NBER WORKING PAPER SERIES

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Working Paper 18366
http://www.nber.org/papers/w18366

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
September 2012

I thank Gianluca Benigno, Ariel Burstein, Emmanuel Farhi, Gita Gopinath, Jonathan Heathcote, Chang-Tai Hsieh, Erik Hurst, Oleg Itskhoki, Ellen McGrattan, Jaromir Nosal, Fabrizio Perri, Andrea Raffo, and seminar participants at Brandeis, Brown, Chicago Booth, Columbia GSB, Federal Reserve Bank of Minneapolis, Federal Reserve Board, Harvard, LSE, Penn State, Stockholm IIES, UCLA Anderson, and University of Iowa for useful conversations and constructive comments. Summer financial support from Chicago Booth is acknowledged. The views expressed herein are those of the author and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 18366
September 2012
JEL No. E32,F41,F44,J22

ABSTRACT

This paper explores implications of non-separable preferences with home production for international business cycles. Home production induces substitution effects that break the link between market consumption and its marginal utility and help explain several stylized facts of the open economy. In an estimated two-country model with complete asset markets in which home production generates a labor wedge that mimics its empirical counterpart, output is more correlated than consumption across countries, labor inputs and labor wedges are positively correlated across countries, and relative market consumption is negatively related to the real exchange rate. International time use surveys corroborate predictions of the model, showing a significant relationship between time spent on home production, labor wedges, and real exchange rates, both at business cycle frequencies and in the cross section of countries. By contrast, non-separabilities based on leisure do not help explain variations in labor wedges or real exchange rates.

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1 Introduction

This paper introduces home production in a two-country dynamic stochastic general equilibrium model to explore the role of non-separable preferences for international business cycles. As in this paper, some international macroeconomists have hypothesized that taste shocks and non-separabilities in preferences may help explain the low degree of international risk sharing observed in the data.[1] However, whether such features actually improve the performance of international business cycle models remains an open question, as it has been difficult to interpret, discipline, and test models with non-separable preferences. In this paper, I propose two strategies that discipline the non-separability in preferences induced by home production. I show that the implied restrictions on preferences help explain a number of puzzles in open economy macroeconomics.

The model economy is a frictionless international business cycle model in which each country has a market and a home sector. Goods produced in the home sector enter in a non-separable way in the utility function with goods produced in the market sector. In the home sector, consumers produce home goods with home time and capital, as in Benhabib, Rogerson, and Wright (1991). Home goods are substitutable to domestic market goods, but they are not tradeable in the market. In the market sector, firms produce specialized market inputs with market time and capital, as in Backus, Kehoe, and Kydland (1994, 1995). The two countries trade specialized market inputs and a complete set of financial securities. International business cycles are driven by productivity shocks in the market and the home sector.

The first strategy to discipline the non-separability in preferences builds upon a recent literature in the closed economy that organizes aggregate data in terms of time-varying wedges from the first-order conditions of the neoclassical growth model. Of particular interest to macroeconomists is the behavior of the "labor wedge," which is defined as the gap between the marginal product of labor and the marginal rate of substitution of leisure for market consumption (Hall, 1997; Shimer, 2009). Under this view, successful models of the business cycle – including international business cycle models – must be able to generate volatile and countercyclical labor wedges (Chari, Kehoe, and McGrattan, 2007).

The proposed strategy is to estimate the non-separability in the utility function from the behavior of the labor wedge as measured in the data. Then, I ask whether the two-country model generates business cycles consistent with stylized facts of international data. I estimate

[1] For other models with non-separable preferences or taste shocks, see Devereux, Gregory, and Smith (1992); Stockman and Tesar (1995); Lewis (1996); Canova and Ubide (1998); Heathcote and Perri (2008); Raffo (2010). For alternative approaches to explaining the low degree of international risk sharing, see Baxter and Crucini (1995); Kollmann (1996); Obstfeld and Rogoff (2000); Heathcote and Perri (2002); Kehoe and Perri (2002); Ghironi and Melitz (2005); Corsetti, Dedola, and Leduc (2008); Fitzgerald (Forthcoming).

a high elasticity of substitution between market and home goods, moderately persistent but volatile productivity shocks in the home sector, and highly correlated productivity innovations between the home and the market sector. These parameters allow the model to generate a labor wedge which is as volatile and persistent as the labor wedge measured for several countries. In addition, these parameters allow the model to match the negative correlation of the labor wedge with output and the positive correlation of the labor wedge with market productivity observed in the data.

Under the same parameters that restrict moments of the labor wedge in the model to match moments of the labor wedge in the data, the two-country model is consistent with salient features of international business cycles. The "quantity anomaly" is that, contrary to most theoretical models, market output correlates more than market consumption across countries (Backus, Kehoe, and Kydland, 1995). The model accounts for the "Backus and Smith (1993) puzzle" which states that the correlation between relative market consumption and the real exchange rate is negative in the data, but positive and high in most theoretical models. In addition, the model generates countercyclical real net exports and a positive comovement of labor inputs and labor wedges across countries. I stress that, contrary to the labor wedge, open economy features of the data are not targeted when estimating the model. Therefore, matching these features through the endogenous response of the labor wedge validates externally the home production theory of the labor wedge.

Two key efficiency conditions allow home production to explain international macro puzzles through endogenous movements in the labor wedge. The first condition expresses the measured labor wedge as an increasing function of time spent on home production relative to time spent on leisure. Intuitively, households allocate an increasing fraction of their time to produce in the home sector in recessions when market consumption and market work are low. Since the two sectors are substitutes, the marginal utility of market consumption remains relatively low which increases the measured labor wedge during recessions. In a model without home production and complete asset markets, productivity shocks induce strong wealth effects that imply a negative comovement of labor and output across countries. By contrast, home production increases the willingness of households to substitute time in response to productivity shocks, which implies that labor and output correlate positively and more across countries than market consumption.

The second condition, the Backus and Smith (1993) condition, sets the real exchange rate proportional to the ratio of marginal utilities of market consumption across countries. Given that home production is substitutable to market consumption, the Backus-Smith condition implies that countries spending relatively more time on home production tend to experience real exchange rate depreciations. Therefore, in states in which domestic market consumption is lower than foreign market consumption, the real exchange rate tends to depreciate because of the increase in relative domestic home production time.

The second strategy uses evidence from international time use surveys to test these two efficiency conditions and to corroborate the mechanism induced by home production. I test the relationship between labor wedges and home production using both business cycle and cross country variation. The lack of long time series on time use categories other than market work hours is a major challenge in relating non-separabilities in preferences to the labor wedge at business cycle frequencies. This is what necessitates my alternative approach of substituting out changes in home production time and changes in leisure time with an estimated function of changes in market work time. To do so, I use recent findings of Aguiar, Hurst, and Karabarbounis (2011) who, to overcome the difficulty of the short time series, estimate the sensitivity of changes in alternative time use categories with respect to changes in market work hours using a panel of U.S. states between 2003 and 2010. As I show, the home production model implies that the cyclical component of the labor wedge is proportional to the difference between the cyclical component of time spent on home production and the cyclical component of time spent on leisure. Therefore, the micro-level estimates in Aguiar, Hurst, and Karabarbounis (2011) for the U.S. can be used to evaluate the model-generated labor wedge in the data at business cycle frequencies. Doing so, I find that the labor wedge generated by home production tracks closely the measured labor wedge for a number of countries at business cycle frequencies.

Next, using time use data for various countries and years from the Multinational Time Use Survey (MTUS), I explore the relationship between cross country differences in changes in labor wedges and cross country differences in changes in time use. The evidence shows a strong relationship between increasing labor wedges and increasing time spent on home production. Instead, I find no evidence that labor wedges are induced by mis-specifications of the leisure component of preferences. This finding suggests that it is crucial to differentiate between home production time and leisure time in testing for non-separabilities in the utility function.

To explore the role of non-separabilities for real exchange rates, I focus on the wedge between the real exchange rate and the difference of foreign from domestic market consumption scaled by the coefficient of relative risk aversion. As the Backus-Smith puzzle suggests, the "Backus-Smith residual" is significant at business cycle frequencies and volatile. As with the labor wedge, to construct the model-generated analog of the Backus-Smith residual at business cycle frequencies I substitute out changes in time spent on home production and changes in time spent on leisure with an estimated function of changes in market work time. Then I show that there is a significant relationship between the residual from the Backus-Smith condition in the data and its analog in the model with home production for a number of country pairs.

Finally, using time use data for various countries and years from the MTUS, I explore the relationship between changes in the Backus-Smith residual and cross country differences in changes in time use. The evidence shows again a strong relationship between increasing real exchange rates adjusted for relative market consumption scaled by the coefficient of relative risk aversion and increasing time spent on home production in the cross section of countries. Similarly to the case of labor wedges, I find weaker evidence for a significant relationship between real exchange rates, relative market consumption, and leisure changes.

Relation to the Literature. Collectively, the paper shows how a frictionless model with home production generates both a low degree of international risk sharing and countercyclical and volatile labor wedges. These results may appear surprising because typically the low degree of international risk sharing has been related to international asset market frictions. Similarly, previous research has hypothesized that the labor wedge is related to labor market frictions.

The interpretation of the labor wedge as a time-varying distortion may arise from taxes, markup shocks, shocks in union bargaining power and various other labor market frictions.[2] The alternative hypothesis here is that the labor wedge simply reflects unaccounted for substitution of time between the market and the home sector. Omitting home production affects the measured rate at which households are willing to substitute leisure for market consumption, implying that the measured labor wedge increases whenever the percent increase in home production time exceeds the percent increase in leisure.[3] This condition has been shown to hold by Aguiar, Hurst, and Karabarbounis (2011) during the U.S. Great Recession, which implies that the labor wedge is countercyclical to GDP. Importantly, as long as home production time is more elastic than leisure time, the countercyclical behavior of the labor wedge in the home production model does not rest on the underlying source of fluctuations.

Hall (2009) is the closest predecessor of this idea. Hall develops an approach to explaining cyclical movements of the labor wedge which, similarly to this paper, does not assume private inefficiencies in the allocation of time. The difference is that here home production provides an alternative time use to market work, whereas in Hall's model unemployed are spending time at home waiting for job opportunities to come along and are not increasing their home production materially. The evidence I present favors non-separabilities in the utility function due to home production as opposed to leisure in explaining movements in the labor wedge and

[2]Shimer (2009) offers a comprehensive summary of the literature and extends it by discussing how search costs and wage rigidities may affect the behavior of the labor wedge. For other explanations of the labor wedge see Rotemberg and Woodford (1999); Cole and Ohanian (2002, 2004); Chang and Kim (2007); Galí, Gertler, and López-Salido (2007); Cheremukhin and Restrepo-Echavarria (2009).

[3]A theory of the labor wedge focused on explaining household's MRS is justified relative to a theory focused on explaining firm's MPL because the measured MRS is more volatile than the measured MPL.

the real exchange rate.

With respect to the interaction of labor wedges and international risk sharing, I focus on how home production induces labor wedges that rationalize the relationship between real exchange rates and relative market consumption. However, my results also hold in the reverse direction when domestic and international asset markets are complete. That is, alternative sources of the labor wedge cannot explain the Backus-Smith puzzle, no matter how well they perform in explaining the labor wedge. With complete asset markets, the real exchange rate is proportional to the ratio of marginal utilities of market consumption, irrespective of other features of the economy such as sticky prices, sticky wages, search costs, heterogeneity, and money. This implies that any joint explanation of labor wedges, real exchange rates, and relative market consumption within the complete markets model must necessarily operate through non-separabilities in the utility function.

Stockman and Dellas (1989) and Stockman and Tesar (1995) have introduced non-traded *market* goods into the international business cycle model. Home production, a non-traded *non-market* good, differs crucially from non-traded market goods. First, as Backus and Smith (1993) have shown, with complete asset markets the correlation between the real exchange rate and relative market consumption (a basked of traded market consumption and non-traded market consumption) is positive and high in models with non-traded market goods. By contrast, the correlation between the real exchange rate and relative market consumption here in the model with home production is negative. This difference arises because the distinctive feature of home production is not that it cannot be traded internationally but that it is not traded in the market and hence that its (implicit) price does not enter into the consumer price index. Second, Stockman and Tesar (1995) find that the wedge between the marginal rate of substitution of traded with non-traded goods and their relative price is negligible. In contrast, the labor wedge is volatile and countercyclical. Finally, the mechanism induced by home production differs from the Harrod-Balassa-Samuelson (HBS) effect in models with a non-traded market goods sector, as in Benigno and Thoenissen (2008). In the HBS effect, higher productivity in the traded goods sector appreciates the real exchange rate as the relative price of non-traded goods increases, while here the real exchange rate is determined exclusively as a function of the terms of trade.

Other related papers include, first, Boileau (1996) who shows how a model with a single traded good, international externalities in production, and a home sector leads to positive comovements in output and employment. Canova and Ubide (1998) show how home production lowers the correlation of consumption in a model with two traded goods. The impulse responses in Canova and Ubide (1998) show that terms of trade appreciate after a positive productivity shock in the home sector and depreciate after a positive productivity shock in the market sector. In both cases, the correlation between terms of trade and domestic over foreign market consumption is positive. In the present model, terms of trade depreciate in the first case and depreciate weakly in the second case. Overall, terms of trade are negatively correlated with relative market consumption which allows me to explain the Backus-Smith puzzle.

Raffo (2010) shows how investment-specific shocks explain the Backus-Smith puzzle in a model with complete asset markets, non-separable preferences between market consumption and market work (GHH preferences), and variable capacity utilization. Apart from the different source of fluctuations, the main difference relative to Raffo's work is my emphasis on disciplining the source of the non-separability in preferences using the labor wedge and on corroborating the macro calibration with evidence from time use surveys at business cycle frequencies and in the cross section of countries. While Raffo is the first to use GHH preferences in the two-goods class of models, non-separable preferences between consumption and labor are also prominent in one-good models as they help increase the volatility of consumption and the countercyclicality of the trade balance. The result in this paper that it is important to distinguish between leisure and home production in testing for non-separabilities is, therefore, informative for a broad class of models.

2 The Model

There are two ex-ante symmetric countries, the domestic and the foreign country $i = H, F$. The market and the home sector are denoted by $j = m, n$. Time is discrete and the horizon is infinite, $t = 0, 1, 2, ...$ In each period, the economy experiences one of finitely many states s_t. Denote by $s^t = (s_t, ..., s_0)$ the history of events up through period t. Let $\pi\left(s^t|s^r\right)$ be the conditional probability measure. As a shortcut, I will often use the notation X_t to denote any variable $X\left(s_t|s^{t-1}\right)$.

Market Production. Each country specializes in the production of an intermediate traded good, $Y_{ii,t}$. Household $i = H, F$ provides labor services, $N^m_{i,t}$, and capital services, $K^m_{i,t-1}$, to a competitive domestic intermediate goods producer and receives nominal factor returns $W_{i,t}$ and $r_{i,t}$. Intermediate traded goods are produced with a Cobb-Douglas technology:

$$Y_{ii,t} = \exp(z^m_{i,t})(K^m_{i,t-1})^{\alpha_m}(N^m_{i,t})^{1-\alpha_m}, \tag{1}$$

where $z^m_{i,t}$ is productivity in the market sector and α_m is the income share of capital in market production.

Final goods producers are competitive. The law of one price holds for intermediate traded goods, so final good producers purchase domestic and foreign intermediate traded goods at same prices $P_{1,t}$ and $P_{2,t}$ respectively. Let the foreign intermediate good be the numéraire good and fix $P_2\left(s_t|s^{t-1}\right) = 1$ in every state. In the domestic country, the (non-traded) final good is produced with a CES technology:

$$Y_{H,t} = \left(a_C^{1-\rho_C} C_{HH,t}^{\rho_C} + (1-a_C)^{1-\rho_C} C_{HF,t}^{\rho_C}\right)^{\frac{1}{\rho_C}}, \tag{2}$$

where $C_{HH,t}$ denotes purchases of domestic traded goods and $C_{HF,t}$ denotes purchases of foreign traded goods by the domestic final good producer. The parameter $\epsilon_C = 1/(1-\rho_C) > 0$ is the elasticity of substitution between domestic and foreign traded goods. The parameter a_C is the steady state share of the domestic traded good in income. Following the literature, preferences are home biased, i.e. $a_C > 1/2$. Symmetrically, in the foreign country the final good is produced with a CES technology:

$$Y_{F,t} = \left(a_C^{1-\rho_C} C_{FF,t}^{\rho_C} + (1-a_C)^{1-\rho_C} C_{FH,t}^{\rho_C}\right)^{\frac{1}{\rho_C}}, \tag{3}$$

where $C_{FF,t}$ denotes purchases of foreign traded goods and $C_{FH,t}$ denotes purchases of domestic traded goods by the foreign final good producer.

In each country, the final good is sold to domestic households at price $P_{i,t}$ and is used for market consumption ($C_{i,t}^m$) or investment ($I_{i,t}$):

$$Y_{i,t} = C_{i,t}^m + I_{i,t}. \tag{4}$$

The market clearing condition in the intermediate goods sector $i = H, F$ is:[4]

$$Y_{ii,t} = C_{Hi,t} + C_{Fi,t}. \tag{5}$$

Prices. The price of the domestic final good, $P_{H,t}$ is a weighted average of the price of the two traded goods (and symmetrically for the price of the foreign final good $P_{F,t}$):

$$P_{H,t} = \left(a_C P_{1,t}^{1-\epsilon_C} + (1-a_C) P_{2,t}^{1-\epsilon_C}\right)^{\frac{1}{\epsilon_C}}. \tag{6}$$

Define the real exchange rate as the relative price of foreign market consumption, $\text{RER}_t = P_{F,t}/P_{H,t}$. Define the (home) terms of trade as the relative price of foreign exports, $T_t = P_{2,t}/P_{1,t}$. Because preferences are home biased ($a_C > 1/2$), a deterioration of the terms of trade (an increase in T_t) causes a real depreciation (an increase in RER_t). Therefore, this is a terms of trade model of real exchange rate determination.

The strength of this approach is that the relationship between relative market consumption and real exchange rates (the Backus-Smith puzzle) reflects fluctuations in the relative price

[4] A previous version of the paper also considered government spending without a meaningful difference in the results. Below, I explain how to account for taxes when measuring the labor wedge.

of traded goods. The perfect correlation of the terms of trade with the real exchange rate in the model need not hold in the data because price indices also include non-traded market goods prices. However, there are good reasons to abstract from non-traded market goods. Somewhat similar to the finding of Engel (1999), in my sample the mean correlation between relative market consumption and the real exchange rate is -0.16, while with the terms of trade it is -0.12. This implies that the negative correlation between relative market consumption and real exchange rates in the data reflects the negative correlation between relative market consumption and the terms of trade, rather than movements in non-traded goods prices. The weakness of this approach is that it implies that the terms of trade is more volatile than the real exchange rate. More in general, a notable limitation of the model is that it does not explain the volatility of the real exchange rate. See Chari, Kehoe, and McGrattan (2002) and Corsetti, Dedola, and Leduc (2008) for work that addresses the volatility of the real exchange rate.

Home Production. Home production is introduced as in Benhabib, Rogerson and Wright (1991).[5] In the home sector, the household good ($C^n_{i,t}$) is produced according to a Cobb-Douglas technology that combines time in household activities ($N^n_{i,t}$) with household capital goods ($K^n_{i,t-1}$):

$$C^n_{i,t} = \exp(z^n_{i,t}) \left(K^n_{i,t-1}\right)^{\alpha_n} \left(N^n_{i,t}\right)^{1-\alpha_n}, \tag{7}$$

where $z^n_{i,t}$ is productivity in the home sector and α_n is the share of capital in home production.

Capital Accumulation. Equation (4) shows that capital goods are produced exclusively in the market sector. Households allocate their capital across the market and the home sector without cost:

$$I^j_{i,t} = K^j_{i,t} - (1-\delta)K^j_{i,t-1}, \tag{8}$$

for sector $j = m, n$ and country $i = H, F$. In equation (8), the parameter δ is the (common across sectors) rate of capital depreciation. Total investment in every country equals the sum of investments in the two sectors: $I_{i,t} = I^m_{i,t} + I^n_{i,t}$.

Households. Household $i = H, F$ chooses sequences of market consumption, leisure, market work, non-market work, market capital, non-market capital, and a complete set of securities to maximize the conditional expectation of discounted sum of utilities:

$$\max_{\{C^m_{i,t}, L_{i,t}, N^m_{i,t}, N^n_{i,t}, K^m_{i,t}, K^n_{i,t}, \{B_i(s_{t+1}|s^t)\}\}^\infty_{t=r}} \sum_{t=r}^{\infty} \sum_{s^t|s^r} \beta^{t-r} \pi\left(s^t|s^r\right) \frac{1}{1-\sigma} U(C_i(s^t|s^r), L_i(s^t|s^r))^{1-\sigma}, \tag{9}$$

where $0 < \beta < 1$ is the discount factor and $\sigma > 0$ is the risk aversion parameter. In equation (9), U denotes a Cobb-Douglas period utility function which is defined over bundles of aggregate

[5] Other contributions include Greenwood and Hercowitz (1991), McGrattan, Rogerson, and Wright (1997) and Chang and Schorfheide (2003).

consumption ($C_{i,t}$) and leisure ($L_{i,t}$):

$$U(C_{i,t}, L_{i,t}) = C_{i,t}^{1-a_L} L_{i,t}^{a_L}, \tag{10}$$

where the parameter a_L affects the share of time allocated to leisure. Aggregate consumption (C) is a CES basket of market goods (C^m) and home goods (C^n):

$$C_{i,t} = \left[(1-a_h)(C_{i,t}^m)^{\rho_h} + a_h(C_{i,t}^n)^{\rho_h}\right]^{\frac{1}{\rho_h}}, \tag{11}$$

where $a_h \in [0,1]$ parameterizes the preference for the household good and $\epsilon_H = 1/(1-\rho_h)$ is the elasticity of substitution between market and home consumption goods. Leisure (L), market work (N^m), and home work (N^n) exhaust the total endowment of time:

$$L_{i,t} + N_{i,t}^m + N_{i,t}^n = 1. \tag{12}$$

Asset markets are complete. Let $B_i\left(s_{t+1}|s^t\right)$ denote holdings of a security purchased in state s^t that pays off one unit of the numéraire good contingent on the realization of some future state s_{t+1}. Domestic holdings and foreign holdings of these securities are in zero net supply. Let $Q\left(s_{t+1}|s^t\right)$ be the price of this security. Since all firms earn zero profits, the household's flow budget constraint is:

$$P_{i,t}C_{i,t}^m + P_{i,t}I_{i,t} + \sum_{s_{t+1}} Q\left(s_{t+1}|s^t\right) B_i\left(s_{t+1}|s^t\right) = W_{i,t}N_{i,t}^m + r_{i,t}K_{i,t-1}^m + B_i(s_t|s^{t-1}). \tag{13}$$

Exogenous Shocks. The vector of exogenous productivities, $\mathbf{Z}_t = \{z_{H,t}^m, z_{F,t}^m, z_{H,t}^n, z_{F,t}^n\}$, follows a VAR process:

$$\mathbf{Z}_t = \mathbf{R}\mathbf{Z}_{t-1} + \epsilon_t, \tag{14}$$

where $\epsilon_t \sim \mathbf{N}(0, \mathbf{\Sigma})$ is a multivariate normal $i.i.d$ shock and $\mathbf{R}$ is the matrix of spillovers.

Competitive Equilibrium and Solution of the Model. The state of the economy at any point of time is summarized by the vector $\mathbf{s}_{t-1} = (\mathbf{Z}_{t-1}, K_{H,t-1}^m, K_{H,t-1}^n, K_{F,t-1}^m, K_{F,t-1}^n)$. For a given state vector, the competitive equilibrium of the model is a set of decision rules (i.e. quantities and prices) such that: (i) in every country households maximize utility subject to the production function in the home sector (7), the capital accumulation equation (8), the time constraint (12), the budget constraint (13), and appropriate intertemporal solvency constraints; (ii) in every country intermediate and final goods producers maximize their profits subject to the feasible technology; (iii) all intermediate goods, final goods, labor, capital, and asset markets clear. I take a first-order log-linear approximation of equilibrium conditions around the non-stochastic, symmetric steady state of the model and solve numerically the linearized system of stochastic difference equations.

3 The Labor Wedge

I first define the labor wedge and relate it to home production and leisure using the model developed in the previous section. Next, I test the relationship between home production, leisure, and labor wedges, at business cycle frequencies and in the cross section of countries.

Definition 1. Measured Labor Wedge: *The (domestic) measured labor wedge τ^e is the log of the ratio of the value of the marginal product of labor to the value of the marginal rate of substitution of leisure for market consumption in a model without home production ($a_h = 0$):*

$$\exp(\tau^e_{H,t}) := \frac{VMPL_{H,t}}{VMRS_{H,t}(a_h=0)} = \frac{P_{1,t}}{P_{H,t}}\frac{MPL_{H,t}}{MRS_{H,t}} = \frac{P_{1,t}}{P_{H,t}}\frac{(1-\alpha_m)Y_{HH,t}/N^m_{H,t}}{[a_L C^m_{H,t}]/[(1-a_L)(1-N^m_{H,t})]}, \quad (15)$$

where the ratio of prices equals: $P_{1,t}/P_{H,t} = 1/\big(a_C + (1-a_C)T_t^{1-\epsilon_C}\big)^{\frac{1}{1-\epsilon_C}}$.

In the denominator of equation (15) leisure equals time not spent working in the market ($L_{H,t} = 1 - N^m_{H,t}$), as the measured labor wedge omits the home sector ($a_h = 0$). The terms of trade enters equation (15) because in the open economy ($a_C < 1$) the price, P_H, of the market consumption good (C^m_H) may differ from the price, P_1, of the domestic traded good (Y_{HH}). Since for most countries in the sample the terms of trade is not very cyclical and the share of imports is small, the ratio of prices does not contribute significantly to the cyclical behavior of the measured labor wedge. Up to the terms of trade term which is quantitatively unimportant, the expression for the labor wedge in equation (15) is identical to that in Chari, Kehoe, and McGrattan (2007).

To construct the theoretical analog of the measured labor wedge, consider the labor market in the model presented in Section 2. The labor market clears when, first, the value of the marginal product of labor equals the wage:

$$\mathrm{VMPL}_{H,t} = P_{1,t}\mathrm{MPL}_{H,t} = P_{1,t}(1-\alpha_m)\frac{Y_{HH,t}}{N^m_{H,t}} = W_{H,t}. \quad (16)$$

Second, the value of the marginal rate of substitution ($\mathrm{MRS} = U_L/U_{C^m}$) must equal the wage:

$$\mathrm{VMRS}_{H,t}(a_h \neq 0) = P_{H,t}\mathrm{MRS}_{L_H,C^m_H} = P_{H,t}\frac{a_L\,(C_{H,t})^{\rho_h}\,\big(C^m_{H,t}\big)^{1-\rho_h}}{(1-a_h)(1-a_L)(1-N^m_{H,t}-N^n_{H,t})} = W_{H,t}. \quad (17)$$

Combining equation (16) with equation (17), I express the model-generated analog of the measured labor wedge in terms of sectoral employments and sectoral consumptions. (This condition is similar for both countries and the subscript $i = H, F$ is omitted.)

Proposition 1. Model-Generated Labor Wedge: *The model-generated labor wedge τ is:*

$$\exp(\tau_t) = \left(1 + \frac{N^n_t}{L_t}\right)\left[1 + \left(\frac{a_h}{1-a_h}\right)\left(\frac{C^n_t}{C^m_t}\right)^{\frac{\epsilon_H - 1}{\epsilon_H}}\right]. \quad (18)$$

In a model without home production ($a_h = 0$) we take $C_t^m = C_t$, $N_t^n = C_t^n = 0$ and $L_t = 1 - N_t^m$. In this case, the theoretical marginal rate of substitution converges to the measured marginal rate of substitution, which implies that the model-generated labor wedge is always equal to zero ($\tau_t = 0$). Equation (18) shows how the omission of the home sector ($a_h > 0$) generates a positive wedge between the measured value of the marginal product and the measured value of the marginal rate of substitution. As the size of the home sector increases, the model implies a higher labor wedge.

The first term in the right-hand side of equation (18) captures the omission in the measurement of the marginal utility of leisure. This term arises because the measured labor wedge attributes any non-market time to leisure time ($1 - N_t^m = L_t$), while in the home production model non-market time may be spent alternatively in home production ($1 - N_t^m = L_t + N_t^n$). The second term in the right-hand side of equation (18) captures the omission in the measurement of the marginal utility of market consumption. This term arises because the measured labor wedge does not account for the output of the home sector C_t^n.

To be able to measure the model-generated labor wedge in the data and compare it to the measured labor wedge, I express the right-hand side of equation (18) solely as a function of the ratio of time spent on home production relative to leisure $R_t = N_t^n / L_t$. The first step is to substitute out from equation (18) the output of the home sector C_t^n which is unobservable in the data. Using the first-order condition with respect to time spent on home production, the ratio of consumptions C_t^n / C_t^m can be written as a function of R_t:

$$\left(\frac{C_t^n}{C_t^m} \right)^{\frac{\epsilon_H - 1}{\epsilon_H}} = \left(\frac{1 - a_h}{a_h} \right) \left(\frac{a_L R_t}{(1 - a_L)(1 - \alpha_n) - a_L R_t} \right). \tag{19}$$

The second step is to substitute C_t^n / C_t^m from equation (19) into equation (18). After log-linearizing the resulting expression around some approximation point (denoted by asterisks), the model-generated labor wedge can be written as:

$$\widehat{\tau}_t = \left(\frac{(1 + \chi) R^*}{(1 + R^*)(\chi - R^*)} \right) \widehat{R}_t = \left(\frac{(1 + \chi) R^*}{(1 + R^*)(\chi - R^*)} \right) \left(\widehat{N_t^n} - \widehat{L}_t \right), \tag{20}$$

where for the labor wedge define $\widehat{\tau}_t = \tau_t - \tau^*$ and for any other variable X define $\widehat{X} = \log(X_t) - \log(X^*)$. In equation (20), for all countries I calibrate $\chi = (1 - a_L)(1 - \alpha_n)/a_L = 1.32$ and $R^* = 0.72$ from the quantitative model of Section 4.

The key insight from equation (20) is that the labor wedge increases whenever the percent change in home production time exceeds the percent change in leisure. Therefore, if in recessions households substitute sufficiently towards home production time, then the labor wedge is countercyclical. The result that (the omission of) home production explains the countercyclical behavior of the labor wedge does not rest explicitly on the assumed source of fluctuations.

The home production theory of the labor wedge holds in a large class of models, irrespective of whether these models are driven by productivity shocks, demand shocks, financial shocks or government shocks, as long as time spent on home production increases more than time spent on leisure during recessions.

The literature has long suffered from lack of formal tests that home production increases in recessions. This is because consistent and long time time series on time use are not available for any country, which makes impossible to use standard methods to separate cyclical components from trends. To overcome this difficulty, Aguiar, Hurst, and Karabarbounis (2011) use cross state variation with respect to the severity of recessions to estimate the allocation of time over the business cycle in the American Time Use Survey (ATUS). Controlling for aggregate trends in time use, they find that time spent in home production is countercyclical. In addition, these authors estimate that the elasticity of increases in time spent on home production with respect to declines in market work time exceeds substantially the elasticity of increases in time spent on leisure with respect to declines in market work time. Therefore, while both home production time and leisure time increase in recessions, home production time increases by more in percent terms. Below, I use these estimates to test the home production theory of the labor wedge at business cycle frequencies.

I collect quarterly and annual data for 18 countries between 1960 and 2010. Depending on data availability, most of the analysis below is confined to a subset of countries and years. The main source of data is the OECD Quarterly and Annual National Accounts. Real exchange rates are obtained from the Bank of International Settlements. I use population, employment, and hours of market work from Ohanian and Raffo (2012). Tax data are obtained from McDaniel (2007).

Time use data are obtained from the Multinational Time Use Survey (MTUS), which standardizes time use surveys across countries. The MTUS classifications are close to the ATUS classifications, so I follow Aguiar, Hurst, and Karabarbounis (2011) in defining various time use categories. To enlarge the sample, for some countries I collect directly time use data from their national surveys. My benchmark definition of home production excludes child care and my benchmark definition of leisure excludes sleeping time. I discuss robustness with respect to these choices below.

To measure the labor wedge, I adjust equation (15) to account for income and consumption taxes.[6] This adjustment produces negligible changes in the cyclical properties of the labor wedge for the majority of countries. This implies that time-varying taxes cannot explain cyclical properties of the labor wedge. However, this adjustment is necessary because the

[6]Specifically, I divide equation (15) by $(1+q_c)/(1-q_l)$ where q_c denotes effective tax rates on consumption and q_l denotes the sum of effective income tax rates and effective social security tax rates.

level of the labor wedge is substantially affected by the presence of taxes. Henceforth, the model-generated labor wedge is compared to the tax-adjusted labor wedge in the data, i.e. the residual of the labor wedge after accounting for income and consumption taxes.

Other than taxes, I use data on market consumption, total market hours of work, output, and the terms of trade to measure the labor wedge. The parameters a_L, α_m and ϵ_C do not affect the cyclical properties of the measured labor wedge (up to a first-order approximation). The value of α_m and a_L, however, matters for the level of the labor wedge.[7] For all countries I set $\alpha_m = 0.36$ and $a_L = 0.41$ in equation (15) and also fix $\alpha_m = 0.36$ and $a_L = 0.41$ in the model. The value $a_L = 0.41$ allows the model to match the observed average share of time spent on leisure.

Figure 1 presents the measured labor wedge for the U.S., Japan, U.K., Germany, France, and Canada (with and without the terms of trade correction). Figure 2 presents the cyclical component of the measured labor wedge together with the cyclical component of output. A number of stylized facts emerge from these figures. First, the U.S. has the lowest labor wedge. Second, in the U.S. and in Canada the labor wedge trends downward, whereas in France and Germany the labor wedge trends upward over time. Third, in most countries the labor wedge is countercyclical to output. Fourth, the labor wedge is volatile and positively autocorrelated at business cycle frequencies.

I provide two tests of the home production theory of the labor wedge. Both tests aim to measure in the data changes in the model-generated labor wedge in equation (20) and then compare them to changes in the measured labor wedge constructed according to equation (15). The first test is at business cycle frequencies and the second is in the cross section of countries.

To measure equation (20) at business cycle frequencies, I substitute out the term $\widehat{N_t^n} - \widehat{L}_t$, for which long time series do not exist, with a function of the cyclical component of market work hours $\widehat{N_t^m}$, which is easy to measure in the data. To perform this substitution, I use the sensitivity of changes in home production time and changes in leisure time with respect to changes in market work time as estimated in Aguiar, Hurst, and Karabarbounis (2011). These estimates imply that one can write the difference $\widehat{N_t^n} - \widehat{L}_t$ in equation (20) as $-0.56 * \widehat{N_t^m}$.[8]

Figure 3 compares the cyclical component of the measured labor wedge to the cyclical component of the labor wedge implied by the home production model for various countries.

[7] In equation (15), the parameter a_C is estimated separately for every country. The value of ϵ_C does not affect either the cyclical properties or the level of the labor wedge.

[8] Aguiar, Hurst, and Karabarbounis (2011) estimates are $dN^n/dN^m = -0.30$ and $dL/dN^m = -0.29$. I adjust these two estimates proportionally to absorb all changes in market work hours since the model does not include other time uses. The elasticity of home production with respect to market work hours is $\widehat{N^n}/\widehat{N^m} = -0.51 * (N^m/N^n)^* = -0.88$ and the elasticity of leisure with respect to market work hours is $\widehat{L}/\widehat{N^m} = -0.49 * (N^m/L)^* = -0.32$. Including child care would slightly weaken my results since the home production elasticity would increase to -0.75 and the leisure elasticity to -0.30.

The figure shows that the model-generated labor wedge tracks very closely the measured labor wedge in the data for most countries. The mean correlation of the two series across 10 countries is 0.66. The labor wedge induced by home production is somewhat less volatile than the labor wedge in the data. Across 10 countries, the mean standard deviation of the model-generated labor wedge is 65 percent that of the measured labor wedge. The mean R-squared from a regression of the measured labor wedge on the model-generated labor wedge is 41 percent. Collectively, these estimates support the hypothesis that increases in the labor wedge are related to increases in home production time at business cycle frequencies.

Figure 4 presents the second test which is based on long-term relationships in the cross section of countries. This exercise is informative because it uses directly time use data on home production and leisure for various countries and years from the MTUS, instead of using only U.S. estimates based on the 2003-2010 ATUS sample. I follow a difference-in-difference strategy and examine how cross-country differences in changes in measured labor wedges correlate with cross-country differences in changes in model-generated labor wedges. Each observation in Figure 4 plots the difference between two countries in the change in their measured labor wedge $\Delta\tau^e_{H,t} - \Delta\tau^e_{F,t}$ against the difference between the same two countries in the change in their model-generated labor wedge $\Delta\tau_{H,t} - \Delta\tau_{F,t}$.[9] The figure pools across all available observations, so some pairs of countries appear more than once but for different years (corresponding to their multiple time use surveys).[10] The figure considers various definitions of labor and home production. As the figure shows, there is a strong cross sectional relationship between the measured and the model-generated labor wedge. The correlation between the two variables ranges between 0.37 and 0.46 across the four panels and is statistically significant at any conventional level.

The home production theory of the labor wedge looks similar to a theory of mis-specified preferences between consumption and leisure. This is because the marginal rate of substitution between consumption and leisure for utility functions not of Cobb-Douglas form differs from the marginal rate of substitution in the Cobb-Douglas utility function used to measure the labor wedge in the data. Similarly to what I will do in Section 4, one could then choose parameters that affect the behavior of the marginal rate of substitution in order to fit cyclical and long-run moments of the measured labor wedge. Without using data on time use, the labor wedge, while disciplining parameters that govern the non-separability in preferences, does not identify

[9]Differencing over time controls for country-specific fixed effects, such as permanently different home production technologies or tastes for leisure. Differencing across countries controls for common shocks, such as a world-wide improvement in home production technologies, global shifts in tastes, or oil shocks.

[10]Because time use surveys have taken place in more than a year and to increase the sample size, I treat time use surveys within two years as belonging to the same cross section. For example, the U.S.-Canada difference in the measured labor wedge against the U.S.-Canada difference in the model-generated labor wedge is included in the figure, for Canadian surveys 1986 and 1992 and U.S. surveys 1985 and 1993.

whether home production or leisure is the relevant source of non-separability. This equivalence is also related to the well-known fact that models with home production nest models without home production but with non-separable preferences between consumption and leisure.

Given this identification issue, how does home production differ from leisure in explaining movements in the labor wedge? The implicit assumption of models with home production is that time spent on home production is more substitutable to market work time than time spent on leisure. Therefore, modeling home production explicitly matters for testing and interpreting non-separabilities using time use data. For instance, at business cycle frequencies, Aguiar, Hurst, and Karabarbounis (2011) have shown that home production time is roughly three times more elastic than leisure time. As I showed, this feature of home production makes it successful in explaining cyclical movements of the labor wedge. By contrast, an explanation of the labor wedge based on non-separable preferences between consumption and leisure would require much larger cyclical movements of leisure time than found in the U.S. between 2003 and 2010.

I propose a test that differentiates between a theory of the labor wedge based on leisure and a theory based on home production. First, to see the implications of leisure-based explanations for the labor wedge, consider two popular classes of utility functions:

$$U_1 = \left((C^m)^{\frac{\epsilon_L - 1}{\epsilon_L}} + L^{\frac{\epsilon_L - 1}{\epsilon_L}} \right)^{\frac{\epsilon_L}{\epsilon_L - 1}}, \tag{21}$$

$$U_2 = (C^m)^{1-\kappa} - (1 - L)^{1+\frac{1}{\epsilon_F}}, \tag{22}$$

where ϵ_L denotes the constant elasticity of substitution (CES) between consumption and leisure in equation (21) and ϵ_F denotes the Frisch elasticity of labor supply in equation (22). The utility function U_2 nests the GHH utility function (when $\kappa = 0$) and the log-separable utility function that satisfies conditions for balanced growth (when $\kappa \to 1$). In all utility functions, I have fixed to unity all parameters that are not essential for my argument. Under these utility functions, the model-generated labor wedge becomes:

$$\widehat{\tau_{1,t}} \propto \left(\frac{\epsilon_L - 1}{\epsilon_L} \right) \widehat{L_t} - \left(\frac{\epsilon_L - 1}{\epsilon_L} \right) \widehat{C_t^m}, \tag{23}$$

$$\widehat{\tau_{2,t}} \propto \left(\frac{\epsilon_F (1 - L^*) - L^*}{\epsilon_F (1 - L^*)} \right) \widehat{L_t} - (1 - \kappa) \widehat{C_t^m}. \tag{24}$$

The test compares the model-generated labor wedge under the home production explanation in equation (20) to the model-generated labor wedge under leisure-based explanations in equations (23) and (24). In the home production explanation, the labor wedge decreases in leisure, conditional on home production time. In the leisure explanation, the labor wedge must increase in leisure, conditional on market consumption. While I have considered two specific utility functions for illustrative reasons, the condition that leisure is positively related to the labor wedge is intuitive and should restrict any utility function. If leisure were not positively related to the labor wedge, then any leisure-based explanation would fail to generate countercyclical labor wedges. So here I assume $\epsilon_L > 1$, i.e. that leisure and consumption are substitutes as in Hall (2009).

The upper panels of Figure 5 show a positive, unconditional, relationship between home production time (with and without child care) and the measured labor wedge in the data. The lower panels show a negative, unconditional, relationship between leisure time (with and without sleeping) and the measured labor wedge in the data. To test conditional relationships, I estimate:

$$\Delta\Delta\tau^e_{i,t} = \underset{[-0.662,\,-0.110]}{(-0.386)}\,\Delta\Delta\log L_{i,t} + \underset{[-0.357,\,0.042]}{(-0.158)}\,\Delta\Delta\log C^m_{i,t},$$

$$\Delta\Delta\tau^e_{i,t} = \underset{[-0.586,\,-0.011]}{(-0.299)}\,\Delta\Delta\log L_{i,t} + \underset{[0.002,\,0.481]}{(+0.242)}\,\Delta\Delta\log N^n_{i,t},$$

where the double difference operator denotes differencing across time and across countries with time use surveys belonging to the same cross section and the brackets denote 90 percent confidence intervals for estimated coefficients. These results strongly favor the home production theory of the labor wedge, as opposed to explanations based on leisure. This is an important finding because various models use non-separable preferences between consumption and leisure to increase the volatility of macroeconomic aggregates at business cycle frequencies. In practice, differentiating between home production and leisure makes a difference for testing and interpreting such non-separabilities.

4 Labor Wedges and International Real Business Cycles

Having established the relationship between the labor wedge and home production theoretically and empirically, I now explore implications of non-separable preferences with home production for international business cycles. The strategy is to estimate the parameters of the home sector to match moments of the labor wedge and then test whether the two-country model generates business cycles with properties consistent with international data.

4.1 Stylized Facts and Estimation

Table 1 presents summary statistics for the sample period between 1971(1) and 2007(4).[11] The upper panel presents moments of the labor wedge which are used to estimate the struc-

[11] The sample period is chosen to balance the trade-off between longer time series and larger number of countries represented in statistics. 18 countries are included in at least one statistic: Australia, Austria,

tural model. The lower panels present various other closed economy and open economy moments which are not used to estimate the model. Variables are logged and HP filtered with a smoothing parameter of 1600. The columns present the mean estimate of each statistic across countries, the median estimate, the minimum and the maximum value, and the U.S. estimate.

As the table shows, the labor wedge is more volatile than output, which implies a high elasticity of substitution between the market and the home sector. The labor wedge is positively and significantly autocorrelated. The mean contemporaneous correlation of the labor wedge with output across countries is -0.25. The U.S. is a clear outlier here, having the most countercyclical and the most autocorrelated labor wedge. The fact that the labor wedge is not very countercyclical to output implies an important role for productivity shocks in the home sector. This is because productivity shocks in the home sector induce workers to spend more time on the home sector relative to other time use activities, leading to an increase in the labor wedge. However, these type of shocks do not affect much measured GDP, as not only reduced market work but also reduced leisure absorb increases in home production. Thus, productivity shocks in the home sector, while generating volatile labor wedges, lower in absolute value the correlation of the labor wedge with output.

The labor wedge is on average positively correlated with market productivity. This may initially appear surprising because higher market productivity induces workers to increase market time and decrease time spent on home production, leading to a decrease in the labor wedge. In the context of the model, this conditional relationship can be overturned on average, if productivity disturbances in the market and the home sector are positively correlated.

To summarize important features of international data, output and employment are more correlated across countries than consumption and investment and all correlations are positive.[12] The difficulty of the standard international business cycle model to match these regularities constitutes the "quantity anomaly." Note also that the labor wedge is positively correlated across countries, but less so than output. Other well-documented features of the data are that both current-price and constant-price (real) net exports are countercyclical.[13] The import ratio, C_{HF}/C_{HH}, is more volatile than the terms of trade, which implies that the elasticity of substitution between traded goods ϵ_C must exceed one.

The negative relationship between real exchange rates and relative market consumption

Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Korea, Mexico, Netherlands, Norway, Spain, Sweden, United Kingdom, and United States. At least 10 countries are included in every statistic.

[12]To compute these correlations, for each country I first estimate the mean correlation across all its bilateral correlations. Columns 1 and 2 show the mean and the median across countries of the mean correlation.

[13]Current-price and constant-price net exports relative to GDP are defined as $NX_t = (P_{1,t}C_{FH,t} - P_{2,t}C_{HF,t}) / (P_{1,t}Y_{HH,t})$ and $NXQTY_t = (C_{FH,t} - C_{HF,t}) / (Y_{HH,t})$ in the model. Consistent with Raffo (2008), the terms of trade in the model is weakly procyclical and, therefore, the countercyclicality of current-price net exports is mostly due to changes in quantities rather than due to changes in prices.

observed in the data is the "Backus-Smith puzzle." My measure of market consumption $C^m_{i,t}$ in the data is private final consumption for households and my measure of investment $I_{i,t} = I^m_{i,t} + I^n_{i,t}$ is gross fixed capital formation. This is consistent with Backus and Smith (1993), in that market consumption in the data should include both traded and non-traded market goods, even though the model does not consider the latter. On the other hand, while one could potentially differentiate between private consumption of non-durables and services (which clearly belong to market consumption) and private consumption of durables (which could be included either in market consumption or in non-market investment), quarterly data on durables exist for few countries only.[14]

I estimate the structural parameters of the home sector:

$$\theta = (\epsilon_H, a_h, \rho_{z^n_i, z^n_i}, \sigma_{\epsilon^n_i, \epsilon^n_i}, \sigma_{\epsilon^m_i, \epsilon^n_i}), \tag{25}$$

where ϵ_H is the elasticity of substitution between market and home goods, a_h is the preference parameter for household goods in the consumption aggregator (11), $\rho_{z^n_i, z^n_i}$ denotes the persistence of productivity in the home sector, $\sigma_{\epsilon^n_i, \epsilon^n_i}$ denotes the variance of the productivity shock in the home sector, and $\sigma_{\epsilon^m_i, \epsilon^n_i}$ denotes the covariance of productivity innovations in the home and the market sector.

The two countries $i = H, F$ are symmetric in all parameters. I fix parameters other than the ones estimated to values shown in Panel A of Table 3 (these are called "fixed parameters"). To isolate the contribution of home production to explaining international business cycles, the values of the fixed parameters are taken from Backus, Kehoe, and Kydland (1994).

To estimate the model, I minimize the distance between simulated moments of the model and their analogs in the data:

$$\theta_S = \arg\min_{\theta \in \Theta} \left[M_T - M_{TS}(\theta; \epsilon) \right]' W \left[M_T - M_{TS}(\theta; \epsilon) \right], \tag{26}$$

where W is a five-by-five positive definite weighting matrix, M_T denotes empirical moments, M_{TS} denotes model-generated moments under some parameter θ and shocks ϵ, $T = 148$ denotes the sample size, and $S = 300$ denotes the length of the simulation. In the objective function (26), M_T includes the volatility of the labor wedge, its contemporaneous correlation with output and market productivity, its autocorrelation, and its mean sample value. The weighting matrix W is arbitrarily set to the identity matrix since the model generates moments that always match perfectly their empirical analogs.

[14]Classifying durables as investment instead of consumption should not change the cross-country correlation of consumption and investment much because estimates for these correlations with my imperfect consumption and investment definitions are close to each other. On the other hand, excluding durables from consumption will decrease the volatility of consumption, which makes more difficult for the model to match the volatility of the labor wedge.

I follow a Monte Carlo simulated method of moments procedure to estimate the model.[15] First, I estimate the distribution of empirical moments M_T. For each country I draw 200 samples with replacement from its observed sample. Each sample has length 148 quarters. The estimated empirical means differ slightly from the means presented in column 1 of Table 1 because, to avoid compositional changes, I now drop any country with missing observations between 1971(1) and 2007(4).[16] Second, I vary M_T to estimate the model 200 times, with each estimation minimizing equation (26) for empirical moments corresponding to a particular draw from their estimated distribution. This Monte Carlo procedure yields estimates of the joint distribution of estimated parameters θ_S and of estimated moments $M_{TS}(\theta_S)$. Finally, to solve the minimization problem in equation (26), I fix the shock ϵ to make the objective function continuous in the parameters. Given an initial guess for the parameter vector, I solve and simulate the model. Then, I use simulated annealing to update the parameter vector until convergence to the global minimum is achieved.

4.2 Model Results

Figure 6 shows the distribution of estimated parameters. Table 2 (Panel B) presents statistics from the distribution of estimated parameters (means, standard deviations, and 5th and 95th percentile values over 200 Monte Carlo estimations). Table 3 presents various moments. Column 1 of Table 3 presents the mean value of each moment in the data, column 2 presents the mean value of each moment in the model (across 200 estimations), and column 3 presents 5th and 95th percentile values of each moment. Column 4 of the table presents moments in the model without home production, as in Backus, Kehoe, and Kydland (1994). Finally, columns 5 to 8 present moments when I change the values of estimated parameters.

The contribution of home production to explaining international business cycle facts can be seen by comparing column 2 to column 4 of Table 3 (panel C). When the parameters that govern the behavior of the home sector are estimated to generate a labor wedge with moments similar to those observed in the data (panel A), the model performs significantly better than the workhorse international business cycle model. As in Benhabib, Rogerson, and Wright (1991), the home production model also performs better than the workhorse real business cycle model

[15]This simulated estimation is very similar to the GMM estimation. The difference is that in the former case statistics of the model are computed from simulated data, while in the latter case statistics of the model are computed theoretically. I use simulated estimation because computing theoretical statistics is much more costly. Computed at the optimal parameter vector, simulated statistics are very close to their theoretical counterparts. I also note that to generate unbiased Monte Carlo standard errors one would have to vary simultaneously both the underlying moment vector and the seed of the shock. To reduce simulation time, I instead fix the seed. Theoretically, the parameter covariance matrix is biased by a factor of $1 + 1/S$ which for $S = 300$ implies a less than 0.2% bias in standard errors.

[16]The 10 countries with complete data used to estimate the model are Australia, Austria, Canada, Finland, France, Germany, Italy, Japan, United Kingdom, and United States.

with respect to various closed economy statistics. This is shown in Panel B of Table 3.

Focusing on panel C of Table 3 which shows open economy moments not targeted during the estimation, there are a number of interesting differences between the model with home production and the model without home production. First, as in the data, output correlates more than market consumption across countries in the model with home production. By contrast, in the model without home production, market consumption correlates significantly more than output across countries. Market work is positively and highly correlated across countries in the model with home production, whereas it is negatively correlated across countries in the model without home production. Total investment is uncorrelated across countries in the model with home production, but it is negatively correlated in the model without home production. In addition, the model with home production generates a realistic comovement of the labor wedge across countries.

To understand these differences, Figure 7 plots responses of each country's market consumption, market work, leisure, and non-market work when market productivity in the home country z_H^m increases by one percent. In the model without home production, risk sharing ensures that consumption increases are highly correlated across countries. In the home country, labor increases reflecting the increase in the wage induced by higher market productivity. Labor in the foreign country, however, decreases which induces a negative comovement of labor inputs across countries. As it is well-known, when a positive market productivity shock hits the home country, the foreign country experiences a positive wealth effect which tends to depress the labor input (see e.g. Baxter and Crucini, 1995). In the model without home production, this wealth effect on foreign labor dominates any substitution effects from wage, interest rate, and relative price of traded goods movements. In turn, the negative correlation of labor inputs lowers the correlation of output across countries. Output is positively but weakly correlated across countries due to productivity spillovers and correlated market productivity innovations.

By contrast, substitution effects become more important in the model with home production under a high elasticity of substitution between market and home goods $\epsilon_H = 3.93$. In response to a positive market productivity shock in the home country, home market consumption and labor increase by more than in the model without home production as households substitute time and expenditure from the non-market to the market sector. The fact that market consumption becomes more responsive in the home country implies a lower correlation of market consumption across countries. In addition, foreign labor also increases as the substitution from non-market to market time induced by higher wage, interest rate, and relative prices now dominates the tendency of households to work less because of their increased wealth. Therefore, labor and output become highly correlated across countries.

Further, as Figure 7 shows, in both countries time spent on home production decreases more in percent terms than time spent on leisure. Since the cyclical component of the labor wedge is proportional to the difference between the cyclical components of home production and leisure, both countries experience a decrease in their labor wedge. Therefore, conditional on market productivity shocks, labor wedges are positively correlated across countries.[17]

While investment is positively correlated across countries in the data, the model without home production generates a negative investment correlation. Instead, the model with home production implies nearly uncorrelated investment across countries. This difference can be understood by recalling the difference in the response of market labor in the two models. In the model without home production, foreign households work less in response to a positive market productivity shock in the home country. The lower foreign labor decreases the foreign marginal product of capital and diminishes the incentive to invest capital in the foreign country. By contrast, in the model with home production, foreign labor increases in response to a positive market productivity shock in the home country. Even though the increase in foreign labor is not strong enough to induce a positive comovement of total investment, home production improves the performance of the model along this dimension. As discussed below, increasing the persistence of market productivity generates a positive comovement of investment across countries in the model with home production, but not in the model without home production.

Second, in the model with home production, the correlation between real exchange rates and relative market consumption is negative which explains the Backus and Smith (1993) puzzle. This correlation is, however, close to one in the model without home production. To understand this difference, consider the key efficiency condition under complete asset markets that sets the ratio of the marginal utilities of market consumption proportional to the real exchange rate:

$$\frac{U_{C_F^m}(C_{F,t}^m, C_{F,t}^n, L_{F,t})}{U_{C_H^m}(C_{H,t}^m, C_{H,t}^n, L_{H,t})} \propto \mathrm{RER}_t := \frac{P_{F,t}}{P_{H,t}}. \tag{27}$$

Consider a decrease in domestic market consumption $C_{H,t}^m$, for instance due to a negative market productivity shock in the home country. In the model without home production, the marginal utility of market consumption depends mostly on market consumption. Therefore, the domestic marginal utility increases and the real exchange rate appreciates. As a result, relative (domestic over foreign) market consumption is positively correlated with the real exchange rate. While leisure breaks the perfect correlation between relative market consumption and real exchange rates, the non-separability induced by leisure is not strong and the Backus-Smith

[17] In the data, the correlation of the labor wedge across countries is positive but low. The model succeeds in matching this fact because a productivity shock z_H^n in the home sector of the domestic country increases significantly the domestic labor wedge but does not affect much the foreign labor wedge. Therefore, the unconditional correlation of the labor wedge across countries is positive but relatively low.

correlation remains higher than 0.9.

In the model with home production, when domestic market consumption is low, households direct an increasing fraction of their non-market time to home production (increase in $C^n_{H,t}$). Because the two goods are substitutes, the marginal utility of market consumption does not increase as much as in the model without home production. In other words, the endogenous increase in home production acts as a taste shock which keeps the domestic marginal utility of market consumption relatively low. In this case, equation (27) implies that the real exchange rate need not appreciate much when domestic market consumption is relatively low.

The sign and magnitude of the correlation between the real exchange rate and relative market consumption depends on a host of factors, such as the elasticity of substitution between market and home consumption, the size of the home sector, the source of the shock, and its correlation with other sectoral or country shocks. Under the parameters estimated to match moments of the labor wedge, the mean correlation between relative market consumption and the real exchange rate is -0.44. Below I examine the sensitivity of this result to alternative parameterizations. In Section 5, I take the efficiency condition (27) to the data and show that home production helps explain the relationship between relative market consumption and real exchange rates, at business cycle frequencies and in the cross section of countries.

The model with home production generates countercyclical real net exports. In that respect, the results here differ from the results in the one-good model with endogenous incomplete markets of Kehoe and Perri (2002) and the results in the two-good model with financial autarky of Heathcote and Perri (2002). Both papers show that restrictions in international lending and borrowing help increase the cross country correlation of employment, investment, and output relative to the cross country correlation of consumption. However, in the first case the trade balance is procyclical and in the second case trade is always balanced. The model with home production matches cross country correlations in quantities closer than the benchmark model of Backus, Kehoe, and Kydland (1994, 1995), while generating countercyclical trade balances in the complete markets environment. This is because the improvement in cross country correlations reflects stronger substitution effects induced by home production, rather than frictions in international asset markets.

The calibrated value of the elasticity of substitution between traded goods $\epsilon_C = 1.5$ implies that the volatility of the import ratio relative to the volatility of the terms of trade matches closely its mean value in the data. In that respect, my results differ from Corsetti, Dedola and Leduc (2008), who explain the low degree of international risk sharing in economies with incomplete asset markets and either very low or very high values of this elasticity.[18]

[18] In Corsetti, Dedola, and Leduc (2008), the low elasticity of substitution between traded goods implies a downward sloping world demand for domestic traded goods with respect to the terms of trade. The incom-

To understand what features of the labor wedge help improve the open economy dimensions of the model, columns 5 to 8 of Table 3 present moments for alternative values of estimated parameters. In column 5 of Table 3, I set the variance of the shock in the home sector $\sigma_{\epsilon_i^n,\epsilon_i^n}$ equal to the variance of the shock in the market sector $\sigma_{\epsilon_i^m,\epsilon_i^m}$. Under less volatile home production shocks, the model-generated labor wedge is slightly less than two-thirds as volatile as the labor wedge in the data. This change also generates a labor wedge that is more negatively correlated with output and market productivity in the model. Thus, volatile shocks in the home sector reflect, in part, the low in magnitude correlation between the labor wedge and output and the positive unconditional correlation between the labor wedge and market productivity. Under $\sigma_{\epsilon_i^n,\epsilon_i^n} = \sigma_{\epsilon_i^m,\epsilon_i^m}$, the model still generates a negative correlation between real exchange rates and relative market consumption, a relatively low correlation of market consumption across countries, and a high correlation of labor inputs across countries.

In column 6 of Table 3, I set the elasticity of substitution between market and home goods ϵ_H to 2.5. This is lower than the mean estimated value of 3.93 in column 2. While Benhabib, Rogerson, and Wright (1991) set this elasticity equal to 5 in their most preferred specification, Aguiar, Hurst, and Karabarbounis (2011) estimate that a value of roughly $\epsilon_H = 2.5$ is consistent with reallocations of market work hours to home production time and leisure time in the U.S. between 2003 and 2010.[19] Under $\epsilon_H = 2.5$, the model-generated labor wedge is two-thirds as volatile as the labor wedge in the data. This result is consistent with the business cycle results of Section 3. This is because, when feeding estimates of Aguiar, Hurst, and Karabarbounis (2011) into the model, the model-generated labor wedge was found to be 65 percent as volatile as the labor wedge in the data. Further, under $\epsilon_H = 2.5$, the model still generates a negative correlation between real exchange rates and relative market consumption, a relatively low correlation of market consumption across countries, and a high correlation of labor inputs across countries.

In column 7 of Table 3, I decrease the correlation between market and home productivity shocks from roughly 0.66 to 0. When shocks in the two sectors are uncorrelated, the labor wedge becomes more volatile but, similar to lowering the volatility of home production shocks, the labor wedge becomes more countercyclical and negatively correlated with market productivity. Under $\sigma_{\epsilon_i^m,\epsilon_i^n} = 0$, the model still generates a negative correlation between real exchange rates

pleteness of the asset market in their model guarantees that the model behaves more like a financial autarky model than like a complete markets model upon impact of productivity shocks. In a model with financial autarky and a downward sloping world demand, any shock that contracts world demand less than supply (i.e. a "supply disturbance") depreciates the terms of trade. Therefore, the Backus-Smith correlation turns negative. In contrast, in the model here world demand is upward sloping and asset markets are complete.

[19] McGrattan, Rogerson, and Wright (1997) estimate this elasticity to be slightly less than 2. Chang and Schorfheide (2003) estimate an elasticity of roughly 2.3. Rupert, Rogerson, and Wright (1995) estimate an elasticity of roughly 1.8.

and relative market consumption, a relatively low correlation of market consumption across countries, and a high correlation of labor inputs across countries.

In column 8 of Table 3, I set the persistence of home productivity shocks $\rho_{z_i^n,z_i^n}$ to 0.995. This change produces, again, more countercyclical labor wedges in the model. Under this higher value, the model-generated labor wedge becomes more volatile than in the data. Now the model with home production differs even more from the standard model in its open economy predictions. The correlation between real exchange rates and relative market consumption is close to negative one and market consumption is negatively correlated across countries. At the same time, the model still generates a positive comovement of labor and output across countries. However, labor wedges become negatively correlated across countries.

Table 4 presents two additional results of interest. The first result, presented in columns 3 and 4, is that the properties of the home production model are robust to reasonable variations of the elasticity of substitution between traded goods ($\epsilon_C = 0.5$ and $\epsilon_C = 2.5$). With the exception of the volatility of the terms of trade and the volatility of the import ratio, all other domestic and open economy moments are not sensitive to such variations.

Columns 5 to 8 of Table 4 contrast the home production model to the workhorse model of Backus, Kehoe, and Kydland (1994), as I vary the persistence and the spillover parameter of market productivity z^m. First, I set the market productivity spillover $\rho_{z_i^m,z_j^m} = 0$ both in the model without home production (column 5) and in the model with home production (column 6). In columns 7 and 8, I set the market productivity spillovers to zero and increase the persistence of market productivity to $\rho_{z_i^m,z_i^m} = 0.995$.

Two results worth highlighting. First, shutting down market productivity spillovers across countries increases the cross country correlation of labor and investment both in the model without home production and in the model with home production. The reason is that, in the absence of productivity spillovers, the wealth effect which tends to induce a negative comovement becomes weaker. However, the model without home production still generates a higher correlation of market consumption than output across countries and a nearly perfect correlation of real exchange rates with relative market consumption. By contrast, the model with home production generates positive comovement in quantities with output and labor being more correlated across countries relative to market consumption and investment, and a negative correlation of real exchange rates with relative market consumption.

Second, increasing the persistence of market productivity shocks clearly deteriorates the performance of the model without home production. As in the benchmark calibration of column 4 of Table 3, output is less correlated than market consumption across countries, the cross country correlation of labor and investment is negative, and the real exchange rate is almost perfectly correlated with relative market consumption. In addition, real net exports become procyclical. By contrast, the model with home production and persistent shocks to market productivity comes very close to matching stylized facts, along all these dimensions.

5 Real Exchanges Rates and Time Use

This section presents evidence on the relationship between real exchange rates, relative market consumption, and the allocation of time at business cycle frequencies and in the cross section of countries. I start by log-linearizing the Backus-Smith condition in a model without leisure and home production in the utility function:

$$\widehat{\mathrm{RER}}_t = \widehat{U_{C^m_{F,t}}} - \widehat{U_{C^m_{H,t}}} = \sigma\left(\widehat{C^m_{H,t}} - \widehat{C^m_{F,t}}\right). \tag{28}$$

Under separable preferences, real exchange depreciations are proportional to relative market consumption changes. This condition has been tested extensively in open economy macroeconomics, with the typical finding being that real exchange rates do not correlate (or correlate negatively) with relative market consumption. To quantify the Backus-Smith puzzle, I define a residual from the efficiency condition that, under separable preferences, real exchange rates should be proportional to relative market consumption.

Definition 2. Measured Backus-Smith Residual: *The change in the measured Backus-Smith residual $\widehat{BSR}^e_t$ is defined as the deviation between changes in real exchange rates and changes in relative market consumption scaled by the coefficient of relative risk aversion:*

$$\widehat{BSR}^e_t := \widehat{RER}_t - \sigma\left(\widehat{C^m_{H,t}} - \widehat{C^m_{F,t}}\right). \tag{29}$$

In the model with home production, the Backus-Smith residual will in general not be equal to zero. I now derive the theoretical analog of the measured Backus-Smith residual in the model with home production. First, write the marginal utility of market consumption for the home country as:

$$U_{C^m_{H,t}} = \left(\frac{(1-a_L)(1-a_h)U_{H,t}^{1-\sigma}}{C^m_{H,t}}\right)\left(\frac{C^m_{H,t}}{C_{H,t}}\right)^{\frac{\epsilon_H-1}{\epsilon_H}}. \tag{30}$$

Using the functional form for the consumption aggregator $C_{H,t}$ and the utility function $U_{H,t}$, the log-linearized version of the marginal utility of market consumption in equation (30) becomes:

$$\widehat{U_{C^m_{H,t}}} = -\chi_1\widehat{C^m_{H,t}} - \chi_2\widehat{L_{H,t}} - \chi_3\widehat{R_{H,t}}, \tag{31}$$

$$\chi_1 = 1 + (1-a_L)(\sigma-1),$$

$$\chi_2 = a_L(\sigma-1),$$

$$\chi_3 = \left(1 - \frac{\epsilon_H(1-a_L)(1-\sigma)}{\epsilon_H - 1}\right)\left(\frac{R^*}{\chi - R^*}\right),$$

where $R_{H,t} = N^n_{H,t}/L_{H,t}$ denotes the home production to leisure time ratio and asterisks denote approximation points. Using the model's condition $\widehat{\text{RER}}_t = \widehat{U_{C^m_{F,t}}} - \widehat{U_{C^m_{H,t}}}$, the following proposition yields an expression for the Backus-Smith residual in the model with home production.

Proposition 2. Model-Generated Backus-Smith Residual: *The change in the model-generated Backus-Smith residual $\widehat{BSR}_t$ is:*

$$\widehat{BSR}_t = (\chi_1 - \sigma)\left(\widehat{C^m_{H,t}} - \widehat{C^m_{F,t}}\right) + \chi_2\left(\widehat{L_{H,t}} - \widehat{L_{F,t}}\right) + \chi_3\left(\widehat{R_{H,t}} - \widehat{R_{F,t}}\right). \tag{32}$$

A limiting case of the model-generated Backus-Smith residual is when $a_L = 0$, that is when leisure does not enter into the utility function (or enters in a separable way from market consumption), and when $a_h = R^* = 0$, that is when there is no home production in the model. In that case, the change in the model-generated Backus-Smith residual is equal to zero, simply because the Backus-Smith condition under separable preferences holds exactly in the model.

The goal is to compare the Backus-Smith residual as measured by the standard condition (29) with the model-generated Backus-Smith residual when preferences are non-separable as measured by equation (32). If non-separable preferences explain failures of the Backus-Smith condition, then we should see a positive relationship between the model-generated Backus-Smith residual and the residual as measured in the data.

Before taking equation (32) to the data, I deal with two issues. First, as with the labor wedge, a challenge to testing implications of non-separabilities for real exchange rates is that consistent and long time series on home production time and leisure time are not available for any country. Once again, for business cycle analysis, I will therefore use the results of Aguiar, Hurst, and Karabarbounis (2011) and set $\widehat{R_{i,t}} = -0.56 * \widehat{N^m_{i,t}}$ and $\widehat{L_{i,t}} = -0.32 * \widehat{N^m_{i,t}}$ to construct the model-generated Backus-Smith residual.

Second, movements in the real exchange rate in the model are solely because of terms of trade movements and the model abstracts from any nominal factors. Therefore, in addition to the residual as measured by equation (29), I consider two adjustments. The first adjustment is to test directly whether the model predicts terms of trade movements. Since in the model we have $\widehat{\text{RER}}_t = (2a_C - 1)\widehat{T}_t$, I define the measured Backus-Smith residual as $\widehat{\text{BSR}}^e_t := (2a_C - 1)\widehat{T}_t - \sigma\left(\widehat{C^m_{H,t}} - \widehat{C^m_{F,t}}\right)$. The second adjustment takes out the influence of nominal exchange rates (which are very volatile) and defines the Backus-Smith residual in the data as $\widehat{\text{BSR}}^e_t := \widehat{\text{RER}}_t - \widehat{\text{NER}}_t - \sigma\left(\widehat{C^m_{H,t}} - \widehat{C^m_{F,t}}\right)$, where $\widehat{\text{NER}}_t$ denotes the change in the bilateral nominal exchange rate. These two adjustments are especially important at business cycle frequencies, since the model abstracts from nominal exchange rate volatility and non-traded market goods.

Table 5 compares the measured Backus-Smith residual to the model-generated Backus-Smith residual at business cycle frequencies along three dimensions, their correlation, their relative standard deviation, and the R-squared from a regression of the former on a constant and the latter. All statistics are means across 45 bilateral exchange rates (10 countries). The first panel of the table presents these statistics when no adjustment to the real exchange rate series is made, the second panel presents these statistics when the terms of trade is used to measure the residual in the data, and the third panel presents these statistics when subtracting the nominal exchange rate from the real exchange rate. Figure 8 shows bilateral U.S. Backus-Smith residuals in the data (reflecting terms of trade movements) and U.S. model-generated Backus-Smith residuals.

Under the parameters estimated in Section 4, the model generates a Backus-Smith residual which is highly positively correlated with the residual as measured in the data (correlations between 0.30 and 0.47), is 34 to 59 percent as volatile as the residual in the data, and which captures 14 to 24 percent of the variation in the residual in the data. As Table 5 shows, increasing σ to 5 as proposed by Chari, Kehoe, and McGrattan (2002) significantly improves the performance of the home production model in explaining the residual from the Backus-Smith condition. Under $\sigma = 5$, the model generates a Backus-Smith residual which displays a correlation between 0.54 and 0.64 with the residual in the data, which is 62 to 80 percent as volatile as the residual in the data, and which captures 31 to 43 percent of the variation in the residual in the data. To summarize, home production clearly generates a close comovement between the residual in the data and the residual in the model, but generates less volatile residuals than observed in the data.

Figure 9 presents the second test which is based on long-term relationships in the cross section of countries. In parallel to the labor wedge tests, I examine the correlation between changes in the measured bilateral Backus-Smith residual and changes in the model-generated bilateral Backus-Smith residual. Each observation in Figure 4 plots the change in the measured residual $\Delta \log \mathrm{BSR}^{e}_{HF,t}$ for countries H and F against the change in the model-generated residual $\Delta \log \mathrm{BSR}_{HF,t}$. The model-generated residual assumes parameters as estimated in the model of Section 4. In the two upper panels the measured Backus-Smith residual is constructed using the real exchange rate and in the two lower panels the measured Backus-Smith residual is constructed using the terms of trade. In the two left panels the definition of home production excludes child care, whereas in the two right panels it includes child care. The correlation between the two variables ranges between 0.20 and 0.38 across the four panels and is statistically significant at conventional levels.

Finally, as with the labor wedge, I differentiate between home production versus leisure explanations of the residual from the Backus-Smith condition. To explain the Backus-Smith residual, leisure-based non-separabilities must have leisure and consumption enter as substitutes in the utility function. This implies that for various class of preferences, including the CES utility function in (21) with $\epsilon_L > 1$ and the isoelastic/GHH preferences in (22), the Backus-Smith residual is positively related to time spent on leisure conditional on market consumption. For the home production model, equation (32) shows that time spent on home production enters positively conditional on market consumption. For leisure the result is theoretically ambiguous but, for parameter values used in the model, leisure enters with a negative coefficient.

The upper panels of Figure 10 show the unconditional relationship between home production time (with and without child care) and the measured Backus-Smith residual in the data. There is a positive relationship, as predicted by the home production explanation of the Backus-Smith residual. The lower panels show the unconditional relationship between leisure time (with and without sleeping) and the measured Backus-Smith residual in the data. There is essentially a flat relationship. To test conditional relationships, I estimate:

$$\Delta \log \mathrm{BSR}^e_{i,t} = \underset{[-0.229,\, 0.812]}{(+0.291)}\, \Delta\Delta \log L_{i,t} + \underset{[-2.975,\, -2.222]}{(-2.599)}\, \Delta\Delta \log C^m_{i,t},$$

$$\Delta \log \mathrm{BSR}^e_{i,t} = \underset{[0.014,\, 1.070]}{(+0.542)}\, \Delta\Delta \log L_{i,t} + \underset{[-2.780,\, -2.003]}{(-2.391)}\, \Delta\Delta \log C^m_{i,t} + \underset{[0.209,\, 1.151]}{(+0.680)}\, \Delta\Delta \log N^n_{i,t},$$

where the double difference operator denotes differencing across time and across countries with time use surveys belonging to the same cross section and the brackets denote 90 percent confidence intervals for estimated coefficients. To summarize, the first regression rejects leisure-based explanations of the Backus-Smith residual as leisure enters with an insignificant coefficient. The second regression shows that home production time enters with a positive coefficient as predicted by the model with home production. However, leisure also enters with a positive coefficient whereas, for the parameters used in Section 4, this coefficient should have been negative.

6 Conclusions

This paper explores the role of non-separable preferences with home production for international business cycles. Non-separabilities in preferences have the potential to account for several discrepancies between the data and predictions of the workhorse international business cycle model, as they introduce a wedge between market consumption and its marginal utility and they induce stronger substitution patterns over time and across states. The contribution of the paper is to propose two strategies that help discipline and interpret these non-separabilities.

The first main finding is that when the parameters of the home sector are estimated to generate a labor wedge in the model that mimics its empirical analog in several moments, the standard international business cycle model with complete asset markets comes closer to matching key stylized facts of international data. Specifically, the model accounts for the high correlation of output and employment across countries, the low but positive correlation of market consumption across countries, the low but positive comovement of the labor wedge across countries, and the negative relationship between relative market consumption and real exchange rates observed in the data. The model with home production comes closer than the workhorse international business cycle model to explaining the correlation of investment across countries, and matches this correlation when shocks to market productivity are persistent.

Previous literature has related the low degree of international risk sharing and deviations from the efficiency condition that the marginal product of labor be equal to the marginal rate of substitution to imperfections in asset and labor markets. My results suggest that such imperfections are not necessary elements to explaining these features of the data. Unaccounted for substitution of time between the market and the home sector goes a long way towards explaining these features. In fact, within the complete asset markets model, any joint explanation of labor wedges, real exchange rates, and relative market consumption must necessarily attribute an important role to non-separable preferences.

Using international time use data, the second main finding is that the non-separability induced by home production helps explain a significant fraction of variations in the labor wedge and the real exchange rate. The tests show a significant relationship between time spent on home production, the labor wedge, and real exchange rates adjusted for relative market consumption scaled by the coefficient of relative risk aversion, both at business cycle frequencies and in the cross section of countries. Leisure time, as opposed to home production time, does not help explain these patterns.

In theory, a model in which home production provides a substitute to market consumption is equivalent to a model without home production but in which consumption and leisure are substitutable. For some purposes, the shortcut of using a model with non-separable preferences between consumption and leisure may be warranted. However, my results show that such non-separabilities can be difficult to detect in the data and interpret unless one differentiates between home production time and leisure time.

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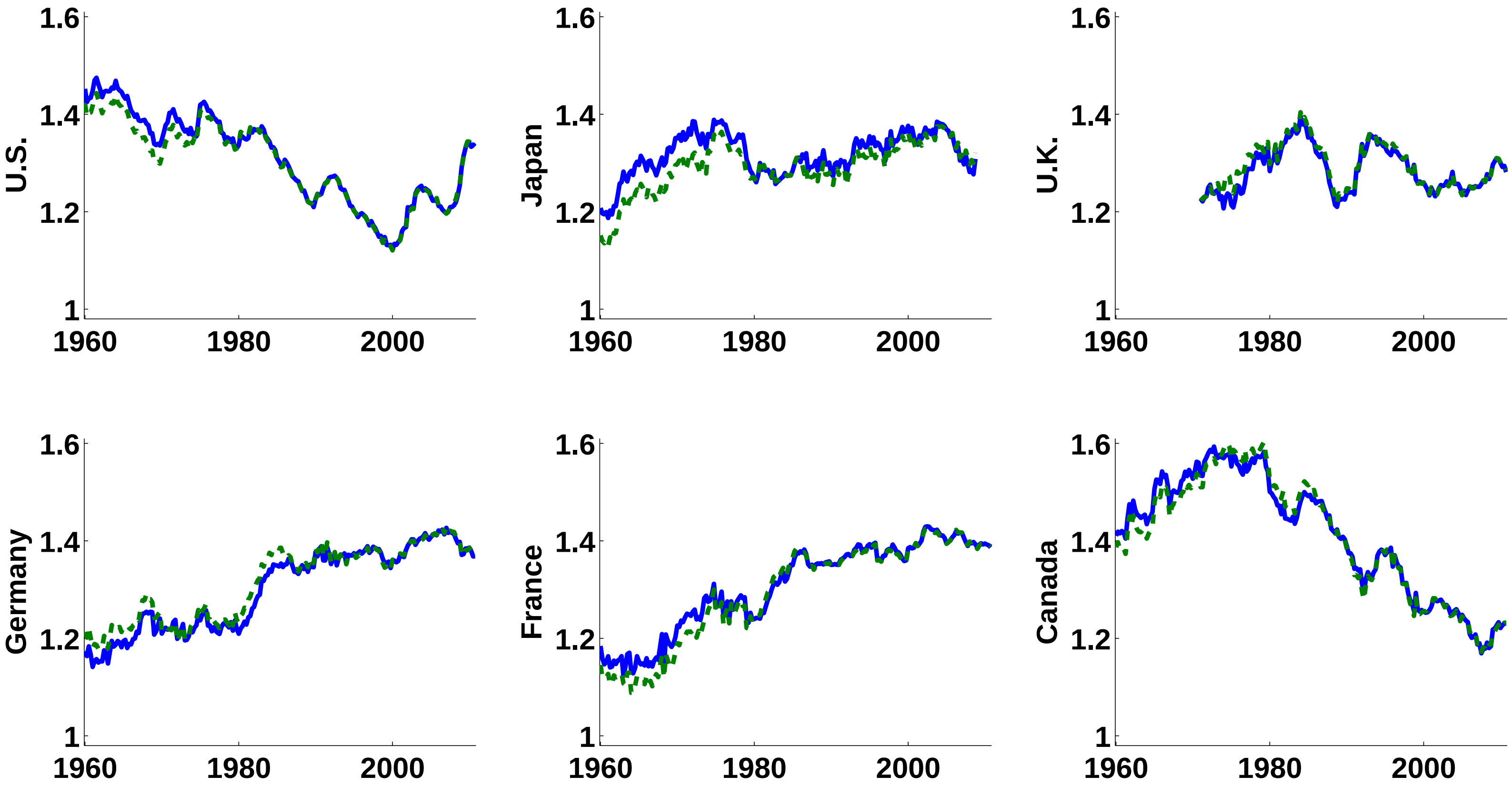
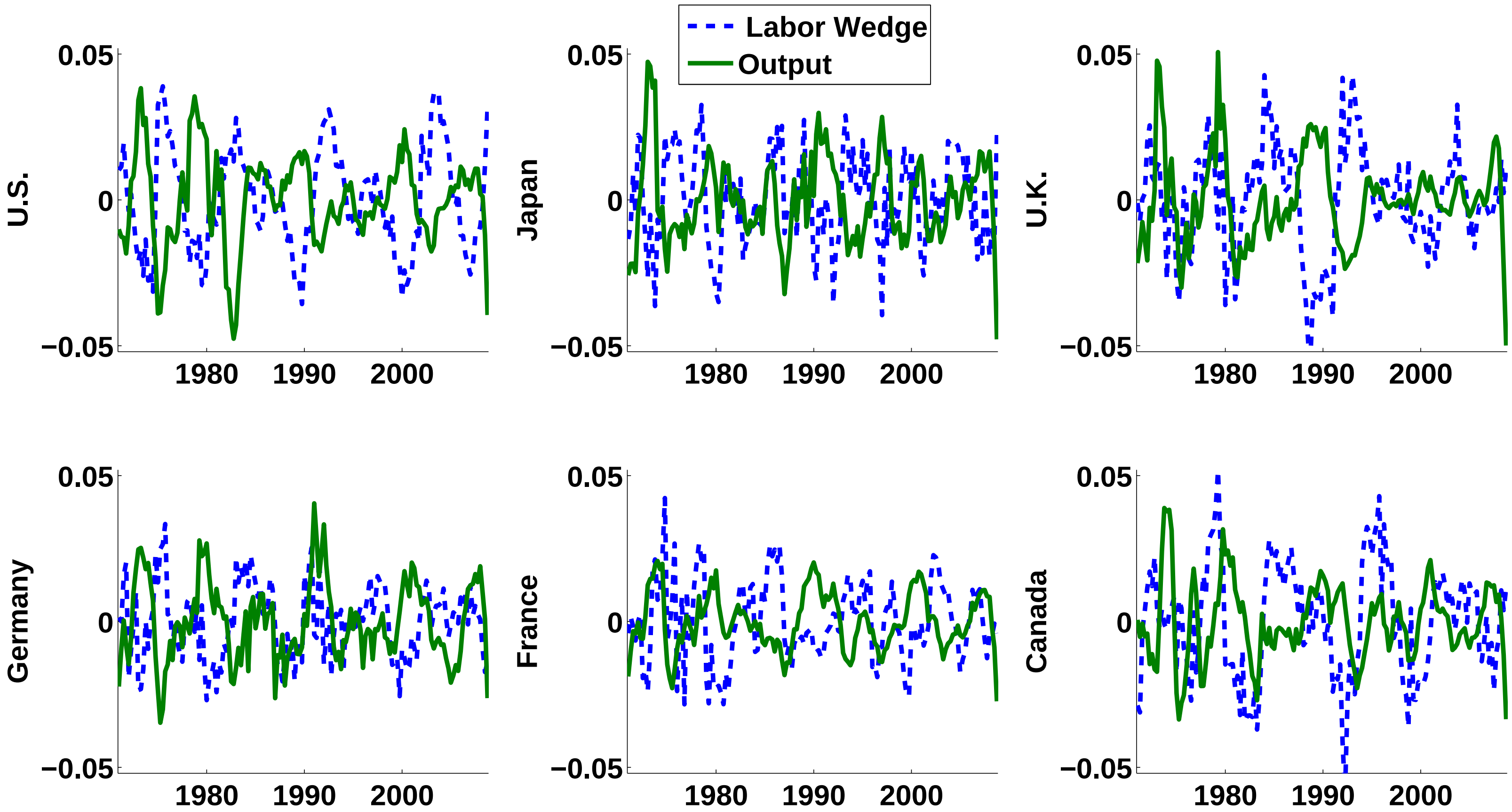
Figure 1: Measured Labor Wedges: Levels



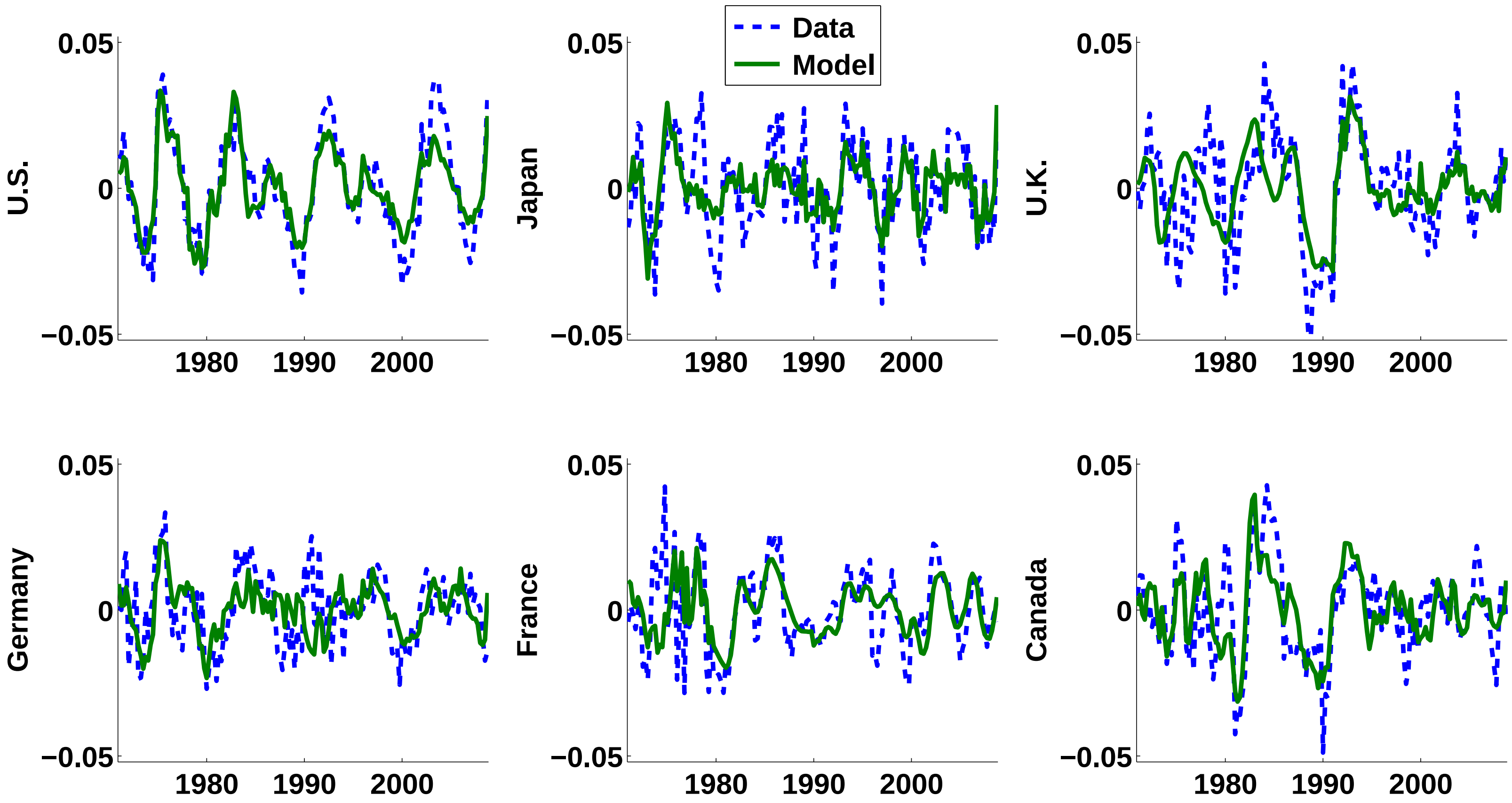
Notes: The solid line is the measured labor wedge constructed according to equation (15), after adjusting for consumption and income taxes, using data on consumption, output, total market work hours, and the terms of trade. The dashed line sets the first term of equation (15) equal to one (when the terms of trade is one), and so this series for the measured labor wedge does not adjust for terms of trade fluctuations. The terms of trade equals one on average during 2005, and therefore the two series roughly coincide in 2005.

Figure 2: Measured Labor Wedges: Cycles



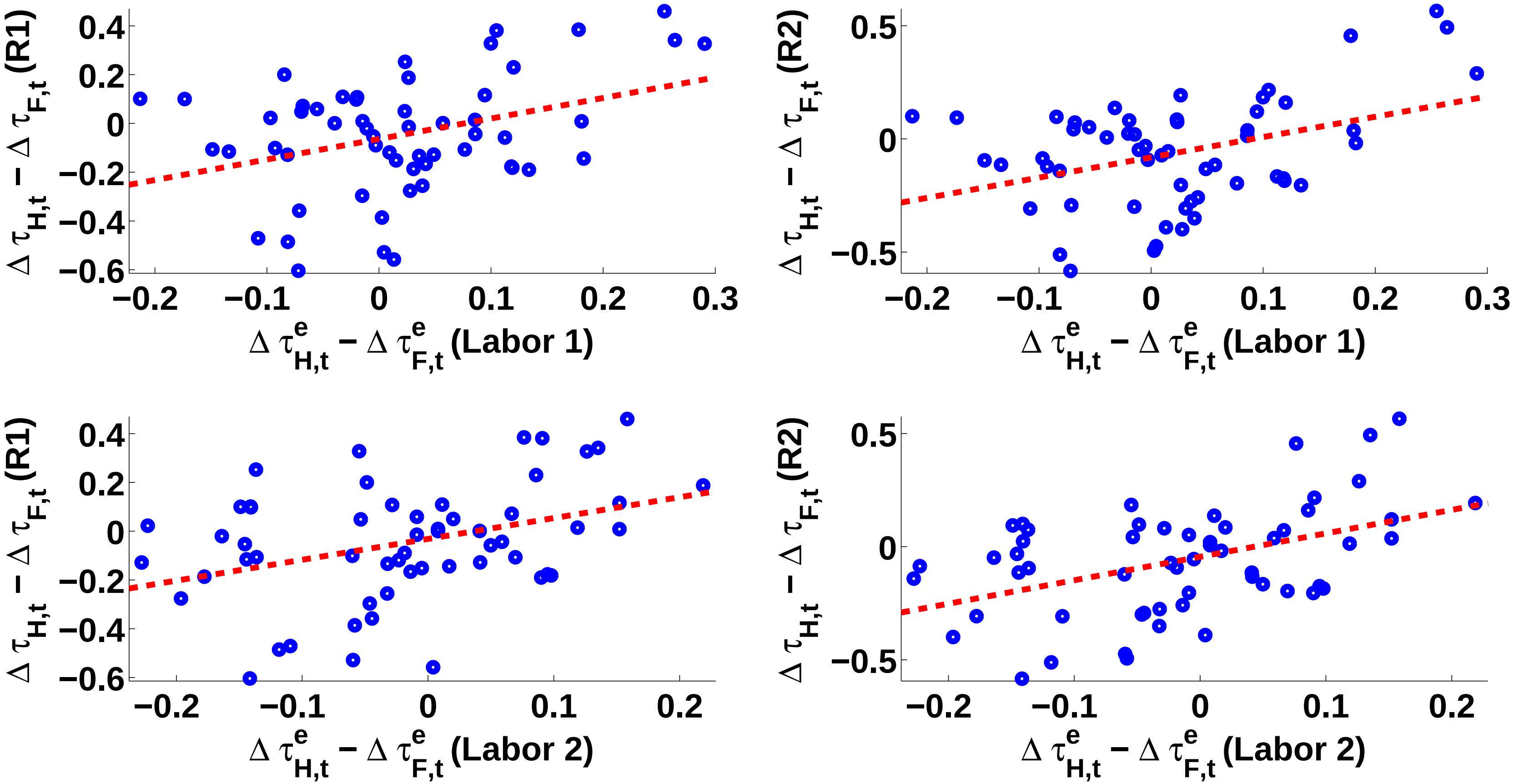
Notes: The dashed line is the cyclical component of the measured labor wedge constructed according to equation (15), after adjusting for consumption and income taxes, using data on consumption, output, total market work hours, and the terms of trade. The solid line is the cyclical component of output. Both series are HP filtered with smoothing parameter equal to 1600.

Figure 3: Labor Wedges: Data vs. Model (Business Cycles)



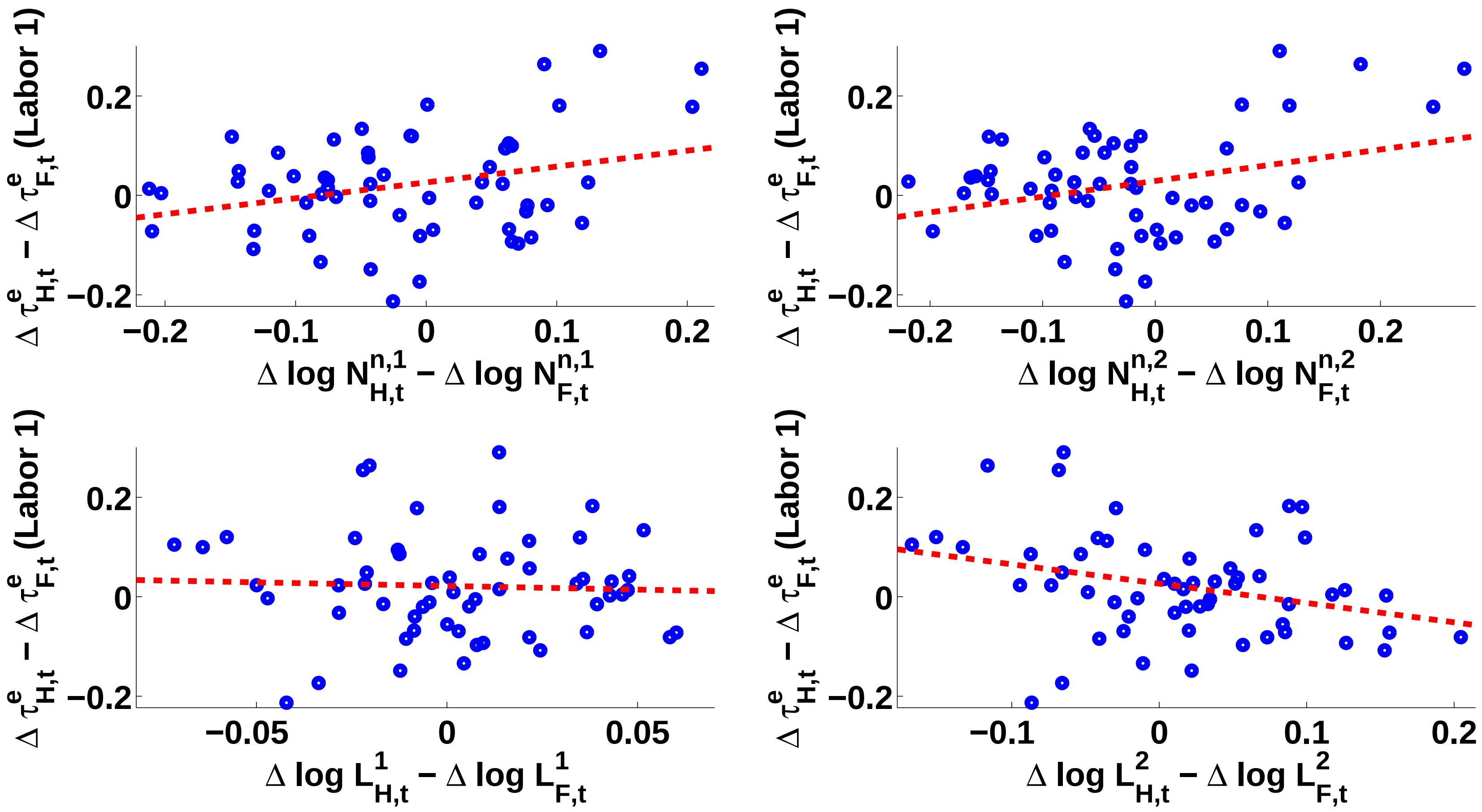
Notes: The dashed line is the cyclical component of the measured labor wedge constructed according to equation (15), after adjusting for consumption and income taxes, using data on consumption, output, total market work hours, and the terms of trade. The solid line shows the cyclical component of the model-generated labor wedge, constructed according to equation (20) and using estimates in Aguiar, Hurst, and Karabarbounis (2011). All series are HP filtered with smoothing parameter equal to 1600.

Figure 4: Labor Wedges: Data vs. Model (Cross Section)



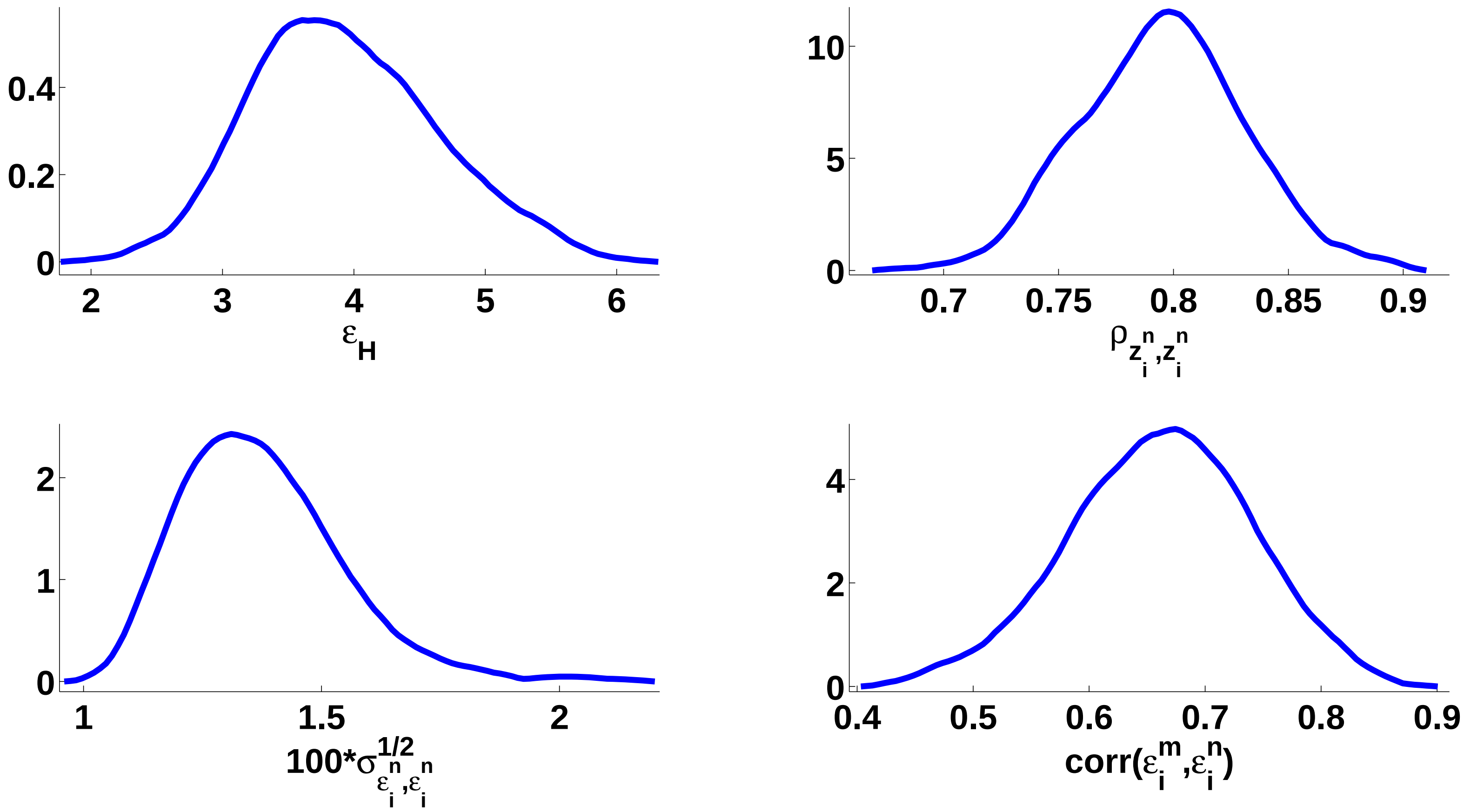
Notes: Each panel plots the difference between two countries in the change in their measured labor wedge ($\Delta\tau^e_{H,t} - \Delta\tau^e_{F,t}$) against the difference between the same two countries in the change in their model-generated labor wedge ($\Delta\tau_{H,t} - \Delta\tau_{F,t}$). The measured labor wedge is constructed according to equation (15), after adjusting for consumption and income taxes, using data on consumption, output, market work hours, and the terms of trade. The model-generated labor wedge is constructed according to equation (20). In the two upper panels the measured labor wedge is constructed using total market hours of work ("Labor 1") and in the two lower panels the measured labor wedge is constructed using only the total number of employed ("Labor 2"). In the two left panels the model-generated labor wedge is constructed using a definition of home production that excludes child care ("R1"), while in the two right panels the model-generated labor wedge is constructed using a definition of home production that includes child care ("R2").

Figure 5: Labor Wedges, Home Production, and Leisure



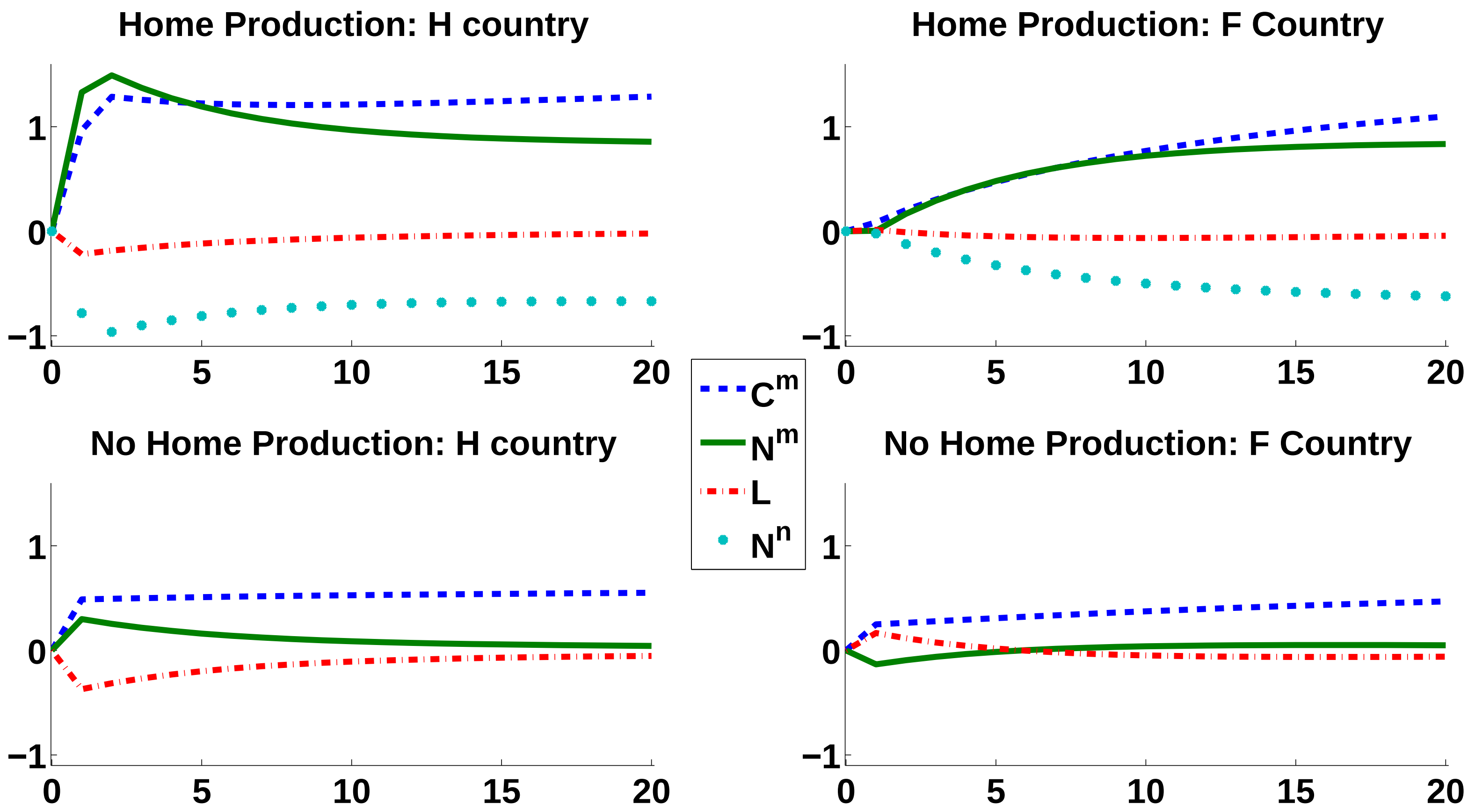
Notes: Each panel plots the difference between two countries in the change in their measured labor wedge $(\Delta\tau^{e}_{H,t} - \Delta\tau^{e}_{F,t})$ against the difference between the same two countries in the change in their time use. The measured labor wedge is constructed according to equation (15), after adjusting for consumption and income taxes, using data on consumption, output, market work hours, and the terms of trade. In the two left panels the measured labor wedge is constructed using total market hours of work ("Labor 1") and in the two right panels the measured labor wedge is constructed using only the total number of employed ("Labor 2"). In the upper left panel home production excludes child care (superscript 1), whereas in the upper right panel home production includes child care (superscript 2). In the lower left panel leisure includes sleeping (superscript 1), whereas in the lower right panel leisure excludes sleeping (superscript 2).

Figure 6: Distribution of Estimated Parameters



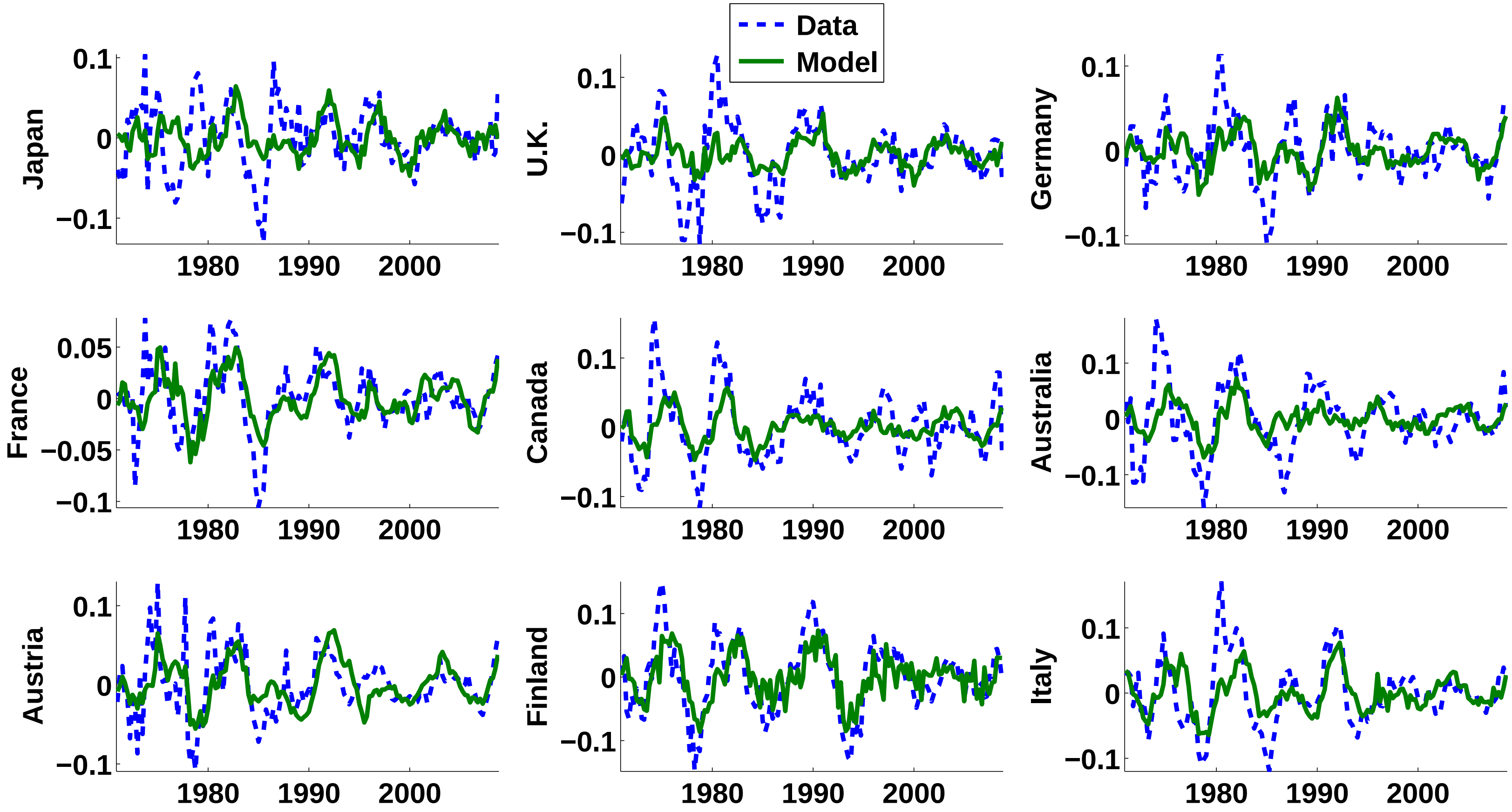
Notes: The panels show the distribution of estimated parameters. The distributions are based on kernel estimates of the probability density function of 200 Monte Carlo parameter estimates as discussed in the text. ϵ_H is the elasticity of substitution between market and home goods; $\rho_{z_i^n, z_i^n}$ is the persistence parameter for productivity in the home sector; $100 * \sigma^{1/2}_{\epsilon_i^n, \epsilon_i^n}$ is the percent standard deviation of the productivity shock in the home sector; $\mathrm{corr}(\epsilon_i^m, \epsilon_i^n)$ is the cross-sector correlation of innovations in productivity. The subscript $i = H, F$ denotes the country and the superscript $j = m, n$ denotes the sector.

Figure 7: Impulse Responses to One Percent Increase in z_H^m



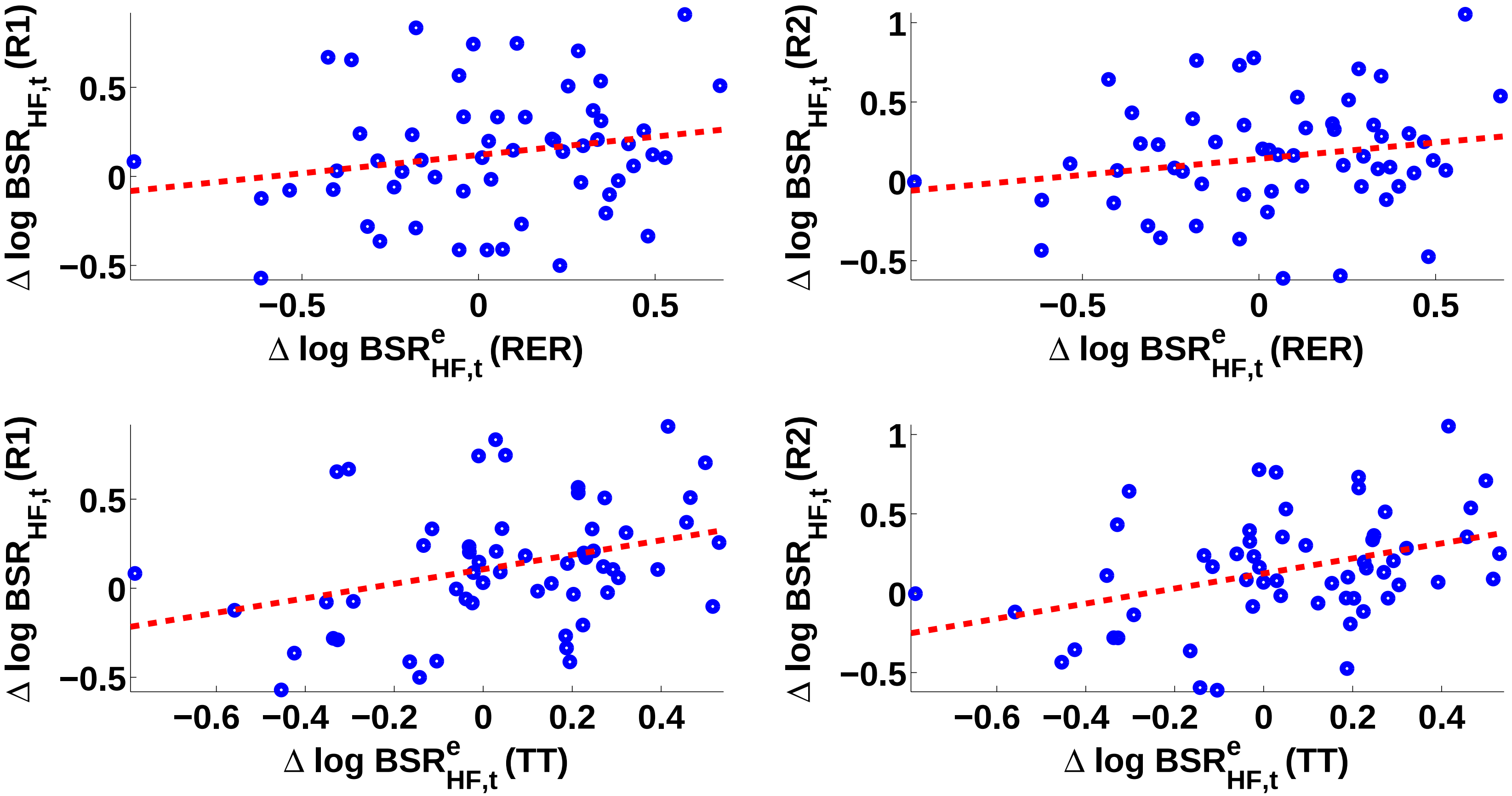
Notes: The figure plots impulse responses to a one percent increase in domestic market productivity z_H^m. The vertical axis measures percent changes relative to steady state values. The upper panels show impulses in the home production model, under the parameters shown in Table 2. The lower panels show impulses in the model without home production, i.e. when the preference parameter for home goods is $a_h = 0$.

Figure 8: US vs. Foreign Backus-Smith Residual: Data vs. Model (Business Cycles)



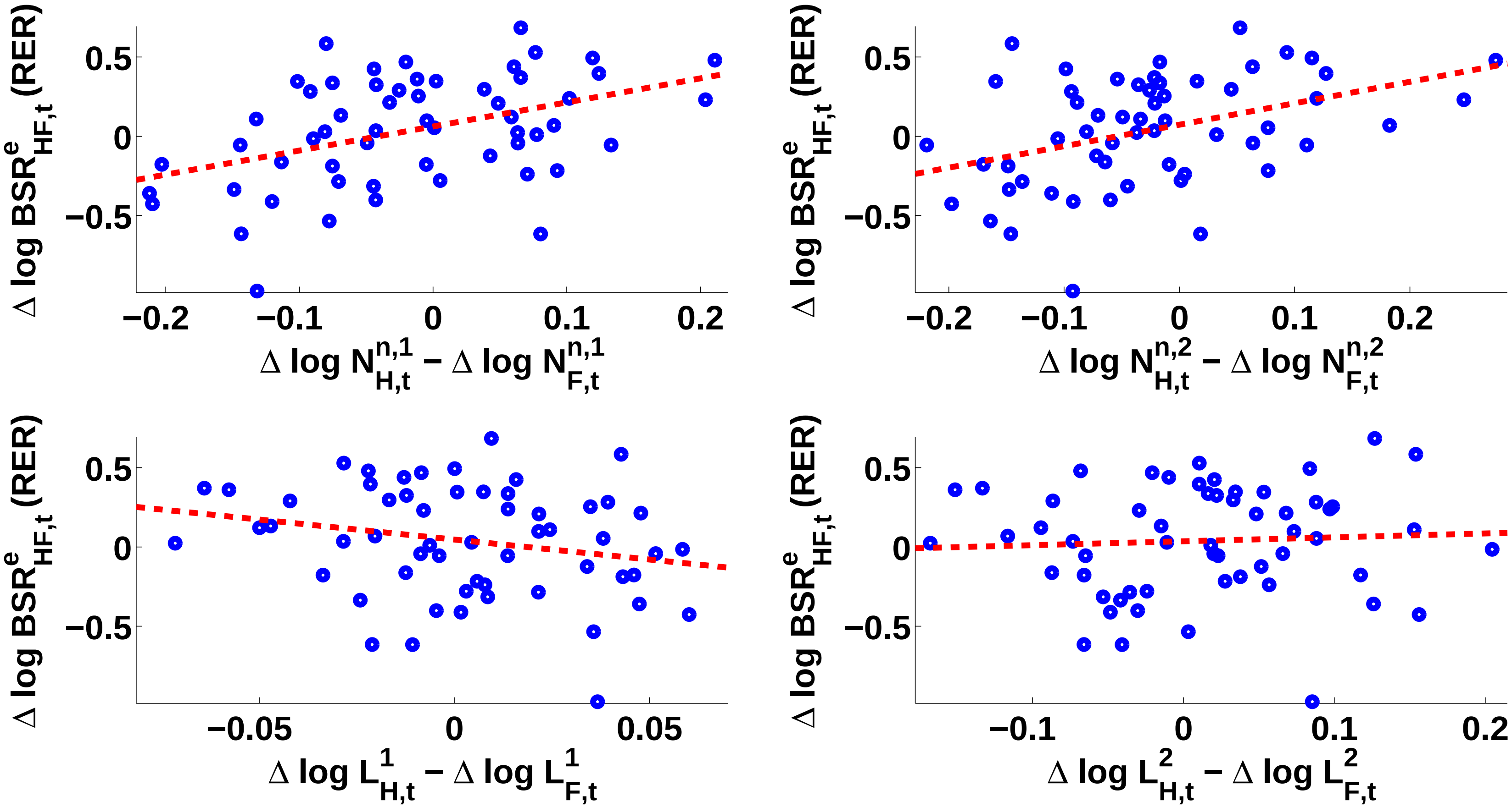
Notes: The dashed line is the cyclical component of the measured Backus-Smith residual of the U.S. against foreign countries, constructed according to equation (29), and adjusted to reflect terms of trade movements as explained in the text. The solid line shows the cyclical component of the model-generated Backus-Smith residual of the U.S. against foreign countries, constructed according to equation (32). All series are HP filtered with smoothing parameter equal to 1600.

Figure 9: Backus-Smith Residual: Data vs. Model (Cross Section)



Notes: Each panel plots the change in the measured bilateral Backus-Smith residual ($\Delta \log \mathrm{BSR}^{e}_{HF,t}$) against the change in the model-generated bilateral Backus-Smith residual ($\Delta \log \mathrm{BSR}_{HF,t}$). The measured Backus-Smith residual is constructed according to equation (29). The model-generated Backus-Smith residual is constructed according to equation (32). In the two upper panels the measured Backus-Smith residual wedge is constructed using the real exchange rate ("RER"), while in the two lower panels the measured Backus-Smith residual is constructed using the terms of trade ("TT"). In the two left panels, the model-generated Backus-Smith residual is constructed using a definition of home production that excludes child care ("R1"), while in the two right panels the model-generated Backus-Smith residual is constructed using a definition of home production that includes child care ("R2").

Figure 10: Backus-Smith Residual, Home Production, and Leisure



Notes: Each panel plots the change in the measured bilateral Backus-Smith residual ($\Delta \log \text{BSR}^{e}_{HF,t}$) against the difference between the same two countries in the change in their time use. The measured Backus-Smith residual is constructed according to equation (29). In the upper left panel home production excludes child care (superscript 1), while in the upper right panel home production includes child care (superscript 2). In the lower left panel leisure includes sleeping (superscript 1), while in the lower right panel leisure excludes sleeping (superscript 2).

Table 1: Stylized Facts, 1971(1)–2007(4)

	Mean (1)	**Median** (2)	**Minimum** (3)	**Maximum** (4)	**U.S.** (5)
A. Labor Wedge Moments					
$\text{sd}(\tau_H)/\text{sd}(y_H)$	1.26	1.24	0.92	1.52	1.15
$\text{corr}(\tau_H, y_H)$	-0.22	-0.24	-0.68	0.22	-0.68
$\text{corr}(\tau_H, z_H^m)$	0.17	0.21	-0.27	0.49	-0.27
$\text{corr}(\tau_H, \tau_{H,-1})$	0.69	0.69	0.56	0.87	0.87
τ_H^*	1.36	1.34	1.28	1.55	1.28
B. Closed Economy Moments					
$\text{sd}(c_H)/\text{sd}(y_H)$	1.03	1.03	0.78	1.27	0.83
$\text{sd}(i_H)/\text{sd}(y_H)$	3.18	3.15	2.26	4.28	2.84
$\text{sd}(emp_H)/\text{sd}(y_H)$	0.94	0.92	0.69	1.70	0.93
$\text{corr}(c_H, y_H)$	0.67	0.67	0.34	0.91	0.86
$\text{corr}(i_H, y_H)$	0.72	0.77	-0.05	0.95	0.95
$\text{corr}(emp_H, y_H)$	0.58	0.61	0.18	0.87	0.87
C. Open Economy Moments					
$\text{sd}(tt_H)/\text{sd}(y_H)$	2.29	1.73	0.99	4.57	1.71
$\text{sd}(iqrty_H)/\text{sd}(tt_H)$	1.72	1.54	0.85	3.68	1.48
$\text{corr}(tt_H, y_H)$	-0.06	-0.02	-0.52	0.40	-0.17
$\text{corr}(nxqty_H, y_H)$	-0.27	-0.30	-0.76	0.21	-0.45
$\text{corr}(y_H, y_F)$	0.30	0.33	0.10	0.44	0.37
$\text{corr}(c_H, c_F)$	0.18	0.22	0.03	0.29	0.24
$\text{corr}(i_H, i_F)$	0.23	0.25	0.00	0.37	0.25
$\text{corr}(emp_H, emp_F)$	0.24	0.28	0.03	0.36	0.32
$\text{corr}(z_H, z_F)$	0.15	0.16	-0.06	0.33	0.33
$\text{corr}(\tau_H, \tau_F)$	0.12	0.15	-0.10	0.22	0.14
$\text{corr}(tt, c_H/c_F)$	-0.12	-0.10	-0.42	0.07	-0.21
$\text{corr}(rer, c_H/c_F)$	-0.16	-0.12	-0.62	0.06	-0.19

Notes: y, c, i emp, $iqrty$, $nxqty$, z, τ, tt, and rer denote market output, market consumption, total investment, total market work hours, import ratio in constant prices, net exports in constant prices divided by GDP, market productivity, labor wedge, terms of trade, and real exchange rate. An asterisk denotes mean values in the sample. All variables (except for means) denote deviations from their trends. Trends are computed with the HP filter, using a smoothing parameter of 1600. The variables $nxqty$, z, and τ are in levels, and all other variables are in logs. The statistics are computed for 18 countries. Countries missing data for some statistic are not dropped from the sample when computing other statistics. The subscript $i = H, F$ denotes the country.

Table 2: Parameter Values

Panel A: Fixed Parameters	**Parameter**	**Value**	**Parameter**	**Value**
	ϵ_C	1.500	a_C	0.850
	a_L	0.410	α_m	0.360
	α_n	0.080	β	0.990
	σ	2.000	δ	0.025
	$\rho_{z_i^m, z_i^m}$	0.906	$\rho_{z_i^m, z_j^m}$	0.088
	$100 * \sigma^{1/2}_{\epsilon_i^m, \epsilon_i^m}$	0.852	$\text{corr}(\epsilon_i^m, \epsilon_j^m)$	0.258
Panel B: Estimated Parameters	**Parameter**	**Mean**	**Standard Error**	**[5th, 95th]**
	ϵ_H	3.931	0.670	[2.947,5.141]
	a_h	0.658	0.006	[0.647,0.667]
	$\rho_{z_i^n, z_i^n}$	0.795	0.034	[0.742,0.851]
	$100 * \sigma^{1/2}_{\epsilon_i^n, \epsilon_i^n}$	1.374	0.162	[1.163,1.648]
	$\text{corr}(\epsilon_i^m, \epsilon_i^n)$	0.661	0.075	[0.524,0.780]

Notes: ϵ_C is the elasticity of substitution between traded goods; a_C is the preference parameter in the traded goods aggregator; a_L is the Cobb-Douglas exponent on leisure; α_m is the share of capital in the production of market output; α_n is the share of capital in the production of home output; β is the discount factor; σ is the relative risk aversion parameter in the utility function; δ is the depreciation parameter in the capital accumulation equation; $\rho_{z_i^m, z_i^m}$ is the persistence parameter for productivity in the market sector; $\rho_{z_i^m, z_j^m}$ is the spillover parameter for productivity in the home sector; $100 * \sigma^{1/2}_{\epsilon_i^m, \epsilon_i^m}$ is the percent standard deviation of market productivity; $\text{corr}(\epsilon_i^m, \epsilon_j^m)$ is the cross-country correlation of innovations in market productivity; ϵ_H is the elasticity of substitution between market and home goods; a_h is the preference parameter is the consumption aggregator; $\rho_{z_i^n, z_i^n}$ is the persistence parameter for productivity in the home sector; $100 * \sigma^{1/2}_{\epsilon_i^n, \epsilon_i^n}$ is the percent standard deviation of the productivity shock in the home sector; $\text{corr}(\epsilon_i^m, \epsilon_i^n)$ is the cross-sector correlation of innovations in productivity. All other parameters in matrices $\mathbf{R}$ and $\mathbf{\Sigma}$ in the VAR process (14) are equal to zero. The subscript $i = H, F$ denotes the country and the superscript $j = m, n$ denotes the sector.

Table 3: Model Results

	Data Mean (1)	**Model Mean** (2)	**Model [5,95]** (3)	$a_h = 0$ **(BKK)** (4)	$\sigma_{\epsilon_i^n,\epsilon_i^n} = \sigma_{\epsilon_i^m,\epsilon_i^m}$ (5)	$\epsilon_H = 2.5$ (6)	$\sigma_{\epsilon_i^m,\epsilon_i^n} = 0$ (7)	$\rho_{z_i^n,z_i^n} = 0.995$ (8)
A. Labor Wedge								
$\text{sd}(\tau_H)/\text{sd}(y_H)$	1.26	1.26	[1.21,1.31]	0.00	0.80	0.82	1.35	1.39
$\text{corr}(\tau_H, y_H)$	-0.22	-0.22	[-0.26,-0.17]	—	-0.40	-0.02	-0.70	-0.43
$\text{corr}(\tau_H, z_H^m)$	0.17	0.17	[0.13,0.21]	—	-0.14	0.16	-0.40	0.19
$\text{corr}(\tau_H, \tau_{H,-1})$	0.69	0.69	[0.69,0.69]	—	0.74	0.67	0.71	0.80
τ_H^*	1.36	1.36	[1.36,1.37]	0.00	1.35	1.36	1.35	1.35
B. Closed Economy								
$\text{sd}(c_H)/\text{sd}(y_H)$	0.91	1.00	[0.95,1.07]	0.53	0.70	0.75	1.11	0.94
$\text{sd}(i_H)/\text{sd}(y_H)$	2.74	3.32	[3.24,3.39]	3.15	2.94	3.38	2.33	2.40
$\text{sd}(emp_H)/\text{sd}(y_H)$	0.88	0.70	[0.66,0.74]	0.25	0.68	0.57	0.84	0.89
$\text{corr}(c_H, y_H)$	0.70	0.38	[0.35,0.41]	0.89	0.58	0.33	0.77	0.65
$\text{corr}(i_H, y_H)$	0.78	0.77	[0.75,0.79]	0.92	0.87	0.86	0.75	0.92
$\text{corr}(emp_H, y_H)$	0.64	0.93	[0.92,0.94]	0.92	0.98	0.97	0.97	0.82
C. Open Economy								
$\text{sd}(tt_H)/\text{sd}(y_H)$	2.21	0.32	[0.28,0.37]	0.34	0.27	0.35	0.21	0.67
$\text{sd}(iqrty_H)/\text{sd}(tt_H)$	1.56	1.50	[1.50,1.50]	1.50	1.50	1.50	1.50	1.50
$\text{corr}(tt_H, y_H)$	-0.01	0.32	[0.30,0.35]	0.48	0.37	0.43	0.21	0.09
$\text{corr}(nxqty_H, y_H)$	-0.26	-0.28	[-0.32,-0.23]	-0.48	-0.39	-0.36	-0.52	-0.24
$\text{corr}(y_H, y_F)$	0.41	0.51	[0.39,0.64]	0.16	0.45	0.34	0.29	0.36
$\text{corr}(c_H, c_F)$	0.24	0.24	[0.09,0.40]	0.87	0.50	0.31	0.06	-0.28
$\text{corr}(i_H, i_F)$	0.31	-0.04	[-0.13,0.05]	-0.55	-0.09	-0.23	-0.08	-0.12
$\text{corr}(emp_H, emp_F)$	0.27	0.59	[0.38,0.80]	-0.57	0.56	0.36	0.23	0.28
$\text{corr}(z_H, z_F)$	0.21	0.30	[0.30,0.30]	0.30	0.30	0.30	0.30	0.30
$\text{corr}(\tau_H, \tau_F)$	0.12	0.14	[0.02,0.29]	—	0.36	0.11	0.03	-0.22
$\text{corr}(tt, c_H/c_F)$	-0.11	-0.44	[-0.56,-0.31]	0.91	-0.06	-0.33	-0.17	-0.80
$\text{corr}(rer, c_H/c_F)$	-0.08	-0.44	[-0.56,-0.31]	0.91	-0.06	-0.33	-0.17	-0.80

Notes: y, c, i emp, $iqrty$, $nxqty$, z, τ, tt, and rer denote market output, market consumption, total investment, total market work hours, import ratio in constant prices, net exports in constant prices divided by GDP, market productivity, labor wedge, terms of trade, and real exchange rate. An asterisk denotes mean values in the sample. All variables (except for means) denote deviations from their trends. Trends are computed with the HP filter, using a smoothing parameter of 1600. The variables $nxqty$, z, and τ are in levels, and all other variables are in logs. The subscript $i = H, F$ denotes the country.

Table 4: Robustness of Model Results

	Data Mean	**Baseline**	$\epsilon_C = 0.5$	$\epsilon_C = 2.5$	$\rho_{z_i^m, z_j^m} = 0$ **(BKK)**	$\rho_{z_i^m, z_j^m} = 0$	$\rho_{z_i^m, z_i^m} = 0.995$ **(BKK)**	$\rho_{z_i^m, z_i^m} = 0.995$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A. Labor Wedge								
sd(τ_H)/sd(y_H)	1.26	1.26	1.34	1.29	—	1.27	—	1.32
corr(τ_H, y_H)	-0.22	-0.22	-0.25	-0.21	—	-0.15	—	-0.32
corr(τ_H, z_H^m)	0.17	0.17	0.19	0.18	—	0.24	—	0.11
corr($\tau_H, \tau_{H,-1}$)	0.69	0.69	0.70	0.69	—	0.67	—	0.71
τ_H^*	1.36	1.36	1.35	1.35	0.00	1.35	0.00	1.35
B. Closed Economy								
sd(c_H)/sd(y_H)	0.91	1.00	1.05	1.03	0.29	0.99	0.56	0.96
sd(i_H)/sd(y_H)	2.74	3.32	3.34	3.36	3.37	3.43	2.27	2.86
sd(emp_H)/sd(y_H)	0.88	0.70	0.71	0.71	0.31	0.70	0.20	0.71
corr(c_H, y_H)	0.70	0.38	0.41	0.36	0.94	0.30	0.94	0.47
corr(i_H, y_H)	0.78	0.77	0.74	0.77	0.98	0.80	0.97	0.75
corr(emp_H, y_H)	0.64	0.93	0.91	0.93	0.99	0.93	0.95	0.92
C. Open Economy								
sd(tt_H)/sd(y_H)	2.21	0.32	0.49	0.24	0.40	0.37	0.66	0.45
sd($iqrty_H$)/sd(tt_H)	1.56	1.50	0.50	2.50	1.50	1.50	1.50	1.50
corr(tt_H, y_H)	-0.01	0.32	0.29	0.31	0.52	0.41	0.63	0.44
corr($nxqty_H, y_H$)	-0.26	-0.28	-0.40	-0.21	-0.35	-0.27	0.44	-0.09
corr(y_H, y_F)	0.41	0.51	0.59	0.48	0.23	0.42	0.16	0.44
corr(c_H, c_F)	0.24	0.24	0.24	0.21	0.52	0.08	0.76	0.11
corr(i_H, i_F)	0.31	-0.04	0.00	-0.08	-0.01	0.08	-0.15	0.23
corr(emp_H, emp_F)	0.27	0.59	0.64	0.55	0.22	0.52	-0.36	0.50
corr(z_H, z_F)	0.21	0.30	0.30	0.30	0.25	0.25	0.25	0.25
corr(τ_H, τ_F)	0.12	0.14	0.12	0.12	—	0.03	—	0.05
corr($tt, c_H/c_F$)	-0.11	-0.44	-0.45	-0.44	0.96	-0.26	0.99	-0.15
corr($rer, c_H/c_F$)	-0.08	-0.44	-0.45	-0.44	0.96	-0.26	0.99	-0.15

Notes: y, c, i emp, $iqrty$, $nxqty$, z, τ, tt, and rer denote market output, market consumption, total investment, total market work hours, import ratio in constant prices, net exports in constant prices divided by GDP, market productivity, labor wedge, terms of trade, and real exchange rate. An asterisk denotes mean values in the sample. All variables (except for means) are deviations from their trends. Trends are computed with the HP filter, using a smoothing parameter of 1600. The variables $nxqty$, z, and τ are in levels, and all other variables are in logs. The subscript $i = H, F$ denotes the country.

Table 5: Backus-Smith Residuals: Data vs. Model (Business Cycles)

Panel A: Real Exchange Rates	**Case**	**Correlation**	**Relative Std. Dev.**	**R-squared**
	$\sigma = 1$	0.12	0.17	0.06
	$\epsilon_H = 2, \sigma = 2$	0.28	0.40	0.13
	$\epsilon_H = 2, \sigma = 5$	0.49	0.77	0.27
	$\epsilon_H = 3, \sigma = 2$	0.30	0.36	0.14
	$\epsilon_H = 3, \sigma = 5$	0.52	0.66	0.30
	$\epsilon_H = 4, \sigma = 2$	0.30	0.34	0.14
	$\epsilon_H = 4, \sigma = 5$	0.54	0.62	0.31
Panel B: Terms of Trade	**Case**	**Correlation**	**Relative Std. Dev.**	**R-squared**
	$\sigma = 1$	0.23	0.31	0.08
	$\epsilon_H = 2, \sigma = 2$	0.44	0.61	0.22
	$\epsilon_H = 2, \sigma = 5$	0.59	0.91	0.36
	$\epsilon_H = 3, \sigma = 2$	0.46	0.54	0.23
	$\epsilon_H = 3, \sigma = 5$	0.63	0.78	0.41
	$\epsilon_H = 4, \sigma = 2$	0.47	0.52	0.24
	$\epsilon_H = 4, \sigma = 5$	0.65	0.73	0.43
Panel C: Without Nominal Exchange Rates	**Case**	**Correlation**	**Relative Std. Dev.**	**R-squared**
	$\sigma = 1$	0.17	0.35	0.06
	$\epsilon_H = 2, \sigma = 2$	0.39	0.69	0.18
	$\epsilon_H = 2, \sigma = 5$	0.58	0.99	0.35
	$\epsilon_H = 3, \sigma = 2$	0.41	0.61	0.19
	$\epsilon_H = 3, \sigma = 5$	0.62	0.85	0.40
	$\epsilon_H = 4, \sigma = 2$	0.41	0.59	0.20
	$\epsilon_H = 4, \sigma = 5$	0.64	0.80	0.42

Notes: The table compares the measured Backus-Smith residual, constructed according to equation (29), to the model-generated Backus-Smith residual constructed according to equation (32). The first column presents the correlation between the two series, the second column presents the standard deviation of the model-generated residual relative to the standard deviation of the residual in the data, and column 3 presents the R-squared from a regression of the residual in the data on the residual in the model. All values denote means across 45 bilateral exchange rates (10 countries). Panel A presents statistics for the measured Backus-Smith residual, constructed to equation (29), which uses the real exchange rate. As discussed in the text, panel B adjusts the real exchange rate to reflect only terms of trade movements and panel C removes the influence of nominal exchange rates from real exchange rates. All series are HP filtered with smoothing parameter equal to 1600.