the large increase in durables imports (Figure 5d) as the lower energy price stimulates Home's durables demand to a greater extent than non-durables. This sensitivity of trade in durables to energy price again determines the behavior of the non-energy trade balance. The result is little movement in the total trade balance in either case.



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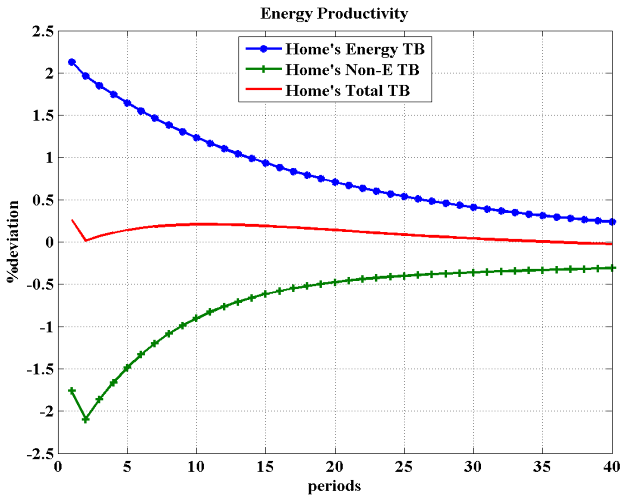

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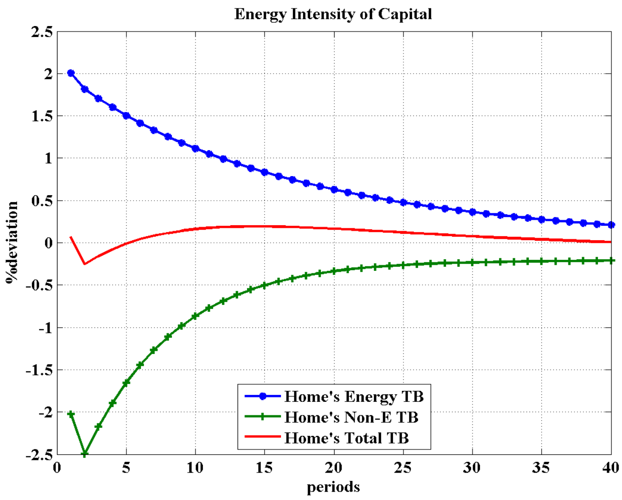

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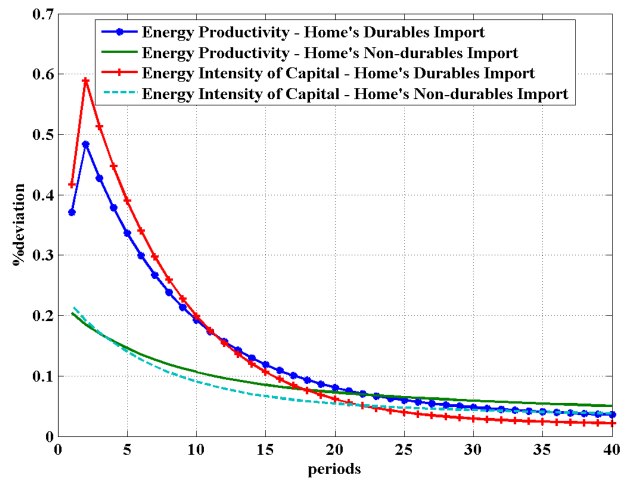

(d)

Figure 5: Impulse responses to Home's energy boom.

Through a lower energy intensity of capital in the energy sector, we arrive at a lower energy price that stimulates the economy and at the same time achieve lower overall energy consumption thanks to the reduced energy demand of the energy sector itself. A more abundant energy supply, as interpreted in this framework, is also beneficial to the economy, but such expansion in energy output also means that more energy is consumed.

These shocks are less beneficial to the Foreign economy, however. In either case, the decrease in energy price has an adverse effect on Foreign's energy sector, which is reduced in size. Though the lower energy price also benefits its household and its non-energy sectors, the effect on its energy sector is larger than the expansion in the other two sectors. The result is that Foreign's output shrinks, though by a rather small percentage.

7 Sensitivity Analysis

In this section, we examine the robustness of the model with respect to the calibration of a couple of important parameters. We investigate whether and how the dynamic properties of the model change when we adjust Home's elasticity of substitution between domestic and foreign goods ($\frac{1}{1-\rho_{d/n}}$). In addition, given the important role of durables in producing the results, we vary the elasticity of substitution between Home's durables and non-durables ($\frac{1}{1-\rho}$) and observe the impact on the dynamic responses of the model. Overall, this analysis demonstrates the robustness of the model with regard to these two parameters. The dynamic responses of the macro variables change quantitatively but not qualitatively when the values of the two parameters are varied, and the change occurs in the direction that is expected based on the roles of these two parameters in the model.

7.1 Home's foreign-domestic goods elasticity of substitution

Figures 6a, b, and c show the responses of Home's trade balances to a Foreign energy supply shock at three values of this elasticity ($\frac{1}{1-\rho_{d/n}}$): 1.2, 1.5 (baseline), and 1.8 (other shocks show similar variations in the responses of Home's trade balances). A higher value of the elasticity means that the Home household is more willing to substitute for domestic goods when the prices of foreign goods rise (as in the case of Foreign adverse supply shock and specific demand shock), and accordingly Home's non-energy imports decrease further (Fig. 6a). The result is a larger improvement in the non-energy trade balance (Fig. 6b). Even though the energy trade balance deteriorates more at higher values of this elasticity, the effect on Home is a larger improvement in its total trade balance during the first 6 quarters (Fig. 6c). This movement in Home's total trade balance, as seen in Fig.6c, occurs because the response of Home's total trade balance is sensitive to the relative proportions of its energy and non-energy trade balances, which can be changed by varying the elasticity. However, the distinct impact of this shock (and indeed of other shocks) is preserved in response to small changes in the value of the elasticity, such as the deterioration observed in the energy trade balance and the qualitative response of the non-energy trade balance.

7.2 Home household's durables-non-durables elasticity of substitution

Figures 6d, e and f show the responses of Home's trade balances to a Foreign energy supply shock at three values of this elasticity ($\frac{1}{1-\rho}$): 0.95, 0.99 (baseline), and 1.1 (again, the other shocks show similar variation in the responses of Home's trade balances). Intuitively, when this elasticity increases, we expect the impact of energy price fluctuations on the consumption and trade of durables to be more pronounced as the Home household is more willing to substitute for non-durables when the relative price of durables increases. This substitution should lead to a stronger decrease in Home's durables imports and a larger improvement in Home's non-energy trade balance, which are shown in Figure 6d and e. Figure 6e also shows that as the elasticity goes from 0.99 to 1.1 (so that ρ changes sign from negative to positive, meaning that durables and non-durables switch being complements to being substitutes), the response of the non-energy balance moves quite significantly. At the same time, Home's energy trade balance deteriorates more at higher values of this elasticity due to higher Home's energy use and import (not shown). The result is that Home's total trade balance shows greater deterioration (Fig. 6f). This deterioration is due mostly to the fact that as durables imports fall while energy import rises, the relative proportion of the non-energy trade balance in Home's total trade balance decreases. Thus, even though Home's non-energy trade balance improves by a greater percentage than does the energy trade balance, the overall effect is still an increase in the deficit of Home's total trade. The qualitative signature of the shock, however, remains. The same pattern applies to the other shocks analyzed in this paper.

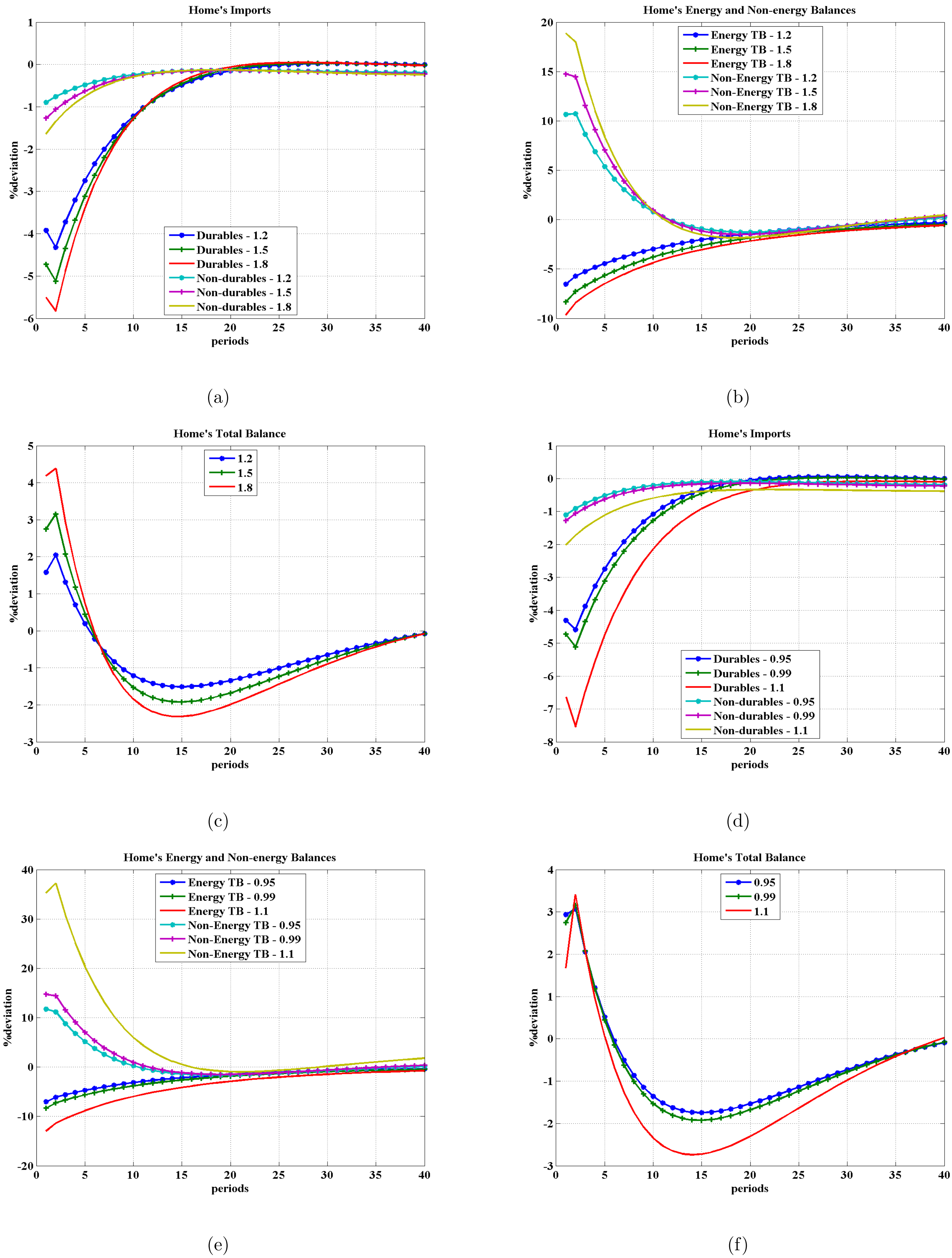

Figure 6: Sensitivity analysis: a b, c: changes in $\frac{1}{1-\rho_{d/n}}$; d, e, f: changes in $\frac{1}{1-\rho}$

8 Conclusion

This paper extends the analysis of energy price shocks on external balances to a number of supply and demand shocks to the energy market in a two-country model comprising multiple sectors and endogenous energy production with convex costs. Convex costs of energy production help produce a low energy price elasticity of energy supply, bringing energy price and production dynamics closer to the data. The explicit modeling of durables and non-durables allows insights into the composition of the non-energy trade balance in response to these diverse energy price shocks.

Our theoretical investigations show that, in line with Kilian et al. (2009), different shocks to the energy market trigger distinct responses of the external trade balances of the energy importing and energy exporting countries. The response of the non-energy trade balance plays a crucial role in determining the dynamics of the overall trade balance. We distinguish the different sources of the energy price increases by tracing their diverse responses back to the nature of the shocks. We show how the volatile nature of durables trade contributes most to differentiate these responses through the large impact of energy price on durables. Our results reinforce the need to look beyond energy price to the sources of energy price shocks, especially in the formulation of appropriate policy responses.

We also demonstrate and compare the two different ways that the energy importing countries could experience an energy boom and how they both could boost the domestic economy, expanding its output and its durables sector. The two cases demonstrate similar responses from the energy importer (Home). The Home economy receives a boost, especially in the durable sector, while its energy trade balance improves. The overall trade balance, however, moves little due to the deterioration of the non-energy trade balance.

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Tables

Moments	**Values**
E_h/Y	0.0456
I_d/Y	0.0932
D/Y	1.3668
E_f/Y	0.0517
K/Y	12.000
H	0.3000

Table 3: Targeted Ratios

The aggregates present in Table 1[3] are real GDP (Y), household's and production energy usages (E_h and E_f respectively), durables consumption (I_d), durables and capital stock (D and K), and labour (H). They each have a broadly corresponding theoretical counterpart in the model of Dhawan and Jeske (2008). Since in these variables our model matches the model of Dhawan and Jeske (2008) quite closely, these ratios provide good empirical bases with which to calibrate the theoretical moments of these variables in our model.

[3] Dhawan and Jeske (2008)

Appendix

A Equilibrium Conditions

Household's first order conditions

Euler equation for durables

$$(1-\alpha)^{1-\rho}\tfrac{p_{d,t}}{p_{n,t}}c_t^{-\rho}n_t^{\rho-1}\left(1+\tfrac{\omega_{d1}}{d_t}\left(\tfrac{d_{t+1}-d_t}{d_t}\right)^{\omega_{d2}}\right)=\beta E\alpha^{1-\rho}c_{t+1}^{-\rho}(u_{t+1}d_{t+1})^{\rho-1}u_{t+1}$$
$$+\beta E\tfrac{(1-\alpha)^{1-\rho}}{p_{n,t+1}}c_{t+1}^{-\rho}n_{t+1}^{\rho-1}[-ap_{e,t+1}u_{t+1}+p_{d,t+1}\left(1-\delta_{d,t+1}+\tfrac{\omega_{d1}d_{t+2}}{d_{t+1}^2}\left(\tfrac{d_{t+2}-d_{t+1}}{d_{t+1}}\right)^{\omega_{d2}}\right)]$$

Euler equation for capital

$$\tfrac{p_{d,t}}{p_{n,t}}c_t^{-\rho}n_t^{\rho-1}\left(1+\tfrac{\omega_{k1}}{k_t}\left(\tfrac{k_{t+1}-d_t}{k_t}\right)^{\omega_{k2}}\right)=$$
$$\beta E\tfrac{c_{t+1}^{-\rho}n_{t+1}^{\rho-1}}{p_{n,t+1}}[r_{t+1}+p_{d,t+1}\left(1-\delta_k+\tfrac{\omega_{k1}k_{t+2}}{k_{t+1}^2}\left(\tfrac{k_{t+2}-k_{t+1}}{k_{t+1}}\right)^{\omega_{k2}}\right)]$$

Euler equation for foreign bond

$$\frac{c_t^{-\rho}n_t^{\rho-1}}{p_{n,t}}\left(1+\omega_{B1}\left(B_{t+1}-\bar{B}\right)^{\omega_{B2}}\right)=\beta E\frac{c_{t+1}^{-\rho}n_{t+1}^{\rho-1}}{p_{n,t+1}}[1+r_B]$$

Intra-temporal nondurables-labor

$$(1-\alpha)^{1-\rho}\frac{\varphi}{1-\varphi}(1-h_t)c_t^{-\rho}n_t^{\rho-1}=\frac{p_{n,t}}{w_t}$$

Intra-temporal nondurables-utilization

$$\frac{(1-\alpha)^{1-\rho}}{\alpha^{1-\rho}}\frac{n_t^{\rho-1}}{(u_td_t)^{\rho-1}}=\frac{p_{n,t}}{ap_{e,t}+p_{d,t}\delta_{d,t}'}$$

with

$$c_t=[\alpha^{1-\rho}(u_td_t)^{\rho}+(1-\alpha)^{1-\rho}{n_t}^{\rho}]^{1/\rho}$$

Budget constraint

$$p_{e,t}au_td_t+p_{n,t}n_t+p_{d,t}i_{d,t}+p_{d,t}i_{k,t}+i_{B,t}=w_th_t+r_tk_t+r_BB_t$$

Investment adjustment costs and variable depreciation

$$i_{d,t}=d_{t+1}-(1-\delta_{d,t})d_t+\frac{\omega_{d1}}{1+\omega_{d2}}\left(\frac{d_{t+1}-d_t}{d_t}\right)^{1+\omega_{d2}}$$

$$i_{k,t}=k_{t+1}-(1-\delta_k)k_t+\frac{\omega_{k1}}{1+\omega_{k2}}\left(\frac{k_{t+1}-k_t}{k_t}\right)^{1+\omega_{k2}}$$

$$i_{B,t}=B_{t+1}-B_t+\frac{\omega_{B1}}{1+\omega_{B2}}\left(B_{t+1}-\bar{B}\right)^{1+\omega_{B2}}$$

$$\delta_{d,t} = \frac{a_1}{a_2+1} {u_t}^{a_2+1}$$

Firms' production functions

$$y_{e,t} = \exp(A_{e,t})(1-\lambda_{e,t}) k_{e,t}^{\gamma_e} h_{e,t}^{1-\gamma_e}$$

$$\lambda_{e,t} = \frac{\omega_{e1}}{(1+\omega_{e2})} (k_{e,t}^{\gamma_e} h_{e,t}^{1-\gamma_e})^{1+\omega_{e2}}$$

$$y_{i,t} = \exp(A_t) \left(k_{i,t}\right)^{\gamma_i} \left(h_{i,t}\right)^{1-\gamma_i}$$

with $i = d, n$

Firms' first order conditions

$$w_t = (1-\gamma_i) \exp(A_t) \left(k_{i,t}\right)^{\gamma_i} \left(h_{i,t}\right)^{-\gamma_i}$$

$$r_t + b p_{e,t} = \gamma_i \exp(A_t) \left(k_{i,t}\right)^{\gamma_i - 1} \left(h_{i,t}\right)^{1-\gamma_i}$$

with $i = d, n$

$$w_t = p_{e,t} \exp(A_{e,t}) \left((1-\gamma_e)(1-\lambda_{e,t}) \left(\frac{k_{e,t}}{h_{e,t}}\right)^{\gamma_e} - \lambda'_{e,t} k_{e,t}^{\gamma_e} h_{e,t}^{1-\gamma_e} \right)$$

$$r_t + b_{e,t} p_{e,t} = p_{e,t} \exp(A_{e,t}) \left(\gamma_e (1-\lambda_{e,t}) \left(\frac{k_{e,t}}{h_{e,t}}\right)^{\gamma_e - 1} - \lambda'_{e,t} k_{e,t}^{\gamma_e} h_{e,t}^{1-\gamma_e} \right)$$

Market clearing

$$k_t = k_{d,t} + k_{n,t} + k_{e,t}$$

$$h_t = h_{d,t} + h_{n,t} + h_{e,t}$$

$$y_{d,t} = I_{DD,t} + I^*_{DM,t}$$

$$y_{n,t} = N_{D,t} + N^*_{M,t}$$

Aggregation

$$I_{D,t} = \left[\alpha_d^{1-\rho_d} I_{DD,t}^{\rho_d} + (1-\alpha_d)^{1-\rho_d} I_{DM,t}^{\rho_d}\right]^{1/\rho_d}$$

$$I_{D,t} = i_{d,t} + i_{k,t}$$

$$N_t = \left[\alpha_n^{1-\rho_n} N_{D,t}^{\rho_n} + (1-\alpha_n)^{1-\rho_n} N_{M,t}^{\rho_n}\right]^{1/\rho_n}$$

$$N_t = n_t$$

Prices

$$p_{d,t} = \left[\alpha_d \left(p_{d,d,t}\right)^{\frac{\rho_d}{\rho_d - 1}} + (1-\alpha_d)(ER_t p^*_{d,d,t})^{\frac{\rho_d}{\rho_d - 1}}\right]^{\frac{\rho_d - 1}{\rho_d}}$$

$$p_{n,t} = \left[\alpha_n \left(p_{n,d,t}\right)^{\frac{\rho_n}{\rho_n - 1}} + (1-\alpha_n)(ER_t p^*_{n,d,t})^{\frac{\rho_n}{\rho_n - 1}}\right]^{\frac{\rho_n - 1}{\rho_n}}$$

$$p_t = \left[\alpha \left(p_{d,t} + a p_{e,t}\right)^{\frac{\rho}{\rho - 1}} + (1-\alpha) p_{n,t}^{\frac{\rho}{\rho - 1}}\right]^{\frac{\rho - 1}{\rho}}$$

$$ER_t = \frac{p^*_t}{p_t}$$

Aggregate value added

$$p_t y_t = p_{d,t} y_{d,t} + p_{n,t} y_{n,t} + p_{e,t} a u_t d_t$$

Exogenous shock process

$$A_t = \rho_A A_{t-1} + \epsilon_{u,t}$$

$$A_{e,t} = \rho_e A_{e,t-1} + \epsilon_t$$

B Calibrated Parameters

Parameter	Value	Description
		Home
β_1	0.99	Time preference
φ_1	0.34	Share of consumption in household's utility
α_1	0.2	Share of durables in household's consumption
ρ_1	1 - 1/0.99	Durables-nondurables CES parameter
δ_k	0.025	Capital depreciation rate
a_1	0.06	Param1 of durables depreciation function
a_2	0.3	Param2 of durables depreciation function
γ_{e1}	0.59	Capital share of energy production function
γ_{d1}	0.366	Capital share of durables production function
γ_{n1}	0.336	Capital share of nondurables production function
α_{d1}	0.845	Share of domestic durables in Home's composite durables
ρ_{d1}	1 - 1/1.5	CES parameter between Home's domestic and imported durables
α_{n1}	0.875	Share of domestic nondurables in Home's composite nondurables
ρ_{n1}	1 - 1/1.5	CES parameter between Home's domestic and imported nondurables
ρ_{A1}	0.95	Persistence of non-energy sectors' productivity process
ρ_{e1}	0.95	Persistence of energy sector's productivity process
ω_{k1}	100	Param1 of capital adj. cost function
ω_{k2}	1.2	Param2 of capital adj. cost function
ω_{d1}	100	Param1 of durables adj. cost function
ω_{d2}	1.2	Param2 of durables adj. cost function
ω_{B1}	0.1	Param1 of portfolio adj. cost function
ω_{B2}	1	Param2 of portfolio adj. cost function
ω_{e1}	23	Param1 of energy convex cost function
ω_{e2}	1	Param2 of energy convex cost function
$\bar{B}$	2	Bond target in PAC function
r_B	0.01	World interest rate
a	0.02	Energy-intensity of durables
b	0.006	Energy-intensity of capital
		Foreign
γ_{e2}	0.49	Capital share of energy production function
γ_{d2}	0.378	Capital share of durables production function
γ_{n2}	0.368	Capital share of nondurables production function
α_{d2}	0.822	Share of domestic durables in Foreign's composite durables
ρ_{d2}	1 - 1/1.5	CES parameter between Foreign's domestic and imported durables
α_{n2}	0.822	Share of domestic nondurables in Foreign's composite nondurables
ρ_{n2}	1 - 1/1.5	CES parameter between Foreign's domestic and imported nondurables

Parameter	Value	Description
ω_{e1}	2.8	Param1 of energy convex cost function
ω_{e2}	1	Param2 of energy convex cost function

Table 4: Calibrated Parameters