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Abstract

A parsimonious model with home production, estimated to match moments of the "labor wedge," explains prominent puzzles of the international business cycle. If market and home activity are substitutes, then the measured labor wedge increases whenever market consumption and employment decrease. Home production breaks the tight negative link between market consumption and its marginal utility and therefore helps explain the international risk sharing puzzle. In an estimated two-country dynamic general equilibrium model in which the labor wedge is endogenously generated to match its empirical moments, market output and market employment are more correlated than market consumption and investment across countries, relative market consumption is negatively related to the real exchange rate and real net exports are countercyclical. Further, the international risk sharing puzzle becomes easier to explain as the degree of financial completeness increases.

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1 Introduction

A recent literature in macroeconomics organizes the aggregate data in terms of time-varying wedges from the first-order conditions of the one-sector neoclassical growth model. The idea is simple and powerful. These wedges provide evidence for the class of models that, relative to the neoclassical benchmark, are likely to explain the cyclical and long-run behavior of the economy. 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, MPL/MRS (Parkin, 1988; Hall, 1997; Shimer, 2009). Notably, the labor wedge is volatile, it increases during recessions and it accounts for more than half of the variance of output in the US business cycle (Chari, Kehoe and McGrattan, 2007).

I propose a theory of the labor wedge that helps to explain some of the most prominent features of the international business cycle. In the theory, the labor wedge and the international business cycle are jointly determined in a parsimonious model with home production. The main result is that when I estimate key parameters of the home sector in order to generate a labor wedge in the model which resembles in cyclical and long-run moments the labor wedge we observe in the data, a standard two-country two-good model with home production produces international business cycles with the following important regularities. The "quantity anomaly" is that, contrary to most theoretical models, market output and market employment correlate more than market consumption and investment 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 or close to zero in the data, but positive and high in most theoretical models. In addition, the model explains the countercyclicality of real net exports and fits the volatility of the import ratio relative to the volatility of the terms of trade. There is no existing research that has accounted for these four open economy facts simultaneously, which together I call the "international risk sharing puzzle" (Obstfeld and Rogoff, 2000).

Often the labor wedge is interpreted as a time-varying distortion that affects the leisure-work choice. This distortion may arise from taxes, markup shocks, shocks in union bargaining power and various other labor market frictions.[1] An alternative hypothesis is that the labor wedge simply

[1]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. Rotemberg and Woodford (1999) emphasize countercyclical price markups while Galí, Gertler and López-Salido (2007) argue that the labor wedge represents an inefficiency gap that can be understood in terms of the countercyclical behavior of the wage markup. Cole and Ohanian (2002, 2004) argue that Roosevelt's "New Deal" policies explain the persistent increase of the labor wedge in the aftermath of the US Great Depression. Cheremukhin and Restrepo-Echavarria (2009) develop a search theoretic interpretation of the labor wedge and find that the labor wedge is mainly driven by shocks in the efficiency of matching. An interesting alternative explanation comes from Chang and Kim (2007) who show how a model with heterogeneous agents, indivisible labor and incomplete markets accounts for the behavior of the labor wedge. Mulligan (2002), Prescott (2004), Ohanian, Raffo and Rogerson (2008) and Rogerson (2008) show how tax policies induce differences in the labor wedge which may account for cross-country differences in labor market outcomes.

reflects the unobserved or the unaccounted for substitution of time between the market and the home sector. To see this, suppose that in recessions households substitute market with home work (e.g. cook more instead of eating out in restaurants, fire their nannies and spend more time in childcare etc.). Suppose, however, that an econometrician omits this margin of substitution from the analysis, perhaps because time series for the output of the home sector are unavailable. This omission affects in two ways the measured rate at which households are willing to substitute leisure for market consumption ($MRS = U_L/U_{C^m}$).[2] First, attributing the increased non-market time only to leisure activities, instead of partly to leisure and partly to homework activities, tends to overestimate the decline of the marginal utility of leisure (U_L) in recessions. Second, when households derive utility from a basket of market and home produced goods, not accounting for the plausible substitution between these goods tends to overestimate the increase of the marginal utility of market consumption (U_{C^m}) in recessions. Put it differently, households look more "lazy" (in the first case) and more "hungry" (in the second case) relative to the alternative hypothesis that in recessions a fraction of their increased non-market time is directed towards home production. I show how these two observations imply that the *observed* labor wedge, i.e. the measured labor wedge in the data that does not control for the home sector, increases whenever (i) market consumption and market employment decrease simultaneously and (ii) market and home activity are sufficiently substitutable. Importantly, under the above conditions, this countercyclical behavior of the labor wedge does not depend on the underlying shock that induces the fluctuation in consumption and employment.

This explanation is closest to Hall (2009). Hall develops an approach to explaining the cyclical movements of the labor wedge which, similarly to this paper, does not assume private inefficiencies in the allocation of time. In Hall's model workers engage in an alternative activity in larger numbers in recessions than in booms. In this paper the alternative activity is home production, while 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. In this paper demand for home production is wage elastic because market and home activity are strong substitutes, while in Hall's model the employment rate is wage elastic and unemployed workers reduce their market consumption more as the complementarity between consumption and work effort increases. The choice between the two approaches to explaining the movements of the labor wedge rests on the evidence about how households spend their time when not working. I draw on several recent studies of time use (Aguiar and Hurst, 2007a and 2007b; Burda, Hamermesh and Weil, 2008; Burda and Hamermesh, 2009; Ramey, 2009; Ramey and Francis, 2009) to argue that home production provides a plausible channel for understanding the cyclical and long-run behavior of the labor wedge.

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

I embed the mechanism that generates the labor wedge in a two-country dynamic general equilibrium model. In the model, every country has a market and a home sector. In the home sector, consumers produce household goods with home time and capital. In the market sector, firms produce specialized market inputs with market time and capital. The two countries trade specialized market inputs and assets. Market consumption and investment are baskets of domestic and imported market inputs. In every country the labor wedge is generated in response to technology shocks in market and home production under the assumption that, as in the data, the econometrician omits the home sector from the analysis. This is called the *model-generated* or *theoretical* labor wedge. This very simple, frictionless and parsimonious environment is an open economy extension of the home production model of Benhabib, Rogerson and Wright (1991).

As in this paper, some international macroeconomists have recognized that non-separabilities and taste shocks may help explain the low degree of international risk sharing observed in the data. However, this paper takes a different approach relative to the previous literature.[3] Rather than simply introducing a non-separability in the utility function that helps explain the low degree of international risk sharing, I choose the non-separability in the utility function optimally in order to explain an important recent finding in closed economy macroeconomics, the labor wedge. With the amount of the non-separability being exclusively determined by closed economy moments, I evaluate the success of the model in terms of explaining the open economy puzzles.

To illustrate this approach, I choose the parameters of the home sector and the sectoral technology shocks to minimize the distance between simulated closed economy moments (which include the volatility of output, the volatility and autocorrelation of market technology and the labor wedge's volatility, autocorrelation, steady-state value and contemporaneous correlation with output) and their empirical analogs in the US data. The result is that a model with mild market and home technology shocks (with the latter accounting for only around 10% of GDP's variance), a reasonably high elasticity of substitution between market and home consumption (around 3.4) and a relatively small home sector (around 19% of measured GDP) accounts precisely for the cyclical and long-run behavior of the labor wedge and leads to a steady-state allocation of time that accords with microeconomic studies of time. Evaluated at the parameters that explained these closed economy moments, the model produces international moments that are close to those observed in the data. Specifically, the Backus-Smith correlation is -0.16, the cross-country correlation in output, employment, investment and consumption is 0.42, 0.30, 0.24 and 0.04 respectively and the correlation of real net exports with output is -0.50. These moments are obtained with an elasticity of substitution between traded goods (1.91) chosen to explain the volatility of the import ratio relative to the

[3]For other models with non-separable preferences or/and taste shocks, see Devereux, Gregory and Smith (1992); Stockman and Tesar (1995); Canova and Ubide (1998); Chari, Kehoe and McGrattan (2002); Heathcote and Perri (2008); Raffo (2009). For alternative approaches to solve the puzzle, see Baxter and Crucini (1995); Heathcote and Perri (2002); Kehoe and Perri (2002); Ghironi and Melitz (2005); Corsetti, Dedola and Leduc (2008).

volatility of the terms of trade in the US data.

The insight that explains the international risk sharing puzzle is that home production breaks the tight negative link between market consumption and its marginal utility. When market consumption is low, households allocate an increasing fraction of their time to produce in the home sector and, because the two sectors are substitutes, the marginal utility remains relatively low. There are two related ways to understand why this feature helps explain the observed negative or close to zero correlation between real exchange rates and relative (domestic over foreign) market consumption. With complete asset markets, the foreign over domestic marginal utility of market consumption is proportional to the real exchange rate. When lower productivity in the market sector or higher productivity in the home sector lower domestic market consumption, the domestic marginal utility of market consumption remains relatively low and the real exchange rate need not appreciate much (or it may even depreciate). With incomplete asset markets (risk-free bond economy), that the marginal utility does not increase as much when market consumption is low implies that countries tend to run stronger savings surpluses in recessions relative to a model without home production. That is, savings do not fall as fast as investment because home production keeps the marginal utility of market consumption relatively low. The boost in net savings due to the ability to substitute towards home production acts as a (static) negative wealth shock which, in domestic recessions, amplifies the contraction of the demand for domestic traded goods and slows down the contraction of their supply. The excess supply of domestic traded goods tends to depress their price, i.e. to depreciate the terms of trade and the real exchange rate. Therefore, the real exchange rate is negatively correlated with relative market consumption.

The key to understanding the cross-country correlation of output relative to consumption is the endogenous response of the terms of trade. In the complete or the incomplete markets models with home production, terms of trade are negatively related to relative (domestic over foreign) market consumption. This implies that when domestic market consumption is relatively low, the foreign country benefits from higher exporting prices while the domestic country faces a deterioration of its purchasing power. That is, terms of trade movements do not allow countries to share their idiosyncratic market risks and market consumption tends to diverge across countries. In the financial autarky model or in models without home production (with complete or incomplete asset markets) terms of trade are positively related to relative market consumption. This implies that when domestic market consumption is relatively low, the foreign country faces a deterioration of its purchasing power while the domestic country benefits from higher exporting prices. That is, terms of trade movements allow countries to share their idiosyncratic market risks and market consumption becomes more correlated across countries. More in general, I show that it is easier to explain the international risk sharing puzzle with complete markets than with incomplete markets and it becomes impossible to explain the international risk sharing puzzle when asset trade is prohibited. The intuition is that when shocks are not very persistent, world allocations under incomplete markets are quite similar to the allocations under complete markets (Baxter and Crucini, 1995). As shocks become more persistent, it becomes more difficult to explain the international risk sharing puzzle in the incomplete markets model because intertemporal wealth effects become dominant relative to static wealth effects. In the financial autarky model, increasing commodity prices smooth a country's wealth in times of lower market production. Therefore, countries share a large fraction of their idiosyncratic market risks even in the absence of financial markets (Cole and Obstfeld, 1991).

Section 2 presents the model. Section 3 derives the labor wedge. Section 4 discusses the international risk sharing puzzle in the data and links the observed labor wedge to recent empirical studies of time use. Section 5 discusses the econometric methodology. Section 6 presents the main results and Section 7 offers extensions and robustness checks. Section 8 concludes.

2 The Model

The model follows closely the workhorse international business cycles model of Backus, Kehoe and Kydland (1994, 1995). In related earlier work, Cole and Obstfeld (1991) extend the original Lucas (1982) model and show how commodity trade allows countries to share efficiently their idiosyncratic risks, even in the absence of financial markets. Corsetti, Dedola and Leduc (2008) explain the low degree of risk sharing in a model with incomplete asset markets and a very low elasticity of substitution between traded goods. The model here explains the risk sharing puzzle with complete or incomplete asset markets and a standard elasticity of substitution between traded goods.

The home production block of the model follows Benhabib, Rogerson and Wright (1991). Other contributions include Greenwood and Hercowitz (1991), McGrattan, Rogerson and Wright (1997) and Chang and Schorfheide (2003). The basic model is augmented with distortionary taxes to compare the results with a strand of literature that emphasizes the role of tax-induced labor wedges (Mulligan, 2002; Prescott, 2004; Ohanian, Raffo and Rogerson, 2008; Rogerson, 2008).

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. Whereas, as shown below, the correlation between the real exchange rate and relative market consumption in a model with home production is negative or close to zero. 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. Because non-traded market goods are measured in GDP while home production is not, an increasing taste for the non-traded market sector tends to increase GDP, while in case of home production measured GDP falls. Second, 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. Third, the substitutability between home goods and market goods with tradeable components (e.g. home-made meal vs. restaurant meal) is much higher than the substitutability between non-traded market goods and market goods with tradeable components (e.g. services vs. restaurant meal). In Stockman and Tesar (1995) the elasticity of substitution between traded and non-traded goods is 0.44, whereas the elasticity of substitution between market and home goods is likely to exceed 2. Fourth, these authors 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 very volatile and strongly countercyclical.

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.[4] In recent related work, Raffo (2009) shows how investment-specific shocks explain the Backus-Smith puzzle in a model with complete asset markets and non-separable preferences (GHH preferences).

Relative to previous papers that have used non-separabilities in the utility function to improve the performance of international macro models, the main innovation here is that the non-separability is pinned down by an important recent finding of closed economy macroeconomics, the labor wedge. To assess the success of the model with home production in explaining international cycles, I compare open economy moments in the model to their empirical counterparts. Importantly, these empirical counterparts are not used as moments to identify the parameters that govern the strength of the non-separability in the utility function.

2.1 Market Production

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 $j = m, n$. All exchanges in the market sector take place

[4] The impulse responses in Canova and Ubide (1998) show that terms of trade appreciate after a positive technology shock in the home sector and depreciate after a positive technology 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 to explain the Backus-Smith puzzle.

in common currency. Time is discrete and the horizon is infinite, $t = 0, 1, 2, ...$

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 technology in the market sector and α_m is the share of capital in market production.

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

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

where $C_{HH,t}$ denotes purchases of the domestic traded good and $C_{HF,t}$ denotes purchases of the foreign traded good 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 net (of government spending) 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:

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

where $C_{FF,t}$ denotes purchases of the foreign traded good and $C_{FH,t}$ denotes purchases of the domestic traded good 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 ($C^m_{i,t}$) or investment ($I_{i,t}$):

$$Y_{i,t} = C^m_{i,t} + I_{i,t} \tag{4}$$

Denote by $G_{i,t}$ the quantity of intermediate goods purchased by the domestic government. The market clearing condition in the intermediate goods sector $i = H, F$ is:[5]

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

[5]The assumption is that the government consumes a final good that uses only domestic intermediate goods as inputs, i.e. that government consumption is extremely home biased. Epifani and Gancia (2009) show that imports account for less than 1% of government consumption in various countries.

2.2 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, $RER_t = P_{F,t}/P_{H,t}$. 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 of T_t) causes a real depreciation (an increase of RER_t). Therefore, this is a terms of trade model of real exchange rate determination. The strength of my approach is that it explains the Backus-Smith puzzle through fluctuations in the relative price of traded goods. The perfect correlation of the terms of trade with the real exchange rate in the model (up to a first-order approximation) 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 correlation between relative consumption and the real exchange rate is -0.20, while with the terms of trade is -0.10. This implies that the negative relative consumption – real exchange rate correlation (the Backus-Smith puzzle) is likely to reflect the negative correlation of relative consumption with the terms of trade, rather than movements in non-traded goods prices. The weakness of my 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 address the volatility of the real exchange rate (see Chari, Kehoe and McGrattan (2002) and Corsetti, Dedola and Leduc (2008) for the volatility of the real exchange rate).

2.3 Home Production

In the home sector, the household good ($C_{i,t}^n$) is produced according to a Cobb-Douglas technology that combines time in household activities ($N_{i,t}^n$) with household capital goods ($K_{i,t-1}^n$):

$$C_{i,t}^n = \exp(z_{i,t}^n)\left(K_{i,t-1}^n\right)^{\alpha_n}\left(N_{i,t}^n\right)^{1-\alpha_n} \tag{7}$$

where $z_{i,t}^n$ is technology in the home sector and α_n is the share of capital in home production.

2.4 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:

$$I_{i,t}^j = K_{i,t}^j - (1-\delta)K_{i,t-1}^j \tag{8}$$

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: $I_{i,t} = I_{i,t}^m + I_{i,t}^n$.

2.5 Households

Household $i = H, F$ chooses sequences of market consumption, leisure, market work, non-market work, market capital, non-market capital and bonds to maximize the conditional expectation of discounted sum of utilities:

$$\max_{\{C_{i,s}^m, L_{i,s}, N_{i,s}^m, N_{i,s}^n, K_{i,s}^m, K_{i,s}^n, B_{i,s}\}_{s=t}^{\infty}} \mathbf{E}_t \sum_{s=t}^{\infty} \beta^{s-t} \frac{1}{1-\sigma} U(C_{i,s}, L_{i,s})^{1-\sigma} \tag{9}$$

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 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:

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

Household $i = H, F$ enters period t with $B_{i,t-1}$ units of an international risk-free bond. The bond costs Q_t units of the numéraire good and pays 1 unit of the good after the realization of any state of nature. The household's flow budget constraint in nominal terms is (all firms earn zero profits):

$$P_{i,t} C_{i,t}^m + P_{i,t} I_{i,t} + Q_t B_{i,t} + \frac{\phi}{2}\left(B_{i,t} - \bar{B}\right)^2 = (1-\pi_{i,t}) W_{i,t} N_{i,t}^m + r_{i,t} K_{i,t-1}^m + B_{i,t-1} + \Pi_{i,t} \tag{13}$$

In the budget constraint, $\pi_{i,t}$ is the labor income tax rate and $\Pi_{i,t}$ is a lump-sum transfer from the government.[6] The parameter $\bar{B}$ denotes bond holdings in the non-stochastic, symmetric steady-state

[6] Consumption taxes could also explain the labor wedge, because they also distort the consumption-work trade-off. To simplify the computations, I abstract from consumption taxes in the model. However, to measure the tax-induced part of the labor wedge in the data I use both effective consumption taxes and effective labor taxes.

and ϕ is a portfolio adjustment cost arising, for instance, because of capital controls or transaction fees paid to financial intermediaries. Following the literature, stationarity in the model is ensured by a very small but positive ϕ (Schmitt-Grohé and Uribe, 2003).[7] Domestic and foreign bonds are in zero net supply.

2.6 Asset Markets

As a benchmark, I use the incomplete asset markets version of the model (with the risk-free bond) because this is the model which recently gained popularity in the literature (e.g. Corsetti, Dedola and Leduc, 2008). However, I will also discuss in detail two other polar versions of the model. In the complete asset markets model, households in the two countries exchange a complete set of state-contingent financial securities. In the financial autarky model, exchange of financial assets is prohibited and the international trade of intermediate goods is always balanced.

2.7 Government

Governments finance their purchases of domestic intermediate goods with distortionary taxes.[8] The government of the domestic country balances its budget in every period:

$$P_{1,t}G_{H,t} + \Pi_{H,t} = \pi_{H,t}W_{H,t}N^m_{H,t} \tag{14}$$

A similar equation characterizes the foreign government. For the largest part of the paper, I focus on the home production channel of the model and set government spending as a fraction of domestic production, $g_{i,t} = G_{i,t}/Y_{ii,t}$, equal to zero. In the version of the model with a government sector, $g_{i,t}$ is exogenous and stochastic and is financed entirely through distortionary taxes $\pi_{i,t}$.

2.8 Shocks

To close the model, consider the process for technology and fiscal policy. The vector of the exogenous stochastic variables, $\mathbf{Z}_t = \{z^m_{H,t}, z^m_{F,t}, z^n_{H,t}, z^n_{F,t}, g_{H,t}, g_{F,t}\}$, follows a VAR process:

$$\mathbf{Z}_t = R\mathbf{Z}_{t-1} + \epsilon_t \tag{15}$$

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

[7]When $\phi = 0$, the economy moves permanently to a new steady-state after a temporary shock. The intuition is that on impact market consumptions diverge, but in the aftermath of the temporary shock the growth rates of market consumptions are equalized (from the Euler equations). As a result, market consumptions do not return to their pre-shock steady-state. Instead, the country that accumulates bonds receives interest payments from holding these bonds indefinitely. Because market consumption and leisure are normal goods, this leads to a permanent increase in market consumption and a permanent decrease in market output for the country that receives the interest payments. A small portfolio adjustment cost ($\phi > 0$) implies that the growth rates of market consumptions need not be equal in the aftermath of the shock.

[8]The results are similar when the government rebates the revenues from distortionary taxation in a lump-sum way to the households. When government's consumption is as home biased as household's consumption, demand for the domestic traded good does not change and the behavior of the terms of trade does not depend on how the tax proceedings are spent. Quantitatively, this also holds when a_C is relatively high.

2.9 Competitive Equilibrium and Solution of the Model

The vector $\mathbf{s}_{t-1} = (\mathbf{Z}_{t-1}, K^m_{H,t-1}, K^n_{H,t-1}, K^m_{F,t-1}, K^n_{F,t-1}, B_{H,t-1})$ completely summarizes the state of the economy at any point of time. 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) governments balance their budgets; (iv) all intermediate goods, final goods, labor, capital and asset markets clear.

Appendix A presents the equilibrium conditions. I take a first-order log-linear approximation of the equilibrium conditions around the non-stochastic, symmetric steady-state of the model and solve numerically the linearized system of stochastic difference equations. When asset markets are incomplete, the symmetric steady-state with $B^*_H = B^*_F = \bar{B} = 0$ is pinned down by assuming the existence of a small but positive portfolio adjustment cost ϕ. The Appendix also presents the complete asset markets model and the model under financial autarky.

3 The Labor Wedge

Consider an econometrician who measures the labor wedge in the data but who, for some reason, omits the home sector from the analysis. A way to motivate this omission is to note that, while some variables of the home sector are observable (e.g. if I^n_t is residential investment), long and consistent time series for the aggregate homework time (N^n_t) and especially for the output of the home sector (C^n_t) are unavailable.

Definition 1. Observed Labor Wedge: *The (domestic) observed labor wedge is the logarithm of the ratio of the value of the marginal product of labor over the value of the marginal rate of substitution of leisure for market consumption when the econometrician omits the home sector from the analysis, i.e.* $a_h = 0$.

$$\exp(\tau^e_{H,t}) := \frac{VMPL_{H,t}}{VMRS_{H,t}(a_h=0)} = \frac{P_{1,t}}{P_{H,t}}\frac{MPL_{H,t}}{MRS_{H,t}(a_h=0)} = \frac{P_{1,t}}{P_{H,t}}\frac{(1-\alpha_m)Y_{HH,t}/N^m_{H,t}}{[a_L C^m_{H,t}]/[(1-a_L)(1-N^m_{H,t})]} \quad (16)$$

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

The observed labor wedge is expressed in terms of variables that can be measured in the data. Because the home sector is omitted from the analysis ($a_h = 0$), in the denominator of equation (16) the econometrician sets leisure equal to the time not spent working in the market ($L_{H,t} = 1 - N^m_{H,t}$). The ratio of prices enters in equation (16) because in the open economy ($a_C < 1$) the price, P_H, of the market consumption good (C_H^m) may differ from the price, P_1, of the domestic traded good (Y_{HH}). Since for most countries in the sample terms of trade are close to acyclical and/or the share of imports is small, the ratio of prices contributes very little to the cyclical behavior of the observed labor wedge. Note that, up to the terms of trade term which is quantitatively unimportant, the expression for the labor wedge in equation (16) is similar to Chari, Kehoe and McGrattan (2007).

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

$$VMPL_{H,t} = P_{1,t}MPL_{H,t} = P_{1,t}(1-\alpha_m)\frac{Y_{HH,t}}{N_{H,t}^m} = W_{H,t} \tag{17}$$

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

$$VMRS_{H,t}(a_h \neq 0) = P_{H,t}MRS_{L,C^m} = P_{H,t}\frac{a_L\left(C_{H,t}\right)^{\rho_h}\left(C_{H,t}^m\right)^{1-\rho_h}}{(1-a_h)(1-a_L)(1-N_{H,t}^m-N_{H,t}^n)} = (1-\pi_{H,t})W_{H,t} \tag{18}$$

Combining equation (17) with equation (18), I express the theoretical analog of the observed labor wedge in equation (16) in terms of exogenous taxes, sectoral employments and sectoral consumptions. (This condition is similar for both countries and the subscript $i = H, F$ is omitted.)

Proposition 1. Theoretical Labor Wedge: *The model-generated or theoretical labor wedge equals:*

$$\exp(\tau_t) = \frac{1}{1-\pi_t}\left(1+\frac{N_t^n}{L_t}\right)\left[1+\left(\frac{a_h}{1-a_h}\right)\left(\frac{C_t^n}{C_t^m}\right)^{\frac{\epsilon_H-1}{\epsilon_H}}\right] \tag{19}$$

In a model without home production ($a_h = 0$) we take $C_{H,t}^m = C_{H,t}$, $N_{H,t}^n = 0$ and $L_{H,t} = 1-N_{H,t}^m$. In this case the theoretical marginal rate of substitution in equation (18) converges to the observed marginal rate of substitution in equation (16) and (up to the exogenous tax rate) the theoretical labor wedge is always equal to zero ($\tau_t = 0$). Equation (19) shows how distortionary taxes ($\pi_t > 0$) or the omission of the home sector ($a_h > 0$) create a positive wedge between the observed value of the marginal product and the observed value of the marginal rate of substitution ($\tau_t > 0$).

The first term in equation (19) shows how tax rates increase the labor wedge. This term leads to a countercyclical labor wedge if higher taxes reduce aggregate market activity as suggested, for instance, by Mertens and Ravn (2008) and Romer and Romer (2010).

The second term in equation (19) captures the omission in the measurement of the observed marginal utility of leisure. This term arises because the observed labor wedge attributes any non-market time to leisure activities ($1 - N^m = L$), while in the home production model non-market time may be spent alternatively in homework ($1 - N^m = L + N^n$). To explore how this term affects the cyclical properties of the labor wedge, consider a shock that decreases market work N^m. If the percentage increase in homework exceeds the percentage increase in leisure time, then the labor wedge increases and the opposite for a shock that increases market work. As a result, conditional on the second term in equation (19), the labor wedge is countercyclical to market work if:

$$\left|\frac{dN^n}{N^n}\right| > \left|\frac{dL}{L}\right| \tag{20}$$

To get a sense of whether equation (20) is likely to hold in the data, define the "offset rate" α as the increase in the time allocated to home production, dN^n, in response to a unit decrease in the time allocated in market work, $dN^m = -1$. I emphasize that, except for some illustrative calculations in the next Section, the offset rate is treated as an endogenous variable in the model. Using the definition of α, rewrite equation (20) as:

$$\alpha > \frac{N^n}{L + N^n} \tag{21}$$

In equation (21), N^n and L are interpreted as initial (pre-shock) or trend values of non-market work and leisure. From the studies of Aguiar and Hurst (2007a) and Burda, Hamermesh and Weil (2008), the values $N^n = 0.25$ and $L = 0.45$ are reasonable. As a result, conditional on the second term in equation (19), the model implies that the labor wedge is countercyclical to market employment (N^m) when the offset rate α exceeds 0.36. That is, for every 10 hours decline in market work, at least 3.6 hours must be allocated to home work. As I argue below, α is likely to be higher than 0.36 in the data.

The third term in equation (19) captures the omission in the measurement of the observed marginal utility of market consumption. This term arises because the observed labor wedge does not account for the output of the home sector. Conditional on the third term, the labor wedge is countercyclical to market consumption (C^m) if home and market consumption are substitutes, $\epsilon_H > 1$. There is ample evidence (cited below) that this elasticity is well above 1.

The key insight from this discussion is that the labor wedge increases in period t if: (i) market consumption, C_t^m and market employment, N_t^m, decrease; (ii) market and home activity are sufficiently substitutable, i.e. $\epsilon_H > 1$ and $\alpha > N^n/(L+N^n)$. In this case, both the second and the third term in equation (19) increase when market consumption and employment decrease, which explains the countercyclicality of the labor wedge.[9]

Importantly, this argument does not rest on any particular shocks that may cause the fluctuation in market consumption and market hours. Thus, while in this paper I focus on technology and tax shocks, the intuition that home production may explain the countercyclicality of the labor wedge extends naturally to a large class of models. For instance, this result holds in models with financial shocks or TFP shocks and in models with sticky prices and monetary shocks that cause consumption

[9]The fact that C^n is a function of N^n and the predetermined capital stock in the home sector K^n makes the argument even stronger (upon impact). Because home production is very time intensive (i.e. α_n is small), this result is likely to hold along the transition path even when investment in the home sector is procyclical.

and hours to move together. The condition that consumption and hours comove positively (which is only sufficient and not necessary for the labor wedge to be countercyclical) may not hold for technology shocks in models with sticky prices and does not hold when government spending shocks are financed with lump-sum taxes (but it holds when taxes are distortionary as in this model).

4 Labor Wedges and Open Economy Puzzles in the Data

The quarterly data for 6 countries in 1981(1)—2006(4) is taken from OECD's MEI. The domestic country is the US and the foreign country is an aggregate of five countries (Australia, Canada, France, Japan and UK). While I would like to differentiate between private consumption of non-durables and services (which proxy for market consumption in the model) and private consumption of durables (which could be included in non-market and total investment), quarterly data on durables exist only for very few foreign countries and as a result it is not possible to construct a consistent foreign aggregate. I construct consistent series for consumption (private final consumption for households) and investment (gross fixed capital formation) and proxy C_t^m with the consumption series and $I_t = I_t^m + I_t^n$ with the investment series. This bias is unlikely to change the cross-country correlations and makes more difficult to explain the volatility of the observed labor wedge.[10] Given the focus on the labor wedge, my proxy for market employment (N_t^m) adjusts both for labor market participation and for hours per worker. The latter comes from the ILO and national agencies. See Appendix B for more details on the data.

Series are logged and HP-filtered with smoothing parameter $\lambda = 1600$. US output's standard deviation is around 1.3 percent per quarter, consumption is somewhat smoother than output, while investment is around three times as volatile as output. Because I adjust for hours per worker, market employment is more volatile than output. Detrended market productivity is around half as volatile as output and moderately persistent. All these series are strongly procyclical.

4.1 Open Economy Puzzles

I call the following four stylized facts the "international risk sharing puzzle." As discussed in more detail in Section 6.2, there is no existing research that has accounted for these facts simultaneously. All facts refer to variables of the market sector.

1. **Quantity Anomaly:** Output is as correlated as employment and more correlated than consumption and total investment across countries. All correlations are positive.

[10] Consistent with the Backus and Smith (1993) puzzle, C^m in the data includes both traded and non-traded market goods, even though the model does not consider the latter. Counting consumer durables as part of investment instead of private consumption should not change the cross-country correlation of consumption and investment because the point estimates for these correlations with my imperfect consumption and investment series coincide. On the other hand, it is likely that the volatility of consumption will decline. This bias works against my results because it increases the volatility of the labor wedge.

2. **Backus-Smith Puzzle:** Domestic over foreign consumption ("relative consumption") correlates negatively with the real exchange rate and with the terms of trade.

3. **Countercyclical External Positions:** Real net exports are countercyclical to output.

4. **Import Ratio Variability:** The import ratio (ratio of imports over non-exportable output, all in constant prices) is significantly more volatile than the terms of trade.

In the sample, the correlation between US and Foreign output and employment exceeds 0.40, while consumption and investment are positively (0.25) but less correlated than output and employment across countries. The terms of trade and the real exchange rate are negatively correlated with relative consumption (correlations: -0.10 and -0.20). The US terms of trade is weakly procyclical and current-price and constant-price net exports are countercyclical.[11] The import ratio in the US is around 1.9 times more volatile than the terms of trade (similarly for foreign countries). This implies that the elasticity of substitution between traded goods (ϵ_C) must be around 1.9, a value in line with most of the open economy macro literature (usually 1 to 2). To see this point, consider the model without government spending. Let $IR_{H,t} = C_{HF,t}/C_{HH,t}$ be the import ratio. From the first-order conditions of the final goods producer we obtain: $\mathbf{sd}\left(\widehat{IR_{H,t}}\right)/\mathbf{sd}\left(\widehat{T_t}\right) = \epsilon_C$, where $\widehat{X_t} = \log(X_t) - \log(X^*)$ denotes the log-deviation of some variable X_t from its steady-state value, X^*, and **sd** denotes the standard deviation. As a result, up to a first-order approximation, the volatility of the import ratio relative to the volatility of the terms of trade moves one-to-one with the elasticity ϵ_C. As shown below, the calibration of ϵ_C makes the mechanism in this paper different from the mechanism analyzed in Corsetti, Dedola and Leduc (2008).

4.2 Observed Labor Wedges

The observed labor wedge is measured with equation (16) using data on market consumption, employment, output and the terms of trade. The parameters a_L, α_m and ϵ_C do not affect the cyclical properties of the observed labor wedge (up to a first-order approximation). The values of α_m and a_L, however, matter for the level of the labor wedge.[12] For all countries I set $\alpha_m = 0.36$ and $a_L = 0.41$ in equation (16) and also fix $\alpha_m = 0.36$ and $a_L = 0.41$ in the model. These values are chosen to target an allocation of time in the steady-state of the model which is consistent with microeconomic studies (see below). Because these parameters are fixed somewhat arbitrarily, the

[11] See equations (A.59) and (A.60) in the Appendix for the definitions of current-price and constant-price net exports in the model. Because the procyclicality of terms of trade is weak, the countercyclicality of current-price net exports is mostly due to changes in quantities rather than due to changes in prices. Raffo (2008) makes this important point clear. The model here is consistent with this fact because constant-price net exports are countercyclical and terms of trade are relatively acyclical. As a result, current-price net exports are countercyclical due to changes in quantities.

[12] In equation (16), the parameter a_C is estimated separately for every country. Up to a first-order approximation, the value of ϵ_C does not affect either the cyclical properties or the steady-state value of the labor wedge.

absolute level of the labor wedge may not be very meaningful. However, comparisons of the value of the labor wedge across countries, across time or in the model relative to the data are meaningful since in all these comparisons the two parameters are held constant.

The resulting series is in line with recent research, see e.g. Chari, Kehoe and McGrattan (2007), Galí, Gertler and López-Salido (2007) and Shimer (2009). The upper panels of Figure 1 present the labor wedge series for the US and the Foreign aggregate. The US has the lowest labor wedge, with a mean sample value of $\bar{\tau}_H = 0.86$. The foreign aggregate has $\bar{\tau}_F = 1.10$ with the five countries having mean sample labor wedges between 1.02 and 1.26. The lower panels of Figure 1 present the cyclical fluctuation of the labor wedge. The US labor wedge displays a -0.59 contemporaneous correlation with output and is 1.39 times more volatile than output. In the foreign countries, the labor wedge has a contemporaneous correlation between -0.16 and -0.76 with output and is 1.05 to 2.27 times more volatile than output.

A number of reasons may explain the lower US labor wedge. For example, Mulligan (2002), Prescott (2004) and Ohanian, Raffo and Rogerson (2008) attribute cross-country differences in labor supply to taxes. Alesina, Glaeser and Sacerdote (2005) point out the role of powerful European labor unions. Alternatively, equation (19) suggests that the labor wedge is lower in countries with a smaller home sector. This explanation is in line with a recent literature which shows how a decreased activity at the home sector (rather than less leisure) offsets a higher labor market participation. For example, Freeman and Schettkat (2005) report that in the 1990s Europeans worked 20% more than Americans at home. Burda, Hamermesh and Weil (2008) compare the US to Germany, Italy and the Netherlands and find the same pattern. The emergence of these sizeable differences in the allocation of time across countries can be explained by various factors, including different tax systems, labor market regulations, deeper cultural variables and sectoral technology trends.[13]

The annual series for US home hours produced by Ramey (2009) and Ramey and Francis (2009) support the argument that home production is related to the labor wedge. The authors estimate time in home production by gender, age and employment status from time diaries for a small number of periods and then interpolate to construct a series for aggregate home hours. Because they adjust the weight on the number of employed persons at each interpolation point, fluctuations in the employment rate affect the constructed home hours series. Figure 2 shows that in 1975–2005 the correlation of the cyclical component of home hours is 0.53 with the cycle of the observed labor wedge, -0.57 with the cycle of the observed marginal rate of substitution and -0.69 with the cycle of output. According to their data, home hours increase in recessions and, according to the mechanism suggested by equation (19), this explains the decrease of the observed marginal rate of substitution and the increase of the observed labor wedge in recessions. Burda and Hamermesh (2009) look at

[13] Jones, Manuelli and McGrattan (2003) show that if market and home goods are substitutes, then technological progress in the home sector increases the fraction of time allocated in home work.

the working age population in the American Time Use Survey (2003-2006). The authors report that in response to transitory unemployment shocks (current unemployment rate minus a five year average unemployment rate) at the metropolitan level, individuals offset one hour decline in market work with a 46 minute increase of home work, i.e. the offset rate is $\alpha = 0.77$.[14]

To provide more evidence for the argument that home production is related to the labor wedge, I take the theoretical labor wedge in equation (19) to the data and compare it to the observed labor wedge constructed according to equation (16). I emphasize that this exercise is reduced-form in the sense that it does not specify the shocks that induce the observed movements in market consumption and employment and it treats the offset rate as exogenous. In the next Sections (which contain the main results) time series for consumption, employment and the offset rate are generated endogenously from the optimal decision rules of the economic agents in response to technology and tax shocks. The exercise is, however, useful because it shows that my results regarding the labor wedge do not depend on the other parts of the model or the nature of the shocks that cause market consumption and market employment to fluctuate. This highlights that the mechanism is applicable to a larger class of models (e.g. in monetary economies, in economies with a financial sector etc.). As a benchmark case, assume that there are no taxes ($\pi_t = 0$). Appendix B shows the robustness of the results when effective consumption and labor taxes proxy for the time-varying tax rate π_t.

Let $(N_t^m)^*$ denote the HP trend in market hours. Let $Time_t$ be the total time in the economy, which is equal to a fixed amount of (non-sleeping) hours multiplied by the HP trend in the civilian workforce series. Therefore, the time endowment of temporarily unemployed workers is included in $Time_t$. The economy-wide time constraint is:

$$L_t^* + (N_t^n)^* = Time_t - (N_t^m)^* \tag{22}$$

I calculate a trend for homework hours, $(N_t^n)^*$, from Aguiar and Hurst (2007a). Specifically, the authors report hours per week per adult aged 21-64 spent on non-market work activities and childcare. Total non-market work is 24.64 hours in 1985, 21.51 hours in 1993 and 23.81 hours in 2003.[15] I use these numbers to estimate the trend in non-market work in the following way. First, I interpolate and extrapolate linearly to estimate the "steady-state" share of time allocated to homework activities in other years of the sample, 1981—2006.[16] Second, I multiply this share with the total available time, $Time_t$, to take a trend for home hours, $(N_t^n)^*$. I can calculate L_t^* from equation (22), since the trend for market hours, $(N_t^m)^*$, is observed.

[14] In the cross-section of their US sample, Burda and Hamermesh (2009) show that unemployed allocate 35% of their (higher) non-market time to home production. In contrast, Gelber and Mitchell (2009) examine how single women adjust their allocation of time in response to tax shocks and find that when market hours rise by one hour, time spent on housework falls by around 47 minutes.

[15] The increase between 1993 and 2003 is entirely due to childcare activities. Because the labor wedge is relatively constant in the second half of the sample, excluding child care activities makes my results stronger.

[16] I extrapolate to 1981—1984 using the trend between 1985—1993 and to 2004—2006 using the trend between 1994—2003.

To construct the actual series for home hours, N_t^n, I add the cycle to the trend using the definition of the offset rate (α) introduced in Section 3. Specifically, I allocate to home hours a fraction $-\alpha$ of the cycle of market hours:

$$N_t^n = (N_t^n)^* - \alpha\left[N_t^m - (N_t^m)^*\right] \tag{23}$$

while the residual fraction $-(1-\alpha)$ is allocated to leisure. By construction, the time constraint is satisfied on and off-trend: $L_t + N_t^n + N_t^m = Time_t$. Finally, for this exercise only, assume that the household good is produced with homework time:

$$C_t^n = (N_t^n)^* \left(\frac{(N_t^n) - (N_t^n)^*}{(N_t^n)^*}\right)^{\chi} \tag{24}$$

For instance, C_t^n could refer to a very time intensive activity like childcare. The parameter χ measures the sensitivity of the output of the home sector to the amount of home hours.

I choose the parameters $\theta = (\epsilon_H, a_h, \chi)$ to minimize the distance between the observed labor wedge series, $\{\tau_t^e\}$, constructed according to equation (16) and the theoretical labor wedge series, $\{\tau_t(\theta)\}$, constructed according to equation (19), given data on US market consumption and employment, the assumptions for home consumption and home hours and some θ. The problem is:

$$\min_{\theta} \sum_{t=1}^{T=104} w_t \left(\tau_t^e - \tau_t(\theta)\right)^2 \tag{25}$$

where w_t is a weight function. Weighting observations uniformly or inversely to their absolute value does not affect the results.

Figure 3 presents the results in the benchmark specification in which the offset rate is fixed at $\alpha = 0.75$, close to the value suggested by Burda and Hamermesh (2009). As we can see, the theoretical labor wedge series tracks very closely the path of the observed labor wedge. The two series are almost indistinguishable when expressed in log-deviations from their trend (not shown). Equation (19) generates a wedge that looks like the observed labor wedge in equation (16) for two reasons: (1) Because the estimates of Aguiar and Hurst (2007a) show a strong decline of home hours per person in the first half of the sample, which mimics the strong decline of the observed labor wedge. (2) Because market consumption and employment move together in the data, which according to the theoretical derivation in equation (19) implies a countercyclical labor wedge. Appendix B presents robustness checks with different parameters and estimates with tax rates. I have also repeated this experiment in the Ramey (2009) and Ramey and Francis (2009) dataset with similar results.

5 Econometric Methodology

I now turn to model-generated time series to show how the model of Section 2 explains quantitatively the labor wedge. In turn, I show how the estimated labor wedge generates an international transmission mechanism that accounts for the international risk sharing puzzle. This Section discusses the econometric methodology and the next Section presents the results.

I choose the structural parameters of the model to minimize the distance between observable statistics in the data and model statistics generated from simulations of the artificial economy of Section 2. This simulated estimation is very similar to the GMM estimation. The difference is that in the former case the statistics of the model are computed from the simulated data, while in the latter case the statistics of the model are computed theoretically. I use simulated estimation because the computation of the theoretical statistics is much more costly. However, computed at the optimal parameter vector, the simulated statistics are very close to their theoretical counterparts.

Let $h(.)$ be a vector of continuous functions of the simulated or observed data. Here, $h(.)$ will denote simulated or observed first and second moments. Denote the simulated time series under some realization of shocks ϵ and under some parameter vector θ by $\{x_t^s(\theta,\epsilon)\}$. Denote the observed time series by $\{x_t\}$. In practice, the literature focuses on statistics such as standard deviations, relative volatilities and correlation coefficients. Therefore, define the continuously differentiable function m and let $M_T = m\left(\frac{1}{T}\sum_{t=1}^{T} h(x_t)\right)$ and $M_{TS} = m\left(\frac{1}{TS}\sum_{t=1}^{TS} h(x_t^s(\theta;\epsilon))\right)$ be the mapping from means, variances and covariances to a vector of Q means, standard deviations and correlations.[17] T denotes the size of the observed data and TS is the size of the simulated data. The parameter θ is a $NX1$ vector.

Under the null hypothesis, the structural model is the data generating process and the time series $\{x_t(\theta^*)\}_{t=1}^{TS}$ and $\{x_t\}_{t=1}^{T}$ share the same distribution at the true parameter vector, θ^*. If the series are stationary and ergodic, the sample means, $\frac{1}{TS}\sum_{t=1}^{TS} h(x_t^s(\theta,\epsilon))$ in the simulated data and $\frac{1}{T}\sum_{t=1}^{T} h(x_t)$ in the observed data, converge a.s. to the same limit. Since the mapping $m(.)$ is continuous, M_{TS} and M_T also share the same probability limit under the true parameter θ^*. Therefore, a natural estimator for θ is the vector that minimizes the weighted sum of the squared deviations of the simulated from the observed statistics:

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

where W is a QXQ positive definite weighting matrix converging to a deterministic matrix with rank greater than or equal to N. Under the regularity conditions in Lee and Ingram (1991), θ_S is asymptotically consistent for any weighting matrix W. Standard errors are obtained from the asymptotic distribution:

$$\sqrt{T}(\theta_S - \theta^*) \rightarrow \mathbf{N}\left(0, \left(1+\frac{1}{S}\right)\left(D'W^{-1}D\right)^{-1} D'W^{-1}\Omega W^{-1}D\left(D'W^{-1}D\right)^{-1}\right) \tag{27}$$

[17] Since the functions M_T and M_{TS} are functions of time averages of observed and simulated statistics, rather than time averages of functions of observed and simulated statistics, the estimator here is not a special case of the Simulated Method of Moments (SMM) estimator. Alternative simulation estimators, such as the SMM of Lee and Ingram (1991) and Duffie and Singleton (1993) and the Extended SMM of Smith (1993), are very similar to my method and their results extend in my setting.

where $D = \partial M_{TS}/\partial\theta'$ is a finite and of full rank QXN gradient matrix containing the derivatives of the statistics with respect to the parameters. The term $1/S$ corrects for additional uncertainty generated from the simulation error. In equation (27), Ω is the asymptotic variance of the observed statistics:

$$\sqrt{T}\left(M_T - \mathbf{E}M_T\right) \to \mathbf{N}(0, \Omega) \tag{28}$$

The matrix Ω is estimated from the data using a heteroscedasticity and autocorrelation consistent Newey-West estimator (Bartlett kernel).

To solve the minimization problem in equation (26), fix the shocks ϵ to make the objective function continuous in the parameters. Given an initial guess for the parameters, I solve and simulate the model. Then, I use the simulated annealing method, a stochastic search algorithm motivated by the physical annealing process, to update the parameter values until convergence is achieved. The stochastic optimization algorithm makes convergence to the global minimum more likely relative to multi-start simplex-like or derivative-based methods.

6 Labor Wedges and Open Economy Puzzles in the Model

I estimate the vector of structural parameters:

$$\theta = (\epsilon_H, a_h, \rho_{z^m,z^m}, \rho_{z^n,z^n}, \sigma_{\epsilon^m,\epsilon^m}, \sigma_{\epsilon^n,\epsilon^n}) \tag{29}$$

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), ρ_{z^m,z^m} and ρ_{z^n,z^n} denote the persistence of technology in the market and the home sector respectively and $\sigma_{\epsilon^m,\epsilon^m}$ and $\sigma_{\epsilon^n,\epsilon^n}$ denote the variances of the technology shocks in the two sectors.

The other parameters are fixed at the values shown in Table 1 (these are called "fixed" henceforth). To isolate the home production explanation of the labor wedge, I initially set government spending equal to zero ($g_i^* = 0$). The elasticity of substitution between traded goods, $\epsilon_C = 1.907$, is chosen so that the volatility of the import ratio relative to the volatility of the terms of trade matches its value in the US data. The preference parameter in the traded goods aggregator, $a_C = 0.896$, is chosen so that the steady-state share of imports in GDP in the model matches its average value in the US. In equation (15), the spillover parameters in matrix R and the contemporaneous correlation of the shocks in matrix Σ are set equal to zero. The exception is the contemporaneous correlation of the innovations of market technology which is set equal to $corr(\epsilon_H^m, \epsilon_F^m) = 0.45$.[18] Therefore, the model is evaluated in terms of explaining the correlations of consumption, investment and employment relative to a given output correlation. The other parameters are standard and mostly taken from Benhabib, Rogerson and Wright (1991). See Section 7.1 for extensive sensitivity checks.

[18]The failure of the model to generate endogenously a high output correlation is known in the literature. See also the related literature on the trade-comovement puzzle, e.g. Kose and Yi (2006) and Drozd and Nosal (2008).

The objective function in equation (26) includes the following US moments. The volatility of market output, the volatility and autocorrelation of market technology and the labor wedge's volatility, autocorrelation, steady-state value and contemporaneous correlation with output. Moments are weighted inversely with their variance in the data. Since the moments in the objective function are matched closely, the choice of the weighting matrix does not affect significantly the results.

6.1 Main Results

Table 2 presents the estimated means of the moments and their confidence intervals. The upper panel shows that the model fits closely the moments it was constructed to match. In addition, the model produces standard closed economy business cycle statistics that, as it is well known, are in line with the data (not shown to save space). In particular, consumption, employment and investment are strongly procyclical and their volatilities are relatively close to those in the data.

The lower panel presents estimates for open economy moments that were not included in the objective function. Market output and market employment are more correlated than market consumption and investment across countries. All correlations are positive, statistically significant and in some cases close to their data counterparts, which explains the "quantity anomaly." The correlation between the real exchange rate and relative consumption matches closely its value in the data, which explains the "Backus-Smith puzzle." In addition, the model generates countercyclical real net exports. Therefore, if every country has a labor wedge that resembles the labor wedge emphasized by recent research in the closed economy, then we can explain quantitatively the international risk sharing puzzle. This is a strong result because the requirement that the model explains moments of the observed labor wedge generates an international transmission mechanism that explains the open economy puzzles, even though the parameters of the model were not chosen a priori to explain these puzzles. As the last column of Table 2 shows, in a model without home production the Backus-Smith correlation is high and consumption is more correlated than output across countries.

Table 3 reports the estimated parameters. All parameters are well-identified from the moments included in the objective function and therefore the standard errors are small. The elasticity of substitution between market and home goods (ϵ_H) is around 3.4. Benhabib, Rogerson and Wright (1991) set this elasticity equal to 5 in their most preferred specification. In McGrattan, Rogerson and Wright (1997) the estimated elasticity is slightly less than 2, while in Chang and Schorfheide (2003) the estimate is around 2.3. Using micro data, Rupert, Rogerson and Wright (1995) estimate a value of around 1.8, Aguiar and Hurst (2007b) estimate a value of around 2 and Gelber and Mitchell (2009) estimate a value of around 2.5. Rogerson (2008) considers various estimates between these values.[19] In conclusion, the estimated elasticity is somewhat higher, but not unreasonably so, than

[19] Aguiar and Hurst (2007b) estimate the elasticity of substitution between market goods and household time. This equals the elasticity between market and home goods in the model here if home goods are produced with a linear

the typical value in the literature.

The estimated technology shocks are mild. In particular, the estimated standard deviations of the innovations in sectoral technology, the estimated persistence parameters and the estimated preference parameter for home goods imply that technology shocks in the home sector explain only around 10% of GDP's unconditional variance. The size of the home sector necessary to account for the behavior of the labor wedge turns out to be very reasonable, at around 19% of measured GDP. This value lies towards the lower bound of Eisner (1988) who estimates the size of the home sector to be between 20% and 50% of market GDP. In addition, the model produces an allocation of time that accords with recent microeconomic studies of time. In steady-state, a fraction 0.43 is allocated to leisure, a fraction 0.35 to market work and a fraction 0.22 to home work. From the studies of Aguiar and Hurst (2007a) and Burda, Hamermesh and Weil (2008), the fraction of leisure activities in the US and a couple of European countries lies somewhere between 0.37 and 0.51, while the fraction of market work is between 0.21 and 0.35.

Table 4 presents results from the complete markets model and the financial autarky model. In the first three columns I set all parameters equal to their benchmark values shown in Tables 1 and 3. The results under complete markets are very similar to the benchmark results under incomplete markets. The only exception is the Backus-Smith correlation which becomes slightly more negative. On the other hand, in the financial autarky model the Backus-Smith correlation is positive and high. In the last three columns, I assume that shocks are very persistent and set $\rho_{z^m,z^m} = \rho_{z^n,z^n} = 0.999$. In the complete asset markets model, the Backus-Smith correlation is negative and consumption is negatively correlated across countries. In the incomplete asset markets model, the Backus-Smith correlation is positive but close to zero and output is more correlated than consumption. In the financial autarky model, the Backus-Smith correlation is close to one and consumption is as correlated as output. I summarize these results in Figure 4, which shows the Backus-Smith correlation and the correlation of consumption as a function of the completeness of the asset market and the persistence of the shocks.

To summarize, the complete asset markets model explains the international risk sharing puzzle. The incomplete asset markets model explains the international risk sharing puzzle provided that shocks are not extremely persistent. The financial autarky model fails to explain the international risk sharing puzzle.

6.2 The International Transmission Mechanism

The key to understanding the international transmission mechanism is the marginal utility of market consumption. The marginal utility depends on the consumption of market goods, the consumption of

technology of time. Similarly in Rogerson (2008).

home goods and leisure, $U_{C^m}(C^m, C^n, L)$. As the two consumption goods become more substitutable, the marginal utility of market consumption decreases more in the consumption of home goods.

6.2.1 Backus-Smith Correlation under Complete Asset Markets

In the complete asset markets model the ratio of the marginal utilities of market consumption is proportional to the real exchange rate in every state of nature:

$$\frac{U_{C_F^m}(C_{F,t}^m, C_{F,t}^n, L_{F,t})}{U_{C_H^m}(C_{H,t}^m, C_{H,t}^n, L_{H,t})} \propto RER_t := \frac{P_{F,t}}{P_{H,t}} \tag{30}$$

Consider a decrease in domestic market consumption $C_{H,t}^m$, e.g. due to a negative market technology shock. When the marginal utility of market consumption depends only on market consumption, the marginal utility increases and, from equation (30), the real exchange rate appreciates. As a result, (domestic over foreign) relative market consumption correlates positively with the real exchange rate, which is the Backus and Smith (1993) puzzle.

Now suppose that preferences are non-separable. If in recessions households allocate an increasing fraction of their non-market time to home production (increase of $C_{H,t}^n$) and if the two goods are substitutes, then the marginal utility of market consumption does not increase as much as in a model with separable preferences. In other words, the endogenous increase of home production following a domestic recession in the market sector acts as a taste shock which keeps the marginal utility of market consumption relatively low. In this case, equation (30) implies that the real exchange rate need not appreciate much in states in which domestic market consumption is low. Depending on a number of factors (e.g. 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, how leisure affects the above calculation), the correlation between relative market consumption and the real exchange rate may even be negative, as it is in fact estimated in the model here.

Two specific features of the home sector make it a strong candidate for the solution of the Backus-Smith puzzle. The first is that the output of this sector is likely to be countercyclical to market consumption. The second is that the consumption of the home sector is highly substitutable to market consumption. These two features differentiate home production from other non-separabilities that could explain the Backus-Smith puzzle. For instance, Chari, Kehoe and McGrattan (2002) report that neither money balances nor habit persistence in consumption explain the Backus-Smith puzzle.

6.2.2 Backus-Smith Correlation under Financial Autarky

The Backus-Smith correlation is positive and high in the financial autarky model. In the model here, the real exchange rate is determined exclusively from the equilibrium behavior of the terms of trade, with a terms of trade depreciation (increase of T_t) causing a real exchange rate depreciation (increase of RER_t). Therefore, to understand the intuition for the Backus-Smith correlation, consider the equilibrium behavior of the terms of trade which is determined from the market clearing condition for the domestic intermediate traded good:

$$Y_{HH,t} = C_{HH,t} + C_{FH,t} + G_{H,t} = D_{H,t} \tag{31}$$

In equation (31), $Y_{HH,t}$ is the supply of the domestic traded good. A decrease in the relative price of the domestic traded good (i.e. an increase of the terms of trade $T_t = P_{2,t}/P_{1,t}$) lowers domestic wages. When market and non-market work are sufficiently substitutable (i.e. when ϵ_H is relatively high), the substitution effect dominates the wealth effect and households supply less market work. Therefore, supply $Y_{HH,t}$ is decreasing in T_t. In Figure 5 this is illustrated by a (log-linearized) downward sloping supply curve.

In equation (31), $D_{H,t}$ is the world demand for the domestic traded good. World demand is the sum of three components: $C_{HH,t}$ is the domestic demand for the domestic traded good, $C_{FH,t}$ is the foreign demand for the domestic traded good and $G_{H,t}$ is government's demand (set equal to zero in the benchmark version of the model). Because preferences are home biased ($a_C > 1/2$), the world demand for the domestic traded good ($D_{H,t}$) is mostly affected by the movements of the domestic demand for the domestic traded good ($C_{HH,t}$). When the elasticity of substitution between traded goods (ϵ_C) is not very low, the world demand for the domestic traded good decreases in the relative price of the domestic traded good ($P_{1,t}/P_{2,t}$), i.e. it increases in the terms of trade (T_t).[20] This standard case is illustrated in Figure 5 by an (log-linearized) upward sloping world demand.

A negative market technology shock or a positive non-market technology shock in the domestic country contracts the supply of the domestic traded good ($Y_{HH,t}$). Because income falls in the domestic economy, the domestic demand for the domestic traded good ($C_{HH,t}$) also contracts. However, domestic demand ($C_{HH,t}$) is only a fraction of world demand $D_{H,t}$ (that is, when $a_C < 1$). As a result, world demand for the domestic traded good contacts less than the supply of the domestic traded good and, for given terms of trade, there is an excess demand for domestic traded goods. As the left panel of Figure 5 illustrates, the excess demand causes an increase in the relative price of the domestic traded good, i.e. an appreciation of the terms of trade and of the real exchange rate. In other words, in the financial autarky model shocks act as "supply disturbances." By supply disturbances, I mean any shock that, for given terms of trade, causes supply to shift faster than

[20] More precisely, demand for the domestic traded good *relative* to the demand for the foreign traded good is increasing in the relative price. Consider a terms of trade appreciation. Because the domestic traded good has become more expensive, the substitution effects in the domestic and the foreign country cause a decrease in the relative demand for domestic traded good. Because foreign income falls, the foreign wealth effect tends to decrease relative demand for the domestic traded good. Because domestic income increases, the domestic wealth effect tends to increase relative demand for the domestic traded good. When ϵ_C is not too low, the domestic wealth effect is dominated by the other effects and $D_{H,t}$ is upward sloping.

demand. To clear the market, supply disturbances cause an increase in the price of the traded good whose quantity contracts.

These terms of trade movements tend to insure the domestic country (in which the shock originated) because they smooth the value of its output (the quantity decreases but the price increases; Cole and Obstfeld, 1991). However, when the elasticity of substitution between traded goods is not too low, quantities absorb most of the impact of the shock and the insurance role of terms of trade weakens. Therefore, domestic market consumption decreases more than foreign market consumption, i.e. relative consumption $(C^m_{H,t}/C^m_{F,t})$ decreases.

As a result, market consumption is lower in the country where the basket of goods has become more expensive, which is the Backus-Smith puzzle. This is an interesting result because the literature has mostly focused on relaxing the complete markets assumption in trying to explain the Backus-Smith puzzle.

6.2.3 Backus-Smith Correlation under Incomplete Asset Markets

To understand why the Backus-Smith correlation turns negative or close to zero in the incomplete markets model, I follow the same analysis as in the financial autarky model. The only difference is that when asset trade is not prohibited, savings may differ from investment. Therefore, I consider how the imbalance of savings from investment affects the equilibrium condition (31). The optimal accumulation of bonds $(B_{i,t})$ is determined by a standard Euler equation for country $i = H, F$:[21]

$$\lambda_{i,t} Q_t = \beta \mathbf{E}_t \lambda_{i,t+1} \tag{32}$$

where $\lambda_i = U_{C_i^m}/P_i$ denotes the marginal utility of market consumption divided by the price of market consumption and Q_t is the price of the bond. *Ceteris paribus,* in states of nature where $\lambda_{i,t}$ is relatively high countries tend to borrow more ($B_{i,t}$ decreases relative to $B_{i,t-1}$) and in states of nature where $\lambda_{i,t}$ is relatively low countries tend to save more ($B_{i,t}$ increases relative to $B_{i,t-1}$).

As with complete markets, the key result is that home production introduces an additional margin of substitution which tends to offset the increase of the marginal utility of market consumption in times of low market activity. Thus, in response to negative market technology shocks or positive non-market technology shocks, a country with lower market activity will not decrease savings as much as in a model without the home sector because home production smooths the marginal utility of market consumption.[22] Provided that shocks are not nearly permanent, the additional savings surplus acts as a negative wealth shock because more resources are spent on accumulating bonds.

[21] I suppress a term that captures portfolio adjustment costs because ϕ is quantitatively negligible.

[22] I emphasize that savings do not have to be countercyclical. In the model savings are weakly procyclical because consumption is somewhat smoother than output, but the decrease of savings is smaller in absolute value than the decrease of investment in recessions.

This wealth effect is similar, for instance, to the wealth effect that arises in the neoclassical growth model in response to temporary government spending shocks financed by lump sum taxes.

How this additional negative wealth shock affects the equilibrium condition (31)? In response to a negative market technology shock or a positive non-market technology shock in the domestic country, the negative wealth shock *amplifies* the contraction of the demand for the domestic traded commodity ($C_{HH,t}$) relative to financial autarky because market consumption is a normal good and preferences are biased towards domestic traded goods. This is illustrated in the right panel of Figure 5 in which demand contracts more relative to financial autarky. In response to a negative market technology shock or a positive non-market technology shock, the negative wealth shock *slows down* the contraction of the supply of the domestic traded commodity ($Y_{HH,t}$) relative to financial autarky because leisure is a normal good. This is illustrated in the right panel of Figure 5 in which supply contracts less relative to financial autarky. As a result, when the non-separability in the utility function is sufficiently strong, the world demand for the domestic traded good contracts faster than the supply of the domestic traded good for given terms of trade. With an upward sloping world demand function, the excess supply of domestic traded goods requires a decrease in their price and the terms of trade and the real exchange rate tend to depreciate. Because relative market consumption is lower in the domestic country, the Backus-Smith correlation becomes negative. In other words, when preferences are sufficiently non-separable, shocks will on average act as "demand disturbances." By demand disturbances I mean any shock that, for given terms of trade, causes demand to shift faster than supply. To clear the market, demand disturbances cause a decrease in the price of the traded good whose quantity contracts.

Corsetti, Dedola and Leduc (2008) also explain the negative Backus-Smith correlation in a model with incomplete asset markets. The incompleteness of the asset market guarantees that the model behaves more like a financial autarky model than like a complete markets model upon impact of the shock. The intuitive argument of their model is that when the elasticity of substitution between traded goods ϵ_C is sufficiently low, the world demand for the domestic traded good is downward sloping in the terms of trade. 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.[23] Therefore, the Backus-Smith correlation is negative upon impact of the shock in the Corsetti, Dedola and Leduc (2008) model. In contrast, in the model here world demand is upward sloping. When for given terms of trade demand shifts less than supply (as in the financial autarky model), the Backus-Smith correlation is positive. When for given terms of trade demand shifts more than supply (as in the incomplete asset markets model under a sufficient degree of non-separability in the utility function), the Backus-Smith correlation is negative.

[23]More precisely, this assumes that supply is steeper than demand. For instance, with no leisure-labor choice, supply is vertical.

Suppose that markets are incomplete, but shocks are very persistent. In a world with transitory shocks the key result is that the savings surplus implies a negative *intraperiod* wealth effect which depreciates the terms of trade in recessions. As shocks become more persistent, the offsetting positive *intertemporal* wealth effect from the repayment of the debt becomes stronger and the mechanism explained above becomes weaker in the aftermath of the shock. This explains why the Backus-Smith correlation turns positive (but close to zero) in the model with incomplete markets and very persistent shocks. The intuition of this result is in line with Baxter and Crucini (1995) who have argued that world allocations under incomplete markets deviate from the complete markets allocations only when shocks are persistent and intertemporal wealth effects are strong.

6.2.4 Quantity Anomaly and Countercyclical Real Net Exports

The key to understanding the correlation of consumption (relative to output) across countries is the response of the terms of trade.[24] In the models with complete or incomplete markets, the terms of trade is higher (on average) in states in which domestic market consumption is low relative to foreign market consumption. Because of increased foreign prices, households' income in the foreign country increases and foreign market consumption tends to increase. This makes consumption less correlated across countries. In contrast, in the financial autarky model or in a model without home production, the terms of trade is positively correlated with relative consumption. This means that in states in which domestic market consumption is low, the decrease of foreign prices lowers foreign households' income and foreign market consumption tends to decrease. This makes consumption more correlated across countries.

Existing models have a difficulty to explain simultaneously the correlation in quantities and the countercyclicality of real net exports. In models in which a single commodity is traded intertemporally, when asset markets are complete and there are no shocks in the utility function, consumption is strongly correlated across countries because of the incentive to pool risks. On the other hand, output, employment and investment are likely to be negatively correlated because inputs are efficiently allocated to their most productive use.[25] In Kehoe and Perri (2002) countries exchange a complete set of state-contingent financial securities but contracts are not enforceable. Because countries with higher endowments have an increased incentive to default, capital flows are endogenously restricted and output correlates more than consumption across countries. However, when

[24]The justification is that the correlation between the estimated correlation of consumption across countries and the estimated Backus-Smith correlation conditional on the set of estimated parameters is 0.50. That is, as we vary the estimated parameters, consumption becomes less correlated across countries under the parameters that make the real exchange rate (and the terms of trade) more negatively correlated with relative consumption.

[25]Restricting financial markets to the exchange of a risk-free bond does not solve the anomaly (Baxter and Crucini, 1995; Kollmann, 1996; Heathcote and Perri, 2002; Kehoe and Perri, 2002). The exception is when productivity follows a random walk, in which case output correlates more than consumption across countries due to large intertemporal wealth effects. However, in this case investment and employment are negatively correlated. To solve this issue Baxter and Farr (2005) introduce variable capital utilization and explain the quantity anomaly.

financial frictions limit the flow of international capital across countries, it is difficult to explain how booming economies borrow to finance their growth. Therefore, in models with a single traded commodity either consumption is strongly correlated (when markets are complete and resources flow freely) or real net exports are procyclical (when markets are incomplete and resources do not flow much across countries). In contrast, the model here with two traded goods produces strongly countercyclical real net exports and almost uncorrelated consumption across countries.

7 Extensions

7.1 Sensitivity Analysis

As the theoretical derivation of the labor wedge in equation (19) shows and Figure 6 confirms, when the elasticity of substitution between market and home goods (ϵ_H) approaches 1, the volatility of the labor wedge decreases and the labor wedge becomes less countercyclical. The Backus-Smith correlation is relatively insensitive to variations of the elasticity when the elasticity exceeds 1.5-2. As the elasticity decreases and gets closer to 1, the Backus-Smith correlation starts to increase. When the two goods become complements, the Backus-Smith correlation becomes positive. Note that in this case, the correlation of consumption starts to increase and when the elasticity is very low the correlation of consumption exceeds the correlation of output. Similar results hold for the parameter a_h which pins down the size of the home sector. As home production becomes less important, the non-separability in the utility function weakens, which implies a less volatile and less countercyclical labor wedge, a higher Backus-Smith correlation and a higher consumption correlation.[26] The volatility of the technology shocks in the home sector has also similar effects, except for the fact that less volatile shocks produce a more countercyclical labor wedge. The intuition is that the labor wedge responds to both market and non-market technology shocks. On the other hand, market GDP is relatively insensitive to movements in home technology. Therefore, the more volatile are the shocks in the home sector, the smaller is (in absolute value) the correlation between output and the labor wedge. As Figure 6 shows, the Backus-Smith correlation can turn negative in parameterizations of the model in which shocks in the home sector account for less than 1% of GDP's variance.

Figure 7 presents sensitivity checks for the persistence, spillover and correlation of the technology shocks. As the Figure shows, increasing the spillover from market to non-market technology or the correlation of the market and non-market technology shocks produces a lower Backus-Smith correlation without lowering much the volatility of the labor wedge.[27] Since Benhabib, Rogerson

[26] Since ϵ_H and a_h have similar effects on the volatility and the countercyclicality of the labor wedge, their optimal combination is identified by the steady-state value of the labor wedge. The steady-state value of the labor wedge is decreasing in ϵ_H and increasing in a_h.

[27] Asymmetric sectoral spillovers are interesting because an important observation in the home production liter-

and Wright (1991) have set this correlation as high as $corr(\epsilon_i^m, \epsilon_i^n) = 0.66$, the benchmark calibration with a zero correlation is conservative. Figure 8 shows that decreasing the curvature parameter σ produces a higher Backus-Smith correlation and a less volatile labor wedge. In particular, the Backus-Smith correlation becomes negative for a σ around 0.8. Increasing the share of capital in the home sector, α_n, produces more a volatile labor wedge and a lower Backus-Smith correlation.

Finally, in the last panel of Figure 8 I vary the cross-country spillover in market technology. In the benchmark calibration this spillover has been set equal to zero, as estimates from a symmetric VAR indicated insignificant spillovers. As the spillover increases, the labor wedge becomes only slightly less volatile but the Backus-Smith correlation becomes more negative and the difference between the correlation of output and the correlation of consumption across countries remains the same. Since in the workhorse model of Backus, Kehoe and Kydland (1994) the spillover equals 0.088, the zero spillover in the benchmark calibration is also a conservative choice.

7.2 Tax Shocks

Mulligan (2002), Prescott (2004) and Ohanian, Raffo and Rogerson (2008) show how cross-country differences in the tax system lead to cross-country differences in the wedge between the marginal product of labor and the marginal rate of substitution which, when labor supply is sufficiently elastic, can explain cross-country differences in labor supply outcomes. Rogerson (2008) augments the basic model and argues that home production introduces an additional margin of substitution which magnifies a given effect of taxes on labor supply. We can restate intuitively Rogerson's result in terms of equation (19). When taxes increase, the first term of the wedge increases. But taxes also affect the wedge indirectly, through the second and the third term in equation (19), because the shadow price of working in the home sector increases in the tax rate. Therefore, a given increase in the tax rate magnifies the wedge between the marginal product and the marginal rate of substitution in a model with home production. As the share of home production increases, the sensitivity of the wedge to tax shocks increases. As for business cycles, Mertens and Ravn (2008) use the narrative approach of Romer and Romer (2010) and conclude that tax shocks account for 18% of the variance of output at business cycle frequencies.[28]

ature is the positive correlation between market investment, home investment and market output (Greenwood and Hercowitz, 1991; Chang, 2000). With Cobb-Douglas technology in the home sector and without any adjustment costs in the accumulation of capital, investment in the home sector is negatively correlated with market investment and output because the reallocation of capital across the two sectors is costless. I find that relatively high sectoral spillovers from the market to the non-market sector can induce a positive comovement between investment in the home sector and market output. Alternatively, when I augment the model with adjustment costs, investment in the two sectors is positively correlated. This is without changing much the volatility of the labor wedge (because market consumption becomes more volatile), the cross-country correlation in output, consumption and employment, the Backus-Smith correlation and the correlation of real net exports with output. The correlation of investment across countries, on the other hand, increases.

[28] Shimer (2009) argues that it is difficult to imagine how increasing taxes lead to recessions and a countercyclical labor wedge. I have used McDaniel's (2007) series for effective consumption and labor taxes for a preliminary

To examine the robustness of the results to the inclusion of taxes, I consider the version of the model in which government spending shocks are financed by time-varying labor income taxes. I set the steady-state share of government spending in GDP at $g^* = 0.1673$ which matches the corresponding average sample value in the US. Using US data, the persistence of government spending is set equal to $\rho_{g^i,g^i} = 0.848$ and the volatility of the innovations in government spending as a fraction of GDP is set equal to $(\sigma_{g^i,g^i})^{1/2} = 0.89\%$. All other parameters are fixed at their benchmark values as shown in Table 1. The exceptions are the parameter a_C which is set equal to 0.875 and the parameter ϵ_C which is set equal to 2. These minor changes in the calibration allow the model with government spending to match the average share of imports in the US GDP and the volatility of the import ratio relative to the volatility of the terms of trade for the US.

Table 5 presents the results. Column 1 shows the data moments and column 2 repeats the moments from the benchmark model presented before in Table 2. Column 3 presents the results from the estimated incomplete markets model with taxes and columns 4 and 5 present moments under the complete markets model and under financial autarky respectively. Finally, the last three columns show moments when shocks are very persistent. To summarize, the results seem in general robust to the inclusion of taxes. The Backus-Smith correlation becomes positive but close to zero under the benchmark estimation of column 3. The intuition for this result is that the inclusion of taxes implies that a smaller home sector is required in order to match the steady-state value of the labor wedge. Following the analysis in Section 6.2, when the non-separability in the utility function becomes weaker, market consumption becomes more negatively correlated with its marginal utility and the Backus-Smith correlation increases. But as the Table shows, the quantitative effect is small. When the shocks are very persistent, the Backus-Smith correlation is negative and low in the complete markets model, close to zero in the incomplete markets model and positive and high in the financial autarky model.

8 Conclusion

This paper shows how a parsimonious model with home production explains the behavior of the observed labor wedge. In turn, it shows how the estimated labor wedge generates an international transmission mechanism which accounts for some of the most prominent puzzles of international business cycles theory.

Using a frictionless model I show how home production accounts well for the steady-state value of the wedge, its trend and its cyclical properties. Except for the reallocation of time from the market to the home sector, the labor wedge could also reflect frictions in the labor market. An

inspection of this argument. In line with Shimer's argument, I find that the correlation between the "effective tax distortion" and the labor wedge is not significant for various countries. The effective tax distortion is measured as $(1 + \pi_C)/(1 - \pi_L)$ where π_C is the effective consumption tax rate and π_L is the effective labor income tax rate.

interesting extension of the model is to compare alternative explanations of the labor wedge in a unified framework with home production and more realistic and complicated frictions in the labor market.

As for the implications of the labor wedge for international business cycles, I show how movements of the marginal utility of market consumption help resolve the international risk sharing puzzle. My results suggest that alternative sources of the labor wedge will not be able to explain the international risk sharing puzzle. With complete markets, i.e. under equation (30), other sources of the labor wedge do not affect the correlation of relative consumption with the real exchange rate. For instance, Chari, Kehoe and McGrattan (2002) show how monetary models with stickiness (which generate labor wedges) cannot explain the relative consumption - real exchange rate puzzle. With incomplete markets, tax shocks tend to imply real appreciations when the size of the home sector is small. In general, this analysis suggests that unless world demand for traded goods shifts more than their supply due to non-separabilities in the utility function (as in the model here) or unless world demand for traded goods is downward sloping in the terms of trade (as in Corsetti, Dedola and Leduc, 2008), it is very difficult to explain the low degree of international risk sharing.

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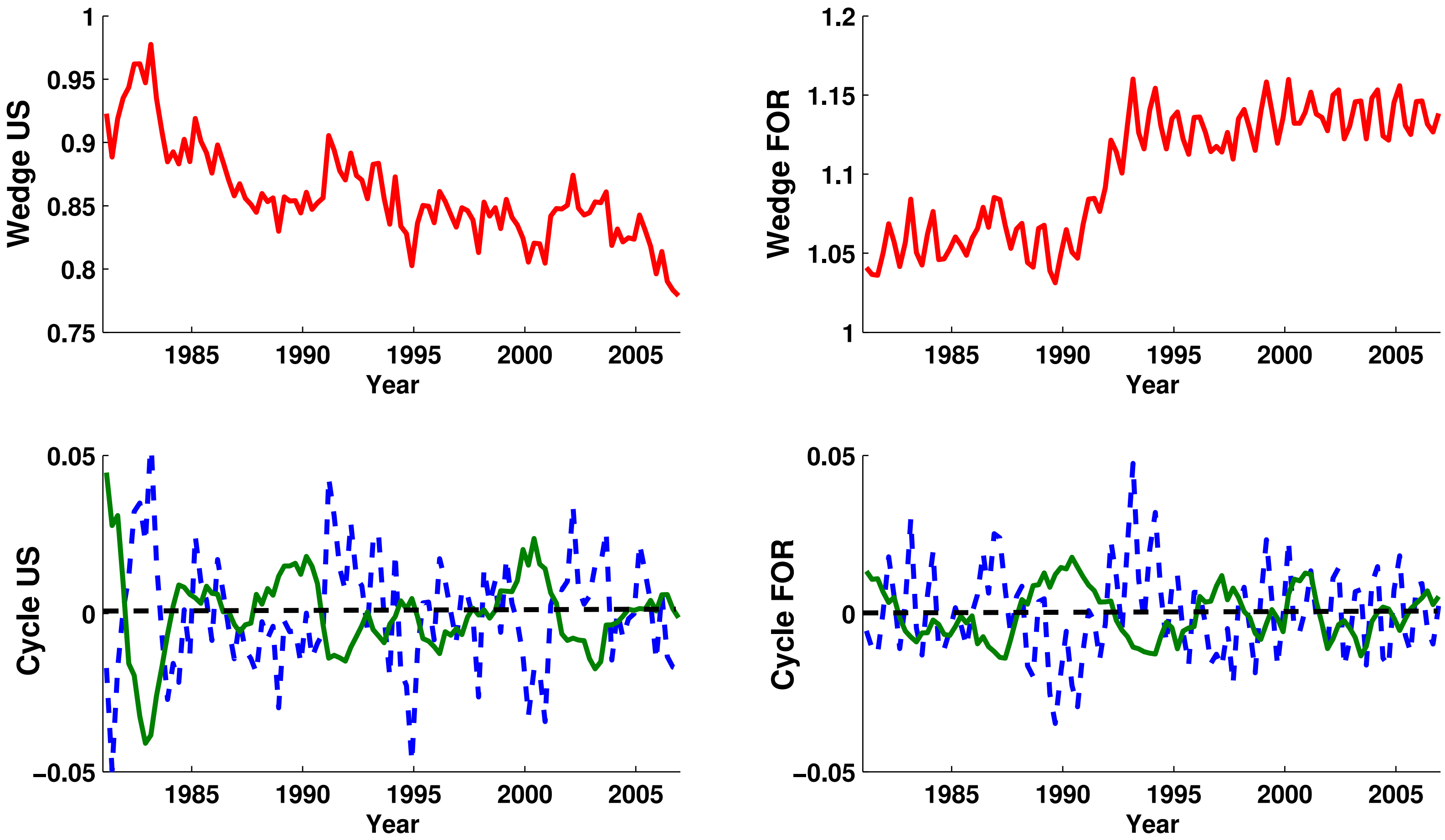
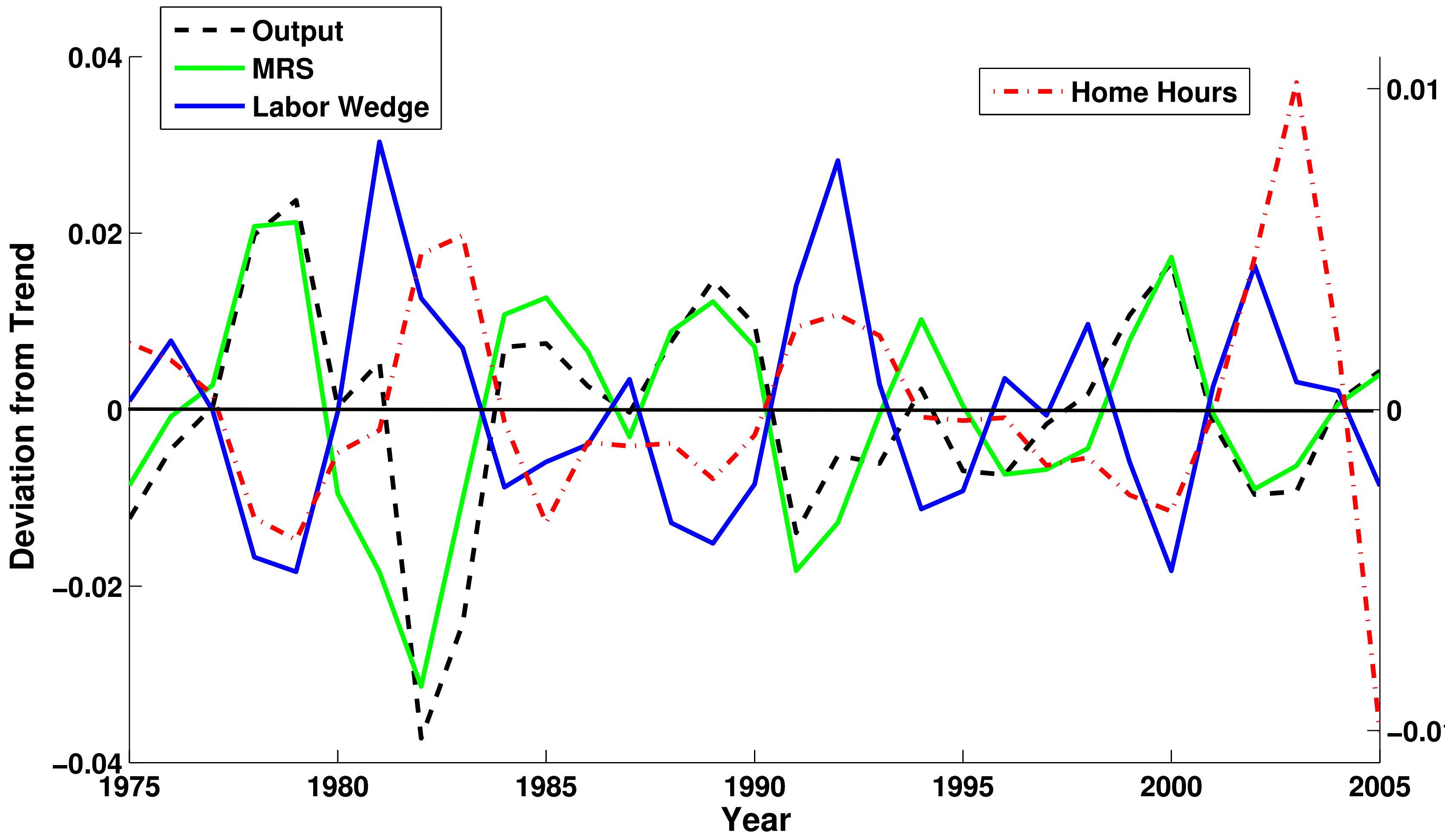
Figure 1: The Observed Labor Wedge: 1981(1)—2006(4)



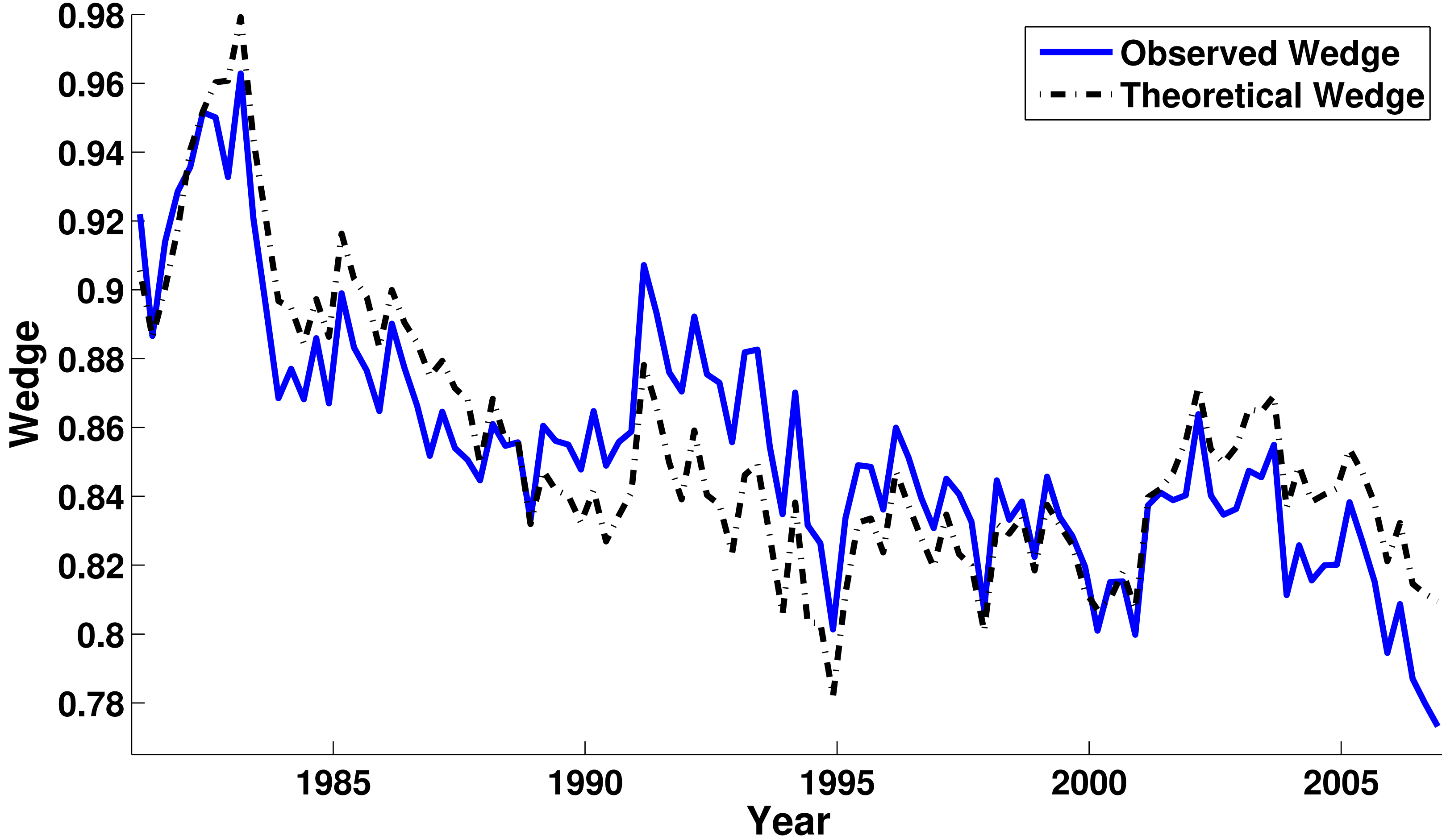
Notes: The observed labor wedge is constructed according to equation (16) with data on consumption, output, employment and the terms of trade (see Section 4.2). The upper panels show the labor wedge in the US and the Foreign aggregate. In the lower panels, the solid line shows the log deviation of output from its HP trend and the dashed line shows the log deviation of the labor wedge from its HP trend (smoothing parameter $\lambda = 1600$). See Appendix B and the text for more details on the sources of the data.

Figure 2: US Observed Labor Wedge, MRS, Output and Time in Home Production: 1975—2005 (Annual Data)



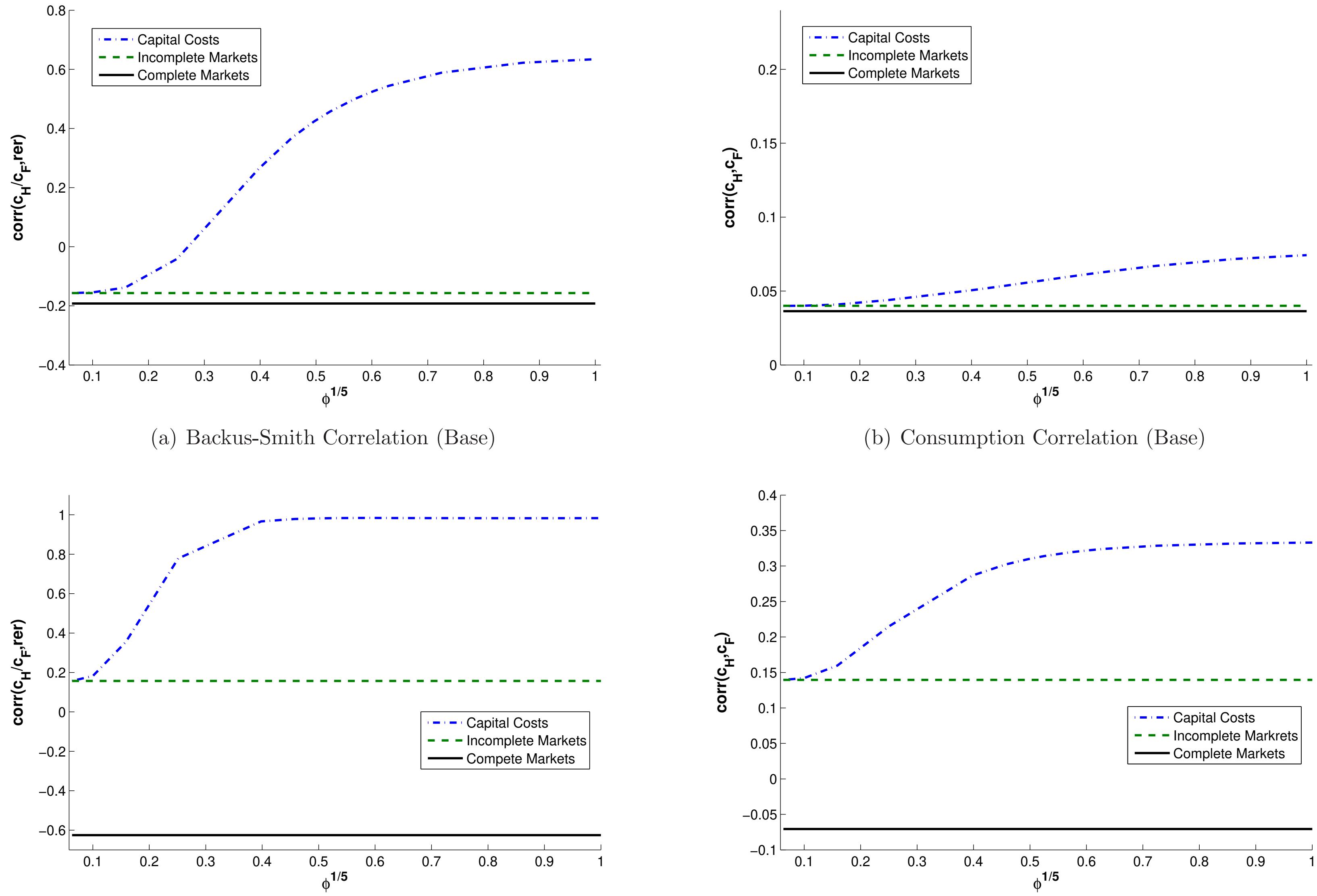
Notes: The vertical axis measures log deviations of the observed labor wedge, output and the marginal rate of substitution (left axis) and hours in home production (right axis) from their trend. Series are logged and HP-filtered with smoothing parameter $\lambda = 6.25$. The horizontal axis shows the year. The observed labor wedge is constructed according to equation (16) with data on consumption, output, employment and the terms of trade (see Section 4.2). See Appendix B for variable definitions and sources. The market hours ("Implied Average Hours per Worker") and home hours variables ("htw14") are taken from Ramey and Francis (2009; Online Appendix, Main Data.xls). In the Figure, their estimates are for 1975 and 1985 (from AHTUS) and then for 2003, 2004 and 2005 (from BLS). As explained in the text, estimates for the other years are constructed with interpolation.

Figure 3: US Observed Labor Wedge vs. Theoretical Labor Wedge with US Data: 1981(1)—2006(4)



Notes: The Figure compares the observed labor wedge constructed according to equation (16) with the theoretical labor wedge constructed according to equation (19) when there are no taxes ($\pi_t = 0$). See Section 4.2 for the construction of the series. The offset rate is fixed at $\alpha = 0.75$. The optimal parameters are $a_h = 0.20$, $\epsilon_H = 1.34$ and $\chi = 7.46$. Observations have been weighted uniformly. See Appendix B for extensions and robustness checks.

Figure 4: International Risk Sharing and Financial Completeness



(a) Backus-Smith Correlation (Base)

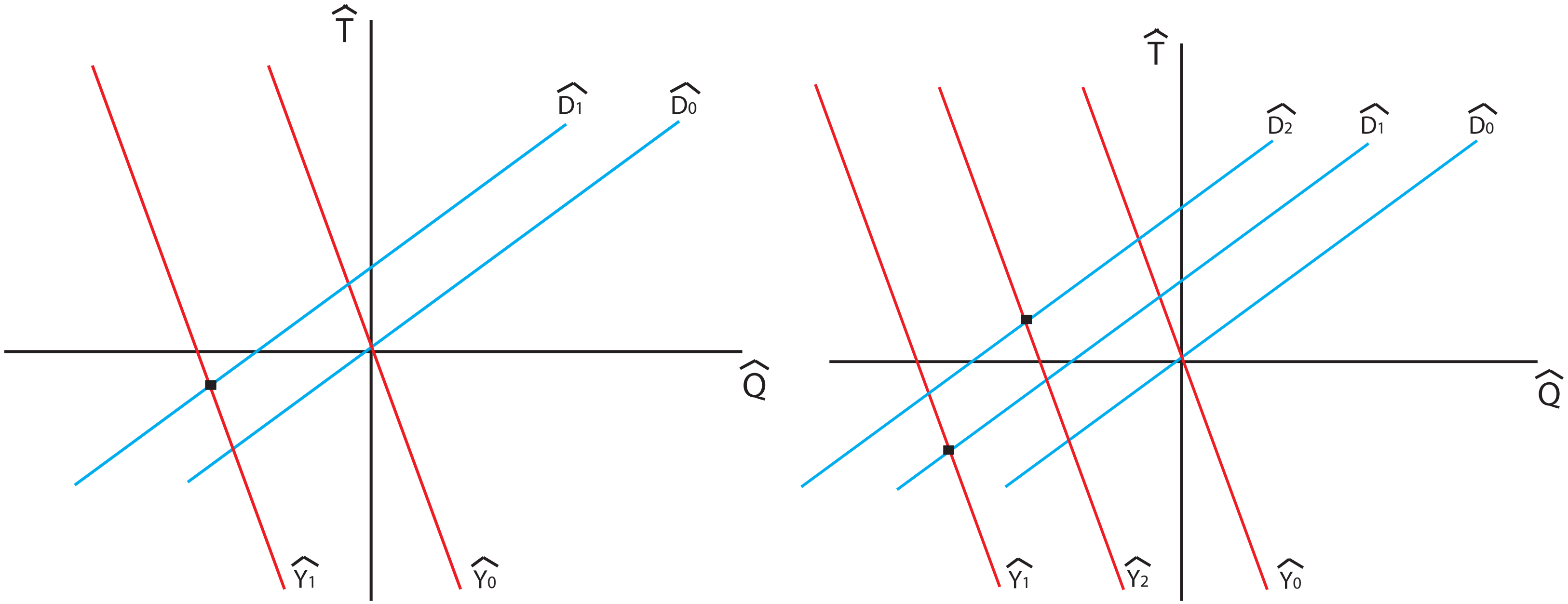
(b) Consumption Correlation (Base)

(c) Backus-Smith Correlation (Persist)

(d) Consumption Correlation (Persist)

Notes: The vertical axis measures the moments. The horizontal axis measures the portfolio adjustment cost parameter ϕ. I take a monotone transformation of ϕ to ease the readability of the graphs. The incomplete markets model has a ϕ which is positive but small to induce stationarity. When ϕ is large the two countries remain in financial autarky (the volatility of the bonds is zero). "Base" refers to the benchmark case with the parameters of Table 1 and Table 3. "Persist" sets the persistence of the technology shocks equal to 0.999, while holding all other parameters fixed at their benchmark values.

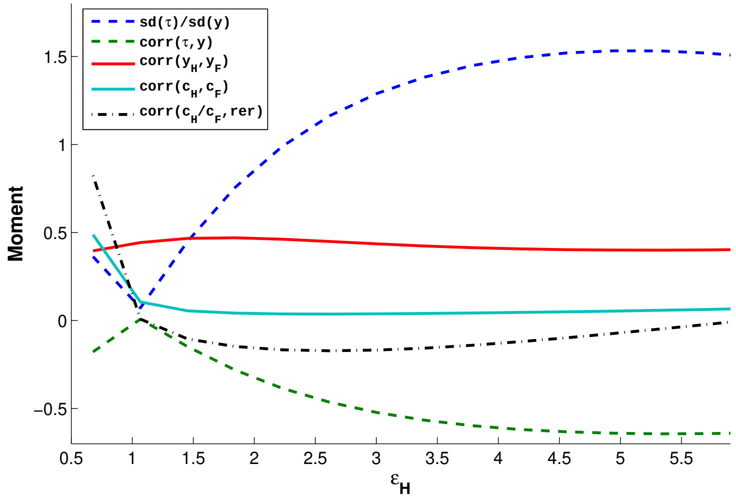
Figure 5: World Demand and Supply



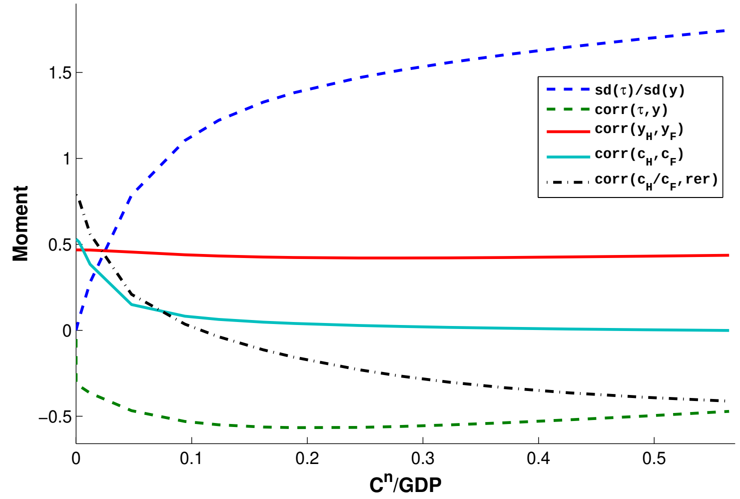
(a) Financial Autarky (b) Incomplete Markets

Notes: The vertical axis measures the log-deviation of the terms of trade from its steady-state value ($\widehat{T}$). The horizontal axis measures the log-deviation of quantities from their steady state values ($\widehat{Q}$). The curves $\widehat{D}$ and $\widehat{Y}$ denote (log-deviations from steady-state) demand and supply of domestic traded goods respectively from the equilibrium condition (31). The left panel illustrates the equilibrium determination of the terms of trade in the financial autarky model and the right panel illustrates the equilibrium determination in the incomplete markets model. $\widehat{D_0}$ and $\widehat{Y_0}$ are the pre-shock world demand and supply respectively. $\widehat{D_1}$ and $\widehat{Y_1}$ are the after-shock world demand and supply respectively in the financial autarky model. $\widehat{D_2}$ and $\widehat{Y_2}$ are the after-shock world demand and supply respectively in the incomplete markets model.

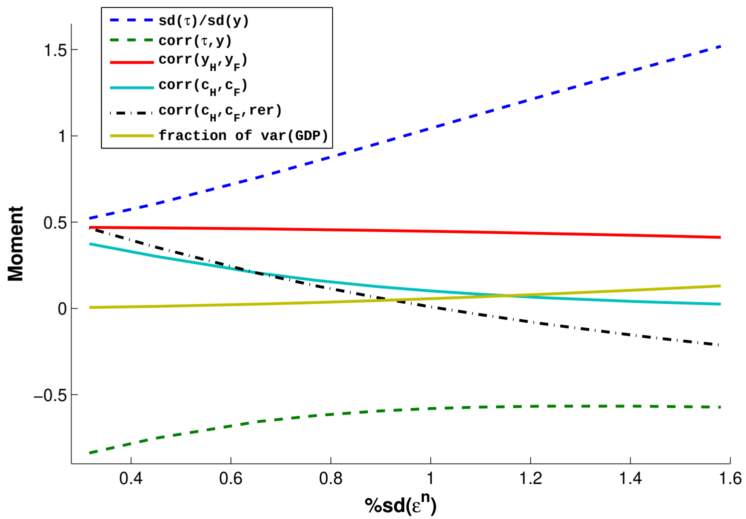
Figure 6: Sensitivity Analysis I



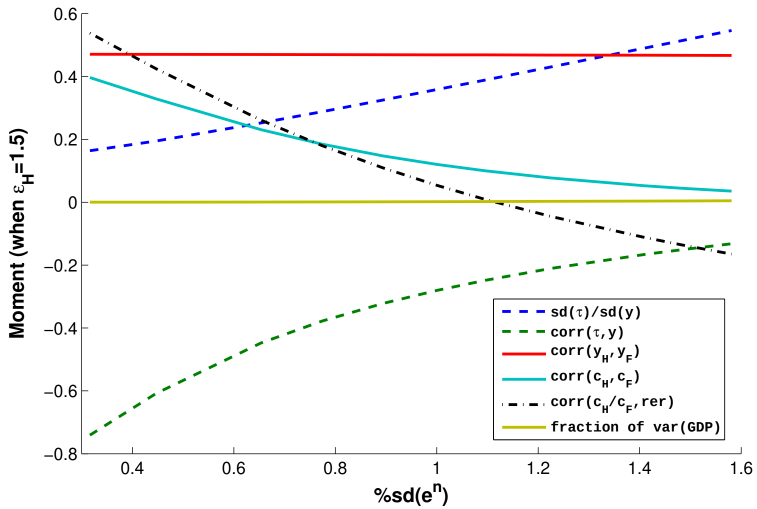
(a) Elasticity of Substitution ϵ_H



(b) Size of the Home Sector C^n/GDP



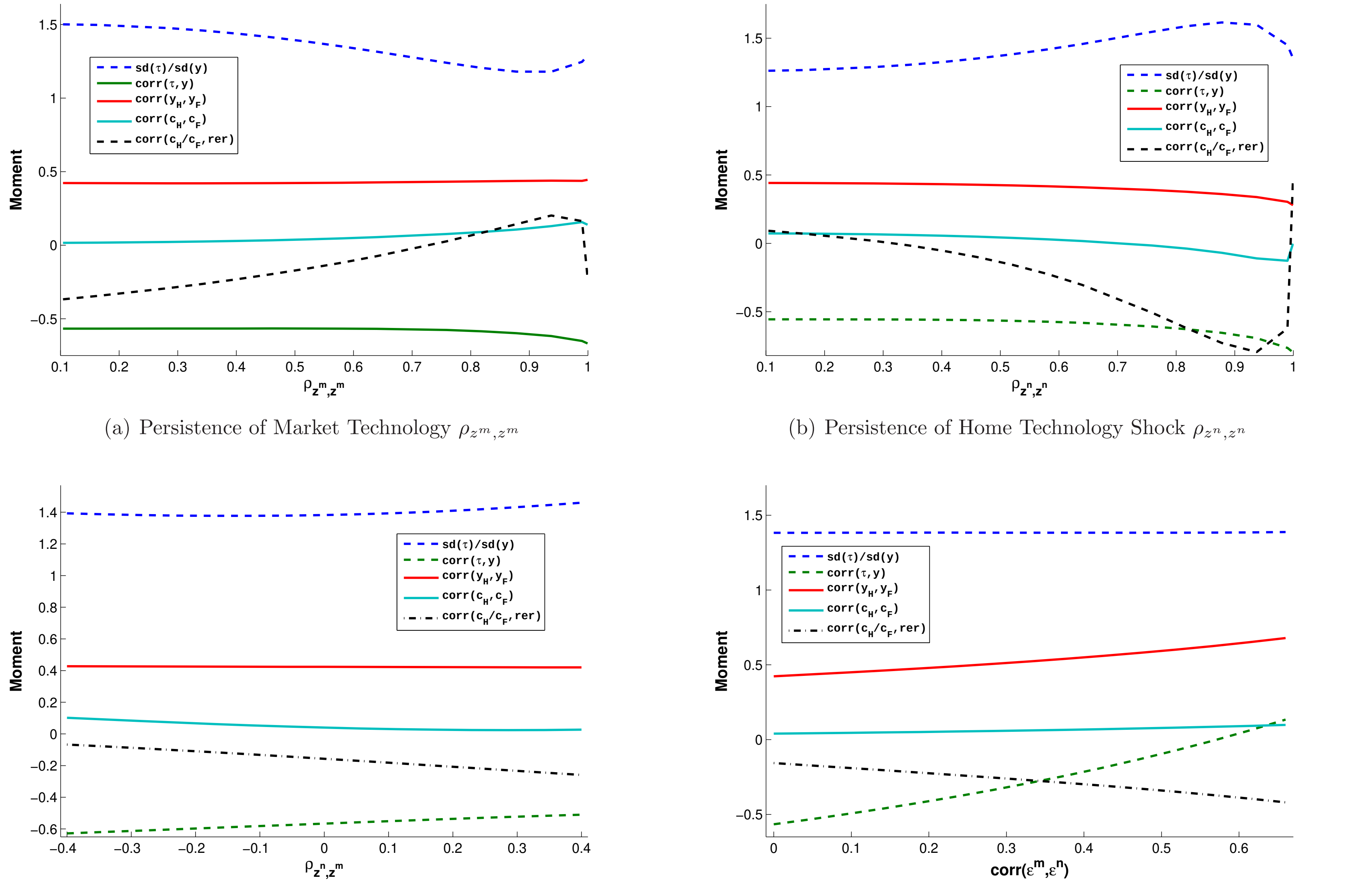
(c) Volatility of Home Technology Shock $\sigma_{\epsilon^n,\epsilon^n}$



(d) Volatility of Home Technology Shock $\sigma_{\epsilon^n,\epsilon^n}$

Notes: The vertical axis measures the moments. The horizontal axis measures the elasticity of substitution between market and home consumption ϵ_H (top-left panel), the size of the home sector C^n/GDP (top-right panel) which is taken by varying the preference parameter a_h and the percent standard deviation of the innovation of technology in the home sector $\sigma_{\epsilon^n,\epsilon^n}$ (bottom panels). In the bottom-right panel the elasticity of substitution ϵ_H has been set equal to 1.5. In all other cases, the parameters that do not vary are set equal to the benchmark values shown in Tables 1 and 3. τ is the labor wedge, y_H and y_F denote domestic and foreign market output, c_H and c_F denote domestic and foreign market consumption and rer is the real exchange rate.

Figure 7: Sensitivity Analysis II



(a) Persistence of Market Technology ρ_{z^m,z^m}

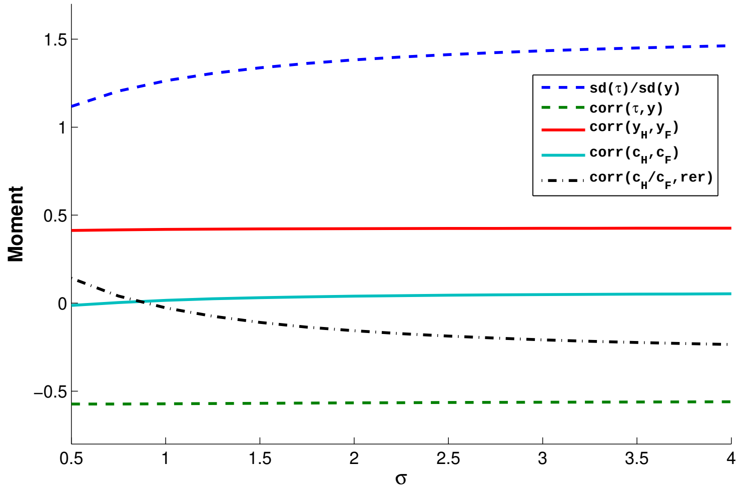
(b) Persistence of Home Technology Shock ρ_{z^n,z^n}

(c) Sectoral Technology Spillover $\rho_{z_i^n,z_i^m}$

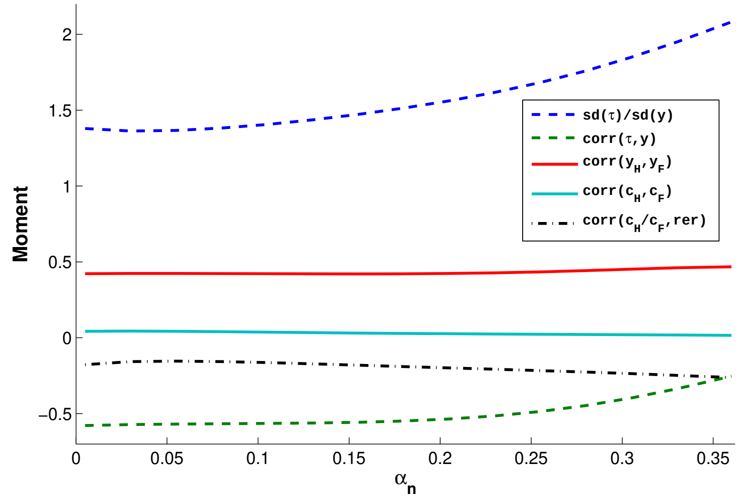
(d) Correlation of Technology Innovations $corr(\epsilon^m,\epsilon^n)$

Notes: The vertical axis measures the moments. The horizontal axis measures the persistence of home technology ρ_{z^n,z^n} (top-left panel), the persistence of the market technology shock ρ_{z^m,z^m} (top-right panel), the spillover from market technology to home technology ρ_{z^n,z^m} (bottom-left panel) and the correlation of the innovations of sectoral technologies $corr(\epsilon^m,\epsilon^n)$ (bottom-left panel). In all cases, the parameters that do not vary are set equal to the benchmark values shown in Tables 1 and 3. τ is the labor wedge, y_H and y_F denote domestic and foreign market output, c_H and c_F denote domestic and foreign market consumption and rer is the real exchange rate.

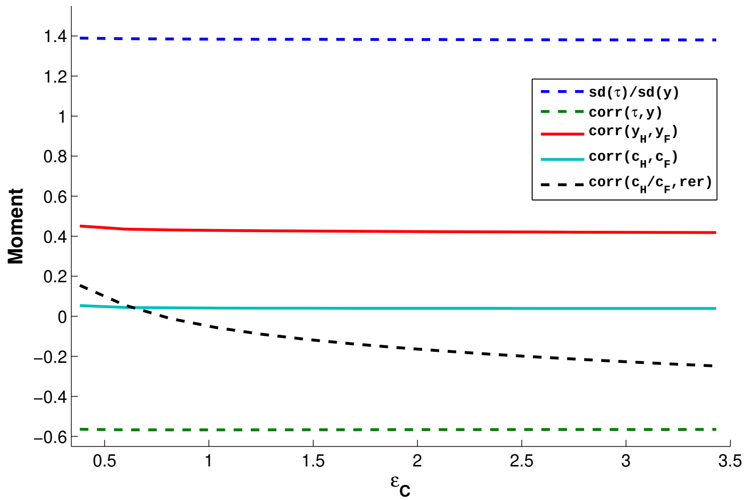
Figure 8: Sensitivity Analysis III



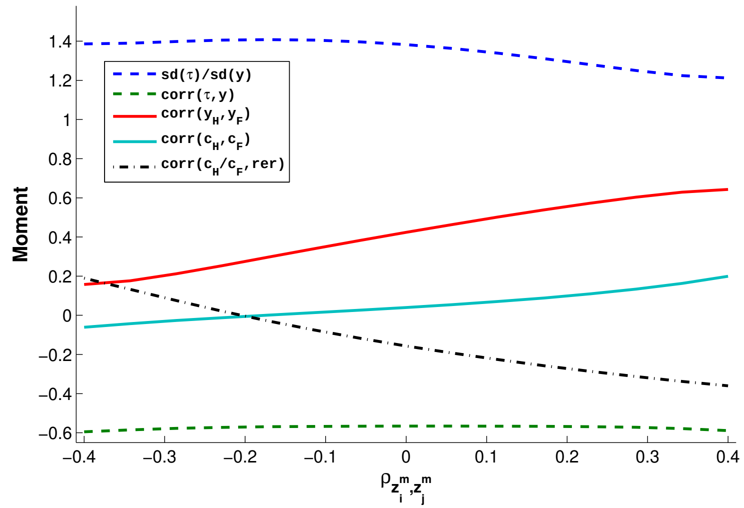
(a) Curvature Parameter σ



(b) Share of Capital in Home Production α_n



(c) Trade Elasticity of Substitution ϵ_C



(d) Cross-Country Technology Spillover $\rho_{z_i^m,z_j^m}$

Notes: The vertical axis measures the moments. The horizontal axis measures the curvature parameter σ (top-left panel), the share of capital in home production α_n (top-right panel), the trade elasticity of substitution ϵ_C (bottom-left panel) and the cross-country spillovers in market technology $\rho_{z_i^m,z_j^m}$ (bottom-right panel). In all cases, the parameters that do not vary are set equal to the benchmark values shown in Tables 1 and 3. τ is the labor wedge, y_H and y_F denote domestic and foreign market output, c_H and c_F denote domestic and foreign market consumption and rer is the real exchange rate.

Table 1: Fixed Parameters in Benchmark Model

	Value	Notes
ϵ_C	1.907	fits US volatility of import ratio relative to volatility of terms of trade
a_C	0.896	fits average US import share in GDP
a_L	0.41	fixed in data and in model (see Section 4.2)
α_m	0.36	taken from Benhabib, Rogerson and Wright (1991); fixed in data and model (see Section 4.2)
α_n	0.08	taken from Benhabib, Rogerson and Wright (1991)
β	0.99	taken from Benhabib, Rogerson and Wright (1991)
δ	0.025	taken from Benhabib, Rogerson and Wright (1991)
σ	2.00	taken from Corsetti, Dedola and Leduc (2008)
ϕ	10^{-6}	induce stationarity in the model
g_i^*	0.00	no government spending in benchmark model
$corr(\epsilon_i^m, \epsilon_j^m)$	0.45	fits cross-country correlation of output

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; δ is the depreciation parameter in the capital accumulation equation; σ is the risk aversion parameter in the utility function; ϕ is the portfolio adjustment cost parameter; g_i^* is the steady-state share of government consumption; $corr(\epsilon_i^m, \epsilon_j^m)$ is the cross-country correlation of the innovations in market technology. The index $i, j = H, F$ denote the countries. All other parameters in the matrices R and Σ in the VAR process (15) are equal to zero, unless estimated in Table 3.

Table 2: Estimated Moments in Benchmark Model

	Data	Benchmark Model	90% CI for Model's Mean	No Home Production ($a_h = 0$)
	(1)	(2)	(3)	(4)
$sd(y_H)$	1.27	1.27	[1.26,1.28]	0.90
$sd(z_H^m)/sd(y_H)$	0.59	0.55	[0.54,0.55]	0.77
$corr(z_{H,t}^m, z_{H,t-1}^m)$	0.41	0.41	[0.40,0.41]	0.41
$sd(\tau_H)/sd(y_H)$	1.39	1.38	[1.37,1.39]	0.00
$corr(\tau_H, y_H)$	-0.59	-0.57	[-0.57,-0.56]	—
$corr(\tau_H, \tau_{H,-1})$	0.47	0.47	[0.46,0.47]	—
τ_H^*	0.86	0.86	[0.85,0.87]	0.00
$corr(nxqty_H, y_H)$	-0.31	-0.50	[-0.50,-0.49]	-0.46
$corr(y_H, y_F)$	0.44	0.42	[0.42,0.42]	0.47
$corr(c_H, c_F)$	0.25	0.04	[0.04,0.04]	0.53
$corr(i_H, i_F)$	0.25	0.24	[0.24,0.24]	0.28
$corr(emp_H, emp_F)$	0.41	0.30	[0.30,0.31]	0.47
$corr(c_H/c_F, rer)$	-0.20	-0.16	[-0.16,-0.15]	0.79

Notes: y, c, i emp, $nxqty$, z, τ and rer denote market output, market consumption, total investment, market employment, net exports in constant prices, market productivity, the labor wedge and the real exchange rate. An asterisk denotes steady-state values. H is the US and F is the Foreign aggregate. See Appendix B for definitions and sources of variables. Column 1 gives the estimated mean of the moments in the data. Column 2 is the estimated mean in the model. Column 3 shows the 90% confidence interval for model's mean. Column 4 presents statistics under the benchmark parameter values as shown in Tables 1 and 3 in a model without home production (i.e. when $a_h = 0$). The moments in the upper panel are fitted in the objective function (26). The moments in the lower panel of the Table are not fitted.

Table 3: Estimated Parameters in Benchmark Model

	Estimate	Standard Error	90% CI
	(1)	(2)	(3)
ϵ_H	3.393	0.029	[3.347, 3.441]
a_h	0.601	0.002	[0.599, 0.604]
$\rho_{z_i^m, z_i^m}$	0.524	0.003	[0.519, 0.530]
$\rho_{z_i^n, z_i^n}$	0.521	0.003	[0.517, 0.525]
$(\sigma_{\epsilon_i^m, \epsilon_i^m})^{1/2}$	0.0065	0.00002	[0.0065, 0.0066]
$(\sigma_{\epsilon_i^n, \epsilon_i^n})^{1/2}$	0.0141	0.0002	[0.0138, 0.0144]

Notes: ϵ_H is the elasticity of substitution between market and home goods; a_h is the preference parameter is the consumption aggregator; $(\sigma_{\epsilon_i^m, \epsilon_i^m})^{1/2}$ is the standard deviation of the technology shock in the market sector; $(\sigma_{\epsilon_i^n, \epsilon_i^n})^{1/2}$ is the standard deviation of the technology shock in the home sector; $\rho_{z_i^m, z_i^m}$ is the persistence parameter for technology in the market sector; $\rho_{z_i^n, z_i^n}$ is the persistence parameter for technology in the home sector. The first column presents the mean estimated parameter, the second its standard error and the third the 90% confidence interval for the estimated mean.

Table 4: Structure of Asset Markets and Persistent Shocks

	Data	Incomplete (Base)	Complete (Base)	Autarky (Base)	Incomplete (Persist)	Complete (Persist)	Autarky (Persist)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$sd(y_H)$	1.27	1.27	1.27	1.25	1.64	1.63	1.63
$sd(z_H^m)/sd(y_H)$	0.59	0.55	0.55	0.55	0.51	0.52	0.52
$corr(z_{H,t}^m, z_{H,t-1}^m)$	0.41	0.41	0.41	0.41	0.71	0.71	0.71
$sd(\tau_H)/sd(y_H)$	1.39	1.38	1.38	1.39	1.31	1.39	1.29
$corr(\tau_H, y_H)$	-0.59	-0.57	-0.57	-0.56	-0.81	-0.76	-0.81
$corr(\tau_H, \tau_{H,-1})$	0.47	0.47	0.47	0.47	0.78	0.78	0.78
τ_H^*	0.86	0.86	0.86	0.86	0.86	0.86	0.86
$corr(nxqty_H, y_H)$	-0.31	-0.50	-0.49	—	-0.50	-0.34	—
$corr(y_H, y_F)$	0.44	0.42	0.42	0.46	0.31	0.33	0.34
$corr(c_H, c_F)$	0.25	0.04	0.04	0.08	0.14	-0.07	0.34
$corr(i_H, i_F)$	0.25	0.24	0.24	0.43	0.03	0.03	0.47
$corr(emp_H, emp_F)$	0.41	0.30	0.30	0.38	0.08	0.16	0.10
$corr(c_H/c_F, rer)$	-0.20	-0.16	-0.19	0.64	0.16	-0.63	0.99

Notes: y, c, i emp, $nxqty$, z, τ and rer denote market output, market consumption, total investment, market employment, net exports in constant prices, market productivity, the labor wedge and the real exchange rate. An asterisk denotes steady-state values. H is the US and F is the Foreign aggregate. See Appendix B for definitions and sources of variables. Column 1 gives the estimated mean of the moments in the data. Columns 2-4 are moments in the incomplete asset markets model, the complete asset markets model and the financial autarky model, using the benchmark parameter values as shown in Tables 1 and 3. In columns 5-7 the persistence parameters are set equal to $\rho_{z_i^m, z_i^m} = \rho_{z_i^n, z_i^n} = 0.999$ and all other parameters are set equal to their benchmark values as shown in Tables 1 and 3.

Table 5: Model with Taxes

	Data	Benchmark	Incomplete (Base)	Complete (Base)	Autarky (Base)	Incomplete (Persist)	Complete (Persist)	Autarky (Persist)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$sd(y_H)$	1.27	1.27	1.27	1.27	1.25	1.55	1.55	1.54
$sd(z_H^m)/sd(y_H)$	0.59	0.55	0.57	0.57	0.57	0.56	0.56	0.57
$corr(z_{H,t}^m, z_{H,t-1}^m)$	0.41	0.41	0.41	0.41	0.41	0.71	0.71	0.71
$sd(\tau_H)/sd(y_H)$	1.39	1.38	1.38	1.39	1.39	1.44	1.48	1.41
$corr(\tau_H, y_H)$	-0.59	-0.57	-0.58	-0.58	-0.56	-0.76	-0.72	-0.75
$corr(\tau_H, \tau_{H,-1})$	0.47	0.47	0.47	0.47	0.46	0.77	0.77	0.77
τ_H^*	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
$corr(nxqty_H, y_H)$	-0.31	-0.50	-0.50	-0.50	—	-0.50	-0.37	—
$corr(y_H, y_F)$	0.44	0.42	0.42	0.42	0.46	0.31	0.32	0.34
$corr(c_H, c_F)$	0.25	0.04	0.06	0.05	0.10	0.12	0.00	0.33
$corr(i_H, i_F)$	0.25	0.24	0.17	0.17	0.49	-0.12	-0.12	0.46
$corr(emp_H, emp_H)$	0.41	0.30	0.26	0.26	0.34	0.05	0.11	0.07
$corr(c_H/c_F, rer)$	-0.20	-0.16	0.11	0.09	0.65	-0.05	-0.44	0.98

Notes: y, c, i emp, $nxqty$, z, τ and rer denote market output, market consumption, total investment, market employment, net exports in constant prices, market productivity, the labor wedge and the real exchange rate. An asterisk denotes steady-state values. H is the US and F is the Foreign aggregate. See Appendix B for definitions and sources of variables. Column 1 gives the estimated mean of the moments in the data. Columns 2 repeats the benchmark results under the parameters of Tables 1 and 3. Column 3 presents the estimated means of the moments in the model with incomplete markets and tax shocks. All non-estimated parameters are set to their values shown in Table 1 except for $\epsilon_C = 2$ (to match the volatility of the US import ratio relative to the terms of trade) and $a_C = 0.875$ (to match the average share of imports in US GDP). The parameters for the stochastic process for government spending as fraction of GDP have been estimated from US data: $g_i^* = 0.1673$, $\rho_{g_i,g_i} = 0.848$ and $(\sigma_{g_i,g_i})^{1/2} = 0.0089$. The estimated parameters are $\epsilon_H = 3.580$, $a_h = 0.515$, $\rho_{z_i^m,z_i^m} = 0.527$, $\rho_{z_i^n,z_i^n} = 0.476$, $\sigma_{\epsilon_i^m,\epsilon_i^m} = 0.0068$ and $\sigma_{\epsilon_i^n,\epsilon_i^n} = 0.0170$. Columns 4 and 5 show moments under the parameters of column 3 but under complete markets and financial autarky respectively. Finally in columns 6-8, all parameters are set as in column 3 with the exception of the persistence of the shocks which is set equal to $\rho_{z_i^m,z_i^m} = \rho_{z_i^n,z_i^n} = \rho_{g_i,g_i} = 0.999$.

Appendix (Not for Publication)

A Model

This Appendix presents the conditions that characterize the competitive equilibrium of the model. I discuss the incomplete asset markets model, the complete asset markets model and the financial autarky model.

A.1 Incomplete Markets Model

Domestic Household:

$$C_{H,t} = \left[(1-a_h)(C^m_{H,t})^{\rho_h} + a_h(C^n_{H,t})^{\rho_h}\right]^{\frac{1}{\rho_h}} \tag{A.1}$$

$$U_{H,t} = C^{1-a_L}_{H,t} L^{a_L}_{H,t} \tag{A.2}$$

$$(1-a_L)(1-a_h)U^{-\sigma}_{H,t} L^{a_L}_{H,t} C^{1-a_L-\rho_h}_{H,t} (C^m_{H,t})^{\rho_h - 1} = \lambda_{H,t} P_{H,t} \tag{A.3}$$

$$a_L U^{-\sigma}_{H,t} L^{a_L-1}_{H,t} C^{1-a_L}_{H,t} = \lambda_{H,t}(1-\pi_{H,t})W_{H,t} \tag{A.4}$$

$$a_L N^n_{H,t} = (1-a_L)a_h(1-\alpha_n)L_{H,t}\left(\frac{C^n_{H,t}}{C_{H,t}}\right)^{\rho_h} \tag{A.5}$$

$$1 = L_{H,t} + N^m_{H,t} + N^n_{H,t} \tag{A.6}$$

$$\lambda_{H,t}\left(Q_t + \phi(B_{H,t} - \bar{B})\right) = \beta \mathbf{E}_t \lambda_{H,t+1} \tag{A.7}$$

$$\lambda_{H,t} P_{H,t} = \beta \mathbf{E}_t \lambda_{H,t+1}\left(r_{H,t+1} + P_{H,t+1}(1-\delta)\right) \tag{A.8}$$

$$\lambda_{H,t} P_{H,t} = \beta \mathbf{E}_t \left\{ \lambda_{H,t+1} P_{H,t+1} + (1-a_L)a_h\alpha_n U^{-\sigma}_{H,t+1} L^{a_L}_{H,t+1} C^{1-a_L-\rho_h}_{H,t+1} \frac{(C^n_{H,t+1})^{\rho_h}}{K^n_{H,t}} \right\} \tag{A.9}$$

$$I_{H,t} = I^m_{H,t} + I^n_{H,t} \tag{A.10}$$

$$I^m_{H,t} = K^m_{H,t} - (1-\delta)K^m_{H,t-1} \tag{A.11}$$

$$I^n_{H,t} = K^n_{H,t} - (1-\delta)K^n_{H,t-1} \tag{A.12}$$

$$K_{H,t} = K^m_{H,t} + K^n_{H,t} \tag{A.13}$$

$$C^n_{H,t} = \exp(z^n_{H,t})(K^n_{H,t-1})^{\alpha_n}(N^n_{H,t})^{1-\alpha_n} \tag{A.14}$$

$$P_{H,t}C^m_{H,t}+P_{H,t}I_{H,t}+Q_tB_{H,t}+\frac{\phi}{2}\left(B_{H,t}-\bar{B}\right)^2 = (1-\pi_{H,t})W_{H,t}N^m_{H,t}+r_{H,t}K^m_{H,t-1}+B_{H,t-1}+\Pi_H \tag{A.15}$$

Foreign Household:

$$C_{F,t} = \left[(1-a_h)(C^m_{F,t})^{\rho_h} + a_h(C^n_{F,t})^{\rho_h}\right]^{\frac{1}{\rho_h}} \tag{A.16}$$

$$U_{F,t} = C^{1-a_L}_{F,t}L^{a_L}_{F,t} \tag{A.17}$$

$$(1-a_L)(1-a_h)U^{-\sigma}_{F,t}L^{a_L}_{F,t}C^{1-a_L-\rho_h}_{F,t}(C^m_{F,t})^{\rho_h-1} = \lambda_{F,t}P_{F,t} \tag{A.18}$$

$$a_LU^{-\sigma}_{F,t}L^{a_L-1}_{F,t}C^{1-a_L}_{F,t} = \lambda_{F,t}(1-\pi_{F,t})W_{F,t} \tag{A.19}$$

$$a_LN^n_{F,t} = (1-a_L)a_h(1-\alpha_n)L_{F,t}\left(\frac{C^n_{F,t}}{C_{F,t}}\right)^{\rho_h} \tag{A.20}$$

$$1 = L_{F,t} + N^m_{F,t} + N^n_{F,t} \tag{A.21}$$

$$\lambda_{F,t}\left(Q_t + \phi(-B_{H,t}-\bar{B})\right) = \beta\mathbf{E}_t\lambda_{F,t+1} \tag{A.22}$$

$$\lambda_{F,t}P_{F,t} = \beta\mathbf{E}_t\lambda_{F,t+1}\left(r_{F,t+1} + P_{F,t+1}(1-\delta)\right) \tag{A.23}$$

$$\lambda_{F,t}P_{F,t} = \beta\mathbf{E}_t\left\{\lambda_{F,t+1}P_{F,t+1} + (1-a_L)a_h\alpha_nU^{-\sigma}_{F,t+1}L^{a_L}_{F,t+1}C^{1-a_L-\rho_h}_{F,t+1}\frac{(C^n_{F,t+1})^{\rho_h}}{K^n_{F,t}}\right\} \tag{A.24}$$

$$I_{F,t} = I^m_{F,t} + I^n_{F,t} \tag{A.25}$$

$$I^m_{F,t} = K^m_{F,t} - (1-\delta)K^m_{F,t-1} \tag{A.26}$$

$$I^n_{F,t} = K^n_{F,t} - (1-\delta)K^n_{F,t-1} \tag{A.27}$$

$$K_{F,t} = K^m_{F,t} + K^n_{F,t} \tag{A.28}$$

$$C^n_{F,t} = \exp(z^n_{F,t})(K^n_{F,t-1})^{\alpha_n}(N^n_{F,t})^{1-\alpha_n} \tag{A.29}$$

$$P_{F,t}C^m_{F,t}+P_{F,t}I_{F,t}-Q_tB_{H,t}+\frac{\phi}{2}\left(-B_{H,t}-\bar{B}\right)^2 = (1-\pi_{F,t})W_{F,t}N^m_{F,t}+r_{F,t}K^m_{F,t-1}-B_{H,t-1}+\Pi_F \tag{A.30}$$

Domestic Intermediate Goods Producer:

$$Y_{HH,t} = \exp(z^m_{H,t})(K^m_{H,t-1})^{\alpha_m}(N^m_{H,t})^{1-\alpha_m} \tag{A.31}$$

$$\alpha_m P_{1,t}\exp(z^m_{H,t})(K^m_{H,t-1})^{\alpha_m-1}(N^m_{H,t})^{1-\alpha_m} = r_{H,t} \tag{A.32}$$

$$(1-\alpha_m)P_{1,t}\exp(z^m_{H,t})(K^m_{H,t-1})^{\alpha_m}(N^m_{H,t})^{-\alpha_m} = W_{H,t} \tag{A.33}$$

Foreign Intermediate Goods Producer:

$$Y_{FF,t} = \exp(z^m_{F,t})(K^m_{F,t-1})^{\alpha_m}(N^m_{F,t})^{1-\alpha_m} \tag{A.34}$$

$$\alpha_m P_{2,t}\exp(z^m_{F,t})(K^m_{F,t-1})^{\alpha_m-1}(N^m_{F,t})^{1-\alpha_m} = r_{F,t} \tag{A.35}$$

$$(1-\alpha_m)P_{2,t}\exp(z^m_{F,t})(K^m_{F,t-1})^{\alpha_m}(N^m_{F,t})^{-\alpha_m} = W_{F,t} \tag{A.36}$$

Domestic Final Goods Producer:

$$Y^{\rho_C}_{H,t} = a_C^{1-\rho_C}C^{\rho_C}_{HH,t} + (1-a_C)^{1-\rho_C}C^{\rho_C}_{HF,t} \tag{A.37}$$

$$a_C^{1-\rho_C}P_{H,t}Y^{1-\rho_C}_{H,t}C^{\rho_C-1}_{HH,t} = P_{1,t} \tag{A.38}$$

$$(1-a_C)^{1-\rho_C}P_{H,t}Y^{1-\rho_C}_{H,t}C^{\rho_C-1}_{HF,t} = P_{2,t} \tag{A.39}$$

Foreign Final Goods Producer:

$$Y^{\rho_C}_{F,t} = a_C^{1-\rho_C}C^{\rho_C}_{FF,t} + (1-a_C)^{1-\rho_C}C^{\rho_C}_{FH,t} \tag{A.40}$$

$$a_C^{1-\rho_C} P_{F,t} Y_{H,t}^{\rho_C - 1} C_{FF,t}^{\rho_C - 1} = P_{2,t} \tag{A.41}$$

$$(1 - a_C)^{1-\rho_C} P_{F,t} Y_{H,t}^{\rho_C - 1} C_{FH,t}^{\rho_C - 1} = P_{1,t} \tag{A.42}$$

Market Clearing:

$$Y_{HH,t} = C_{HH,t} + C_{FH,t} + G_{H,t} \tag{A.43}$$

$$P_{2,t} = 1 \tag{A.44}$$

$$Y_{H,t} = C_{H,t}^m + I_{H,t} \tag{A.45}$$

$$Y_{F,t} = C_{F,t}^m + I_{F,t} \tag{A.46}$$

Government Sector:

$$P_{1,t} G_{H,t} + \Pi_H = \pi_{H,t} W_{H,t} N_{H,t}^m \tag{A.47}$$

$$G_{H,t} = g_{H,t} Y_{HH,t} \tag{A.48}$$

$$\pi_{H,t} = \frac{g_{H,t}}{1 - \alpha_m} \tag{A.49}$$

$$P_{2,t} G_{F,t} + \Pi_F = \pi_{F,t} W_{F,t} N_{F,t}^m \tag{A.50}$$

$$G_{F,t} = g_{F,t} Y_{FF,t} \tag{A.51}$$

$$\pi_{F,t} = \frac{g_{F,t}}{1 - \alpha_m} \tag{A.52}$$

Definitions and Other Equations:

$$\exp(\tau_{H,t}) = \frac{1}{1 - \pi_{H,t}} \left(1 + \frac{N_{H,t}^n}{L_{H,t}}\right) \left[1 + \left(\frac{a_h}{1 - a_h}\right) \left(\frac{C_{H,t}^n}{C_{H,t}^m}\right)^{\frac{\epsilon_H - 1}{\epsilon_H}}\right] \tag{A.53}$$

$$\exp(\tau_{F,t}) = \frac{1}{1 - \pi_{F,t}} \left(1 + \frac{N_{F,t}^n}{L_{F,t}}\right) \left[1 + \left(\frac{a_h}{1 - a_h}\right) \left(\frac{C_{F,t}^n}{C_{F,t}^m}\right)^{\frac{\epsilon_H - 1}{\epsilon_H}}\right] \tag{A.54}$$

$$RER_t = \frac{P_{F,t}}{P_{H,t}} \tag{A.55}$$

$$T_t = \frac{P_{2,t}}{P_{1,t}} \tag{A.56}$$

$$IR_t = \frac{C_{HF,t}}{Y_{HH,t} - C_{FH,t}} \tag{A.57}$$

$$RELC_t = \frac{C^m_{H,t}}{C^m_{F,t}} \tag{A.58}$$

$$NX_t = \frac{P_{1,t}C_{FH,t} - P_{2,t}C_{HF,t}}{P_{1,t}Y_{HH,t}} \tag{A.59}$$

$$NXQTY_t = \frac{C_{FH,t} - C_{HF,t}}{Y_{HH,t}} \tag{A.60}$$

Equations (A.1)-(A.15) characterize the optimization problem of the domestic household. The variable $\lambda_{H,t}$ denotes the Lagrangian multiplier in household's budget constraint. Equations (A.1) and (A.2) define aggregate consumption and the utility function. Equations (A.3)-(A.9) are the first-order conditions with respect to market consumption, market work, non-market work, leisure, bonds, market investment and non-market investment respectively. Equations (A.10)-(A.13) are the capital accumulation equations, equation (A.14) is the home production technology and equation (A.15) is the budget constraint. Equations (A.16)-(A.30) are the corresponding conditions for the foreign household. I have used the asset market clearing condition ($B_{F,t} = -B_{H,t}$) to substitute out foreign bonds from the equilibrium conditions.

Equations (A.31)-(A.33) describe the profit maximization problem of the domestic intermediate goods producer (production function and first-order conditions). Equations (A.34)-(A.36) are the corresponding conditions for the foreign intermediate goods producer.

Equations (A.37)-(A.39) describe the profit maximization problem of the domestic final goods producer (production function and first-order conditions). Equations (A.40)-(A.42) are the corresponding conditions for the foreign final goods producer.

Equation (A.43) is the market clearing condition for the domestic traded good. Equation (A.44) normalizes the price of the foreign traded good to unity. The markets for final goods clear under equations (A.45) and (A.46).

Equations (A.47)-(A.52) describe the government sector. Equations (A.47) and (A.50) are the budget constraints, equations (A.48) and (A.51) define the government spending over GDP ratio and equations (A.49) and (A.52) specify that government spending shocks are financed through labor income taxes. This implies that in response to shocks other than government spending, lump-sum transfers adjust to balance the government budget. Since the steady-state of the model is not available in closed-form, this specification avoids the more involved fixed point problem that arises when the steady-state value of government spending (G_i^*) affects the steady-state tax rate (π_i^*) and as a result it also affects the steady-state level of real GDP (Y_{ii}^*), making the ratio $g_i^* = G_i^*/Y_{ii}^*$ endogenous. Instead, I specify exogenously the steady-state ratio g_i^* and then simply take the tax rate from $\pi_i^* = g_i^*/(1-\alpha_m)$ and the level of government spending from $G_i^* = g_i^* Y_{ii}^*$.

Finally, equations (A.53)-(A.60) define the labor wedge, the real exchange rate, the terms of trade, the import ratio, relative market consumption, net exports in current prices and net exports in constant prices as percentage of GDP.

To close the model I specify a VAR process for technology and fiscal policy in the two countries, $\mathbf{Z}_t = \{z_{H,t}^m, z_{F,t}^m, z_{H,t}^n, z_{F,t}^n, g_{H,t}, g_{F,t}\}$:

$$\mathbf{Z}_t = R\mathbf{Z}_{t-1} + \epsilon_t \tag{A.61}$$

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

Equations (A.1)-(A.61) form a system of 66 stochastic difference equations with 66 endogenous unknown variables. This system is log-linearized around the non-stochastic symmetric steady-state of the model with zero net asset positions.[29] The linearized system of equations is solved with standard methods which are available in the DYNARE software.

A.2 Complete Markets

To obtain the complete markets model, I modify the system of equations (A.1)-(A.61) as follows. I drop the two budget constraints, equations (A.15) and (A.30), and the two Euler equations, equations (A.7) and (A.22), from the system. I drop the bond variable and its price. Finally, I add two equations in the system:

$$\lambda_{H,t} = \lambda_{F,t} \tag{A.64}$$

$$Y_{FF,t} = C_{FF,t} + C_{HF,t} + G_{F,t} \tag{A.65}$$

Equation (A.64) is the risk sharing condition with complete markets. Equation (A.65) is the market clearing condition for the foreign traded good. With these modifications, I obtain a system

[29] From the two Euler equations (A.7) and (A.22) we obtain:

$$Q^* + \phi(B_H^* - \bar{B}) = \beta \tag{A.62}$$

$$Q^* + \phi(B_F^* - \bar{B}) = \beta \tag{A.63}$$

If ϕ is arbitrarily small but positive, these two equations and the asset market clearing condition imply the unique equilibrium $B_H^* = B_F^* = \bar{B} = 0$ and $Q^* = \beta$. Most of the other steady-state variables are not available in closed form and are computed numerically.

of 64 stochastic difference equations with 64 endogenous variables which can be solved following the same methods as the incomplete markets model.

The risk sharing condition is derived as follows. Consider the problem of household $i = H, F$ under complete asset markets (for simplicity, consider a finite number of states):

$$\max_{\{C_{i,j}^m, X_{i,j}, \{B_i(s_{j+1}|s^j)\}\}_{j=t}^{\infty}} \sum_{j=t}^{\infty} \sum_{s^j|s^t} \beta^{j-t} r(s^j|s^t) \frac{1}{1-\sigma} U(C_i^m(s^j|s^t), \mathbf{X}_i(s^j|s^t))^{1-\sigma} \tag{A.66}$$

where $r(.|.)$ denotes the conditional probability measure. In equation (A.66), C_i^m is market consumption and $\mathbf{X}_i$ denotes a vector that stacks other arguments of the utility function. In the specific model here, the vector $\mathbf{X}$ is leisure and the consumption of the household good.

Let $Q(s_{t+1}|s^t)$ be the price of a security $B(s_{t+1}|s^t)$, that promises to deliver one unit of the numéraire good if state s_{t+1} happens, conditional on history s^t. The budget constraint is:

$$P_i(s^t)C_i^m(s^t) + \sum_{s_{t+1}|s^t} Q(s_{t+1}|s^t)B_i(s_{t+1}|s^t) = \mathbf{Y}_i(s^t) + B_i(s^t) \tag{A.67}$$

where $\mathbf{Y}$ denotes some definition of income (in the specific model here, this term equals (net of tax) income from labor supply plus income from providing capital to the firms plus lump-sum transfers from the government minus the expenditure on investment goods). The first-order condition yields:

$$Q(s_{t+1}|s^t) = \beta r(s_{t+1}|s^t) \frac{U_{C^m,i}(s_{t+1}|s^t)}{U_{C^m,i}(s_t|s^{t-1})} \frac{P_i(s_t|s^{t-1})}{P_i(s_{t+1}|s^t)} \tag{A.68}$$

where $U_{C^m,i}(s^j|s^t) = U_{C^m}(C_i^m(s^j|s^t), \mathbf{X}_i(s^j|s^t))$ for $i = H, F$. Applying equation (A.68) to both countries $i = H, F$, I obtain:

$$\frac{U_{C^m,H}(s_{t+1}|s^t)}{U_{C^m,H}(s_t|s^{t-1})} \frac{P_H(s_t|s^{t-1})}{P_H(s_{t+1}|s^t)} = \frac{U_{C^m,F}(s_{t+1}|s^t)}{U_{C^m,F}(s_t|s^{t-1})} \frac{P_F(s_t|s^{t-1})}{P_F(s_{t+1}|s^t)} \tag{A.69}$$

Solving backwards this condition, I obtain:

$$\frac{U_{C^m,H}(s_t|s^{t-1})}{P_H(s_t|s^{t-1})} \propto \frac{U_{C^m,F}(s_t|s^{t-1})}{P_F(s_t|s^{t-1})} \tag{A.70}$$

for all histories $s^t = [s_t, s^{t-1}]$ and all $t = 1, 2, ...$ The factor of proportionality depends on time-0 marginal utilities and price levels and therefore can be omitted without loss of generality. Finally, using the definition of $\lambda_{i,t}$ in equations (A.3) and (A.18), I take that $\lambda_{H,t} = \lambda_{F,t}$ as claimed.

A.3 Financial Autarky

The financial autarky model is simply taken as the limit of the incomplete markets model when the portfolio adjustment cost parameter (ϕ) is sufficiently high to prohibit the exchange of the risk-free bond. The value of ϕ is chosen to induce a close to zero volatility in the risk-free bond.

B Data

B.1 Variables

The main source of data is OECD's Main Economic Indicators (MEI). I use data over 1981(1)—2006(4) for Australia, Canada, France, Japan, UK and the US. With the exception of Japan, for all countries I use the September 2008 Edition of MEI. For Japan I combine the September 2008 with the September 2000 Edition and then I use extrapolation techniques to construct the series. For all countries I deflate the series to constant 2000(1) amounts. I divide the series for Canada, Japan and the US by four, since for these countries GDP data are presented at annual levels.

In Table 2, 4 and 5 the variables y, c, g and i denote quarterly level GDP, private final consumption, government purchases of goods and services as a fraction of GDP and gross fixed capital formation. All series are in constant 2000(1) prices, measured in billions of national currency and are seasonally adjusted. emp denotes the employment variable. The variable is taken by combining OECD's seasonally adjusted civilian employment index with quarterly data for weekly hours. The former is taken from the Labor Force Statistics normalized to take the value 100 on 2000(1). The latter is taken from the ILO and refers to hours worked in manufacturing. For countries with monthly statistics, the median month's series is taken as representative for the quarter. Whenever possible employee's data was used, otherwise the data refers to wage workers. For Australia and the UK data on hours was taken from national agencies. The employment series is constructed as:

$$emp_t = 13 * (emp)^* * h_t * civ_t/100$$

where h_t is the hours series, civ_t is the civilian employment index, $(emp)^*$ is total civilian employment in the base year 2000(1) and 13 represents the number of weeks in a quarter. emp_t corresponds to N_t^m in the model.

The terms of trade variable is constructed as the ratio of imports in current prices over imports in constant prices divided by exports in current prices over exports in constant prices. Constant and current price imports and exports are taken from OECD's MEI. The import ratio in constant prices ($irqty$) is defined as the ratio of imports over non exportable output, all variables in constant prices. Net exports nx is exports minus imports over GDP, all variables in current prices, while net exports $nxqty$ uses constant prices.

The series for the labor wedge is constructed according to (A.71):

$$\exp(\tau^e_{H,t}) := \frac{VMPL_{H,t}}{VMRS_{H,t}(a_h=0)} = \frac{P_{1,t}}{P_{H,t}}\frac{MPL_{H,t}}{MRS_{H,t}(a_h=0)} = \frac{P_{1,t}}{P_{H,t}}\frac{(1-\alpha_m)Y_{HH,t}/N^m_{H,t}}{[a_L C^m_{H,t}]/[(1-a_L)(Time_t - N^m_{H,t})]} \tag{A.71}$$

where the price term equals: $P_{1,t}/P_{H,t} = 1/\big(a_C + (1-a_C)T_t^{1-\epsilon_C}\big)^{\frac{1}{1-\epsilon_C}}$ and T_t is the terms of trade variable defined above. Every quarter is assumed to have 13 weeks and in every week there are

$\bar{T} = 112$ hours of time (i.e. I exclude sleeping time). As discussed in the text, I have fixed $a_L = 0.41$ and $\alpha_m = 0.36$ both in the model and in the data, but up to a first-order approximation these values do not matter for the cyclical fluctuations of the wedge. a_C is estimated for every country separately as $a_C = 1 - \frac{(im/y)^*}{1-g^*}$, where $(im/y)^*$ is the average import share and g^* is the average share of government consumption in GDP. I have fixed $\epsilon_C = 1.9$, but up to a first-order approximation this value does not affect either the steady-state value or the cyclical behavior of the wedge.

In equation (A.71), $Time_t$ denotes total available hours. This variable is constructed as:

$$Time_t = 13 * \bar{T} * ((emp)^* * civ_t/100)^T \tag{A.72}$$

where $E_t^T = ((emp)^* * civ_t/100)^T$ is the trend in the number of employed people. Therefore, total time grows according to the "natural" or trend increase of the working population. Consistently with the other variables in the data and the model, the trend in employed people is computed with the HP filter.

The market technology series is defined as $z_t^m = \log(y_t) - (1 - \alpha_m)\log(emp_t)$, where I set $\alpha_m = 0.36$ for all countries and emp is the employment variable that adjusts for hours per worker. The measurement error in the cyclical component of technology due to the omission of capital is likely to be small, since the capital stock fluctuates very little at quarterly frequency.

To construct the Foreign country I use PPP exchange rates in 2000 from the Penn Tables to aggregate variables. To construct the Foreign employment and hours aggregates I weight countries by their total civilian employment in 2000(1).

The real exchange rate for the US, rer, is taken from the Federal Reserve and refers to a weighted average against major foreign currencies. The weights are derived from US export shares and US and foreign import shares. The data is at monthly frequency so I use the median month in every quarter.

B.2 Further Calculations Related to Section 4.2

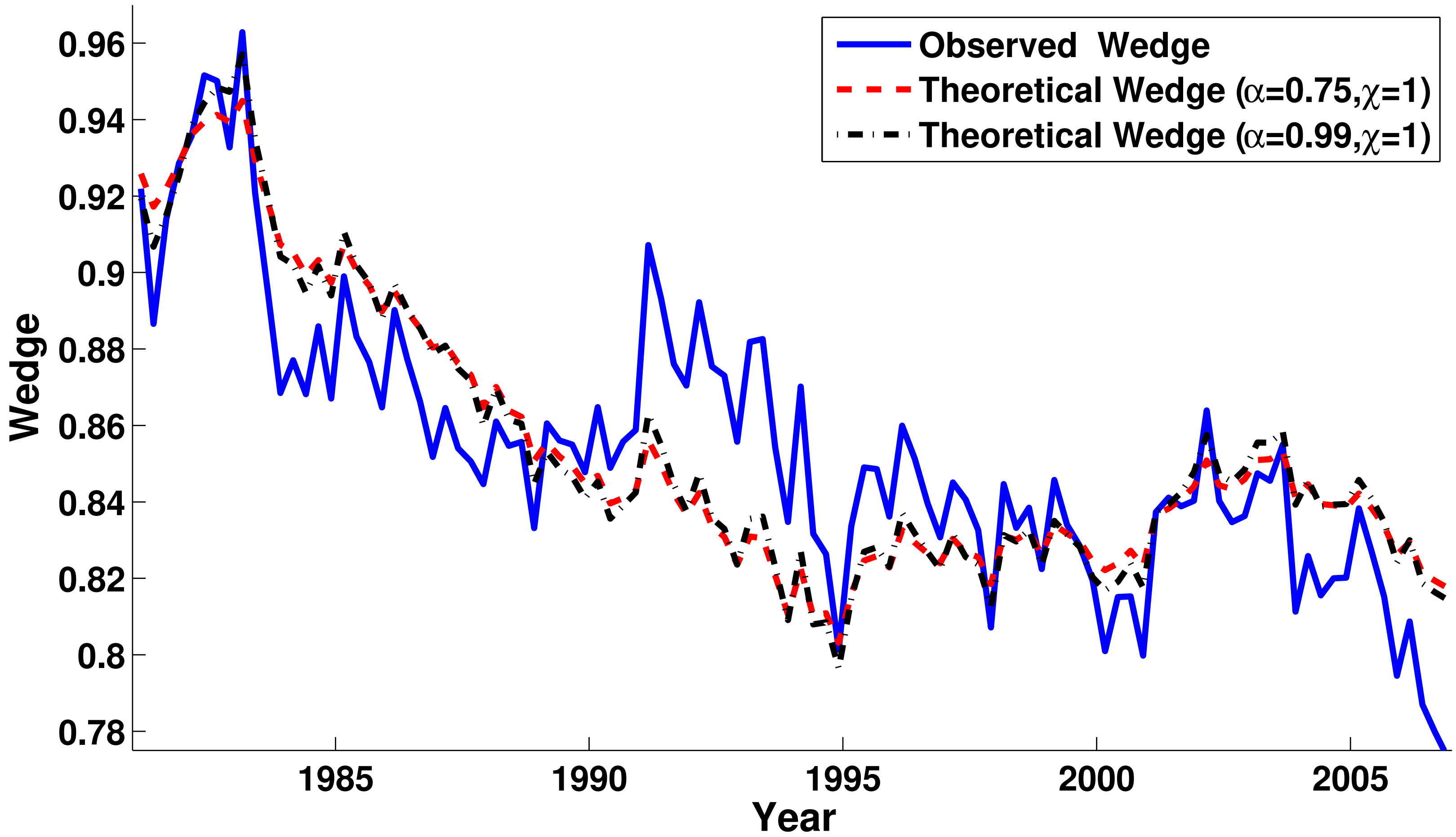
In Section 4.2 I compared the observed labor wedge to the model-generated labor wedge. In this Appendix, I report some sensitivity checks. In the benchmark case with an exogenous offset rate equal to $\alpha = 0.75$, the optimal parameters are $\theta = (a_h, \epsilon_H, \chi) = (0.20, 1.34, 7.46)$. When I fix $\alpha = 0.5$, I take $(a_h, \epsilon_H, \chi) = (0.20, 1.34, 13.88)$. When I fix $\alpha = 0.99$, I take $(a_h, \epsilon_H, \chi) = (0.20, 1.34, 4.35)$. In all cases the model-generated wedge is the same because only the parameter χ adjusts when the offset rate α changes.

In Figure 9 I fix $\chi = 1$ (linear production function) and present the wedge series when the offset rate is $\alpha = 0.75$ and $\alpha = 0.99$. As we see in the Figure, the model-based wedge tracks closely the observed labor wedge series. If I detrend the series, the model-generated wedge is almost perfectly correlated with the observed labor wedge. The detrended model-generated wedge is between 43-61% as volatile as the observed labor wedge.

In Figure 10 I add taxes into the analysis. I define the relevant "tax distortion" in the labor wedge as $(1+\pi_C)/(1-\pi_L)$, where π_C and π_L are the US effective consumption and labor income tax rate respectively. These are taken from McDaniel (2007). I interpolate the tax rates to quarterly frequency using McDaniel's estimated series as the tax rate for the third quarter. As we can see from the Figure, adding tax rates into the calculation makes a small difference. I have verified this result for various combinations of parameters.

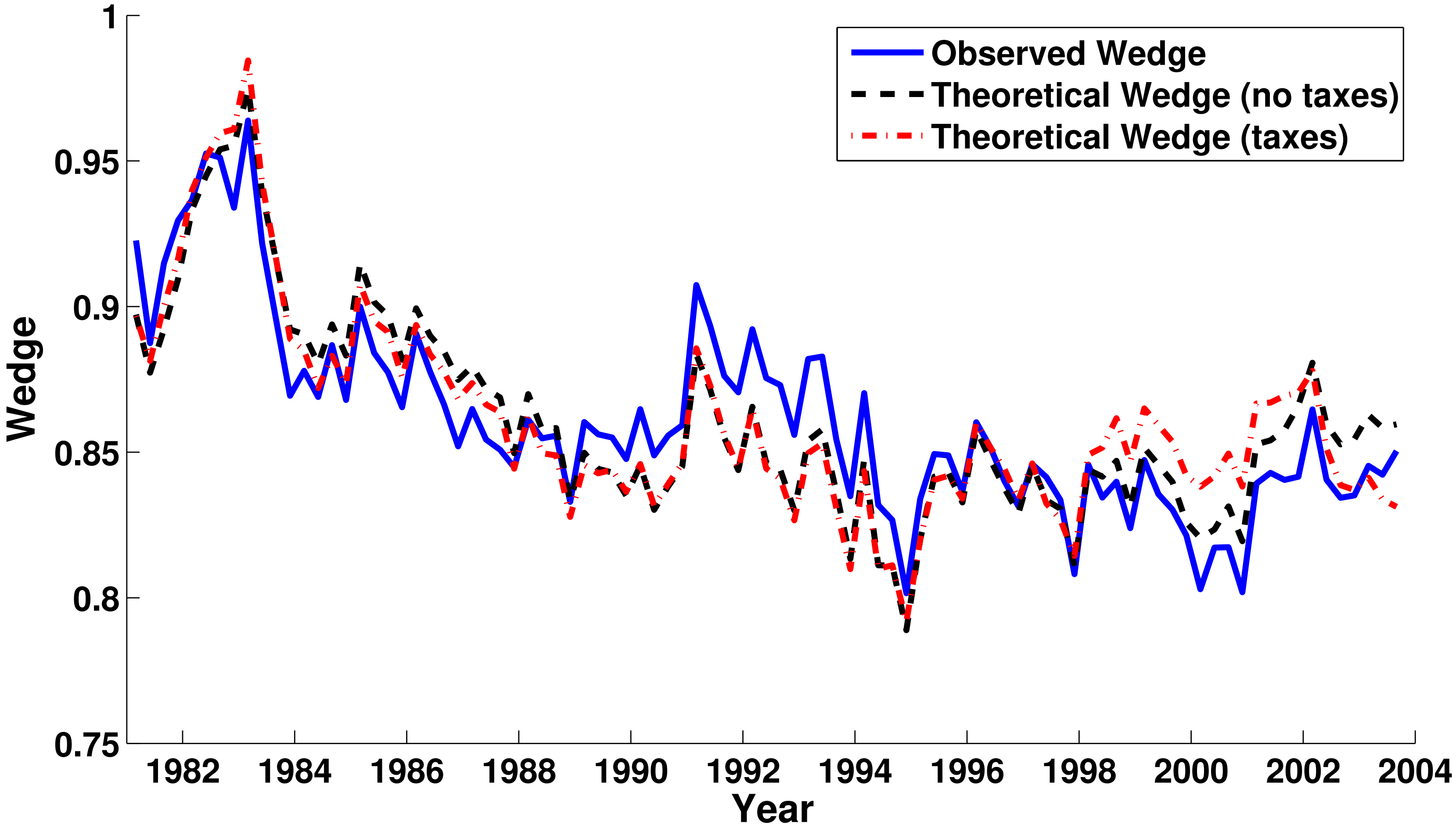
Finally, Figure 11 repeats the calculations in the Ramey (2009) and Ramey and Francis (2009) dataset. The dataset is described in the main text. The resulting series for the observed labor wedge in the US trends down strongly until the 1990s. In the second half of the sample, the labor wedge continues to trend downward but at a slower rate. This exercise provides an additional robustness check on the estimated observed labor wedge series, because the annual series for market hours in the Ramey-Francis dataset are taken from a different source than the quarterly series used in the main text. For the theoretical labor wedge series, I use directly the home hours series from the Ramey-Francis dataset and as a result there is no need to specify the offset rate α. As shown in the Figure, the theoretical labor wedge series captures the downward trend of the observed labor wedge series, but it underestimates somehow the value of the wedge in the early periods. In this case I have fixed the value of the elasticity of substitution at $\epsilon_H = 5$, as suggested by Benhabib, Rogerson and Wright (1991). Increasing the elasticity makes the first observations of the theoretical labor wedge match closer to their empirical counterparts.

Figure 9: US Observed Wedge vs. Theoretical Labor Wedge with US Data: No Taxes



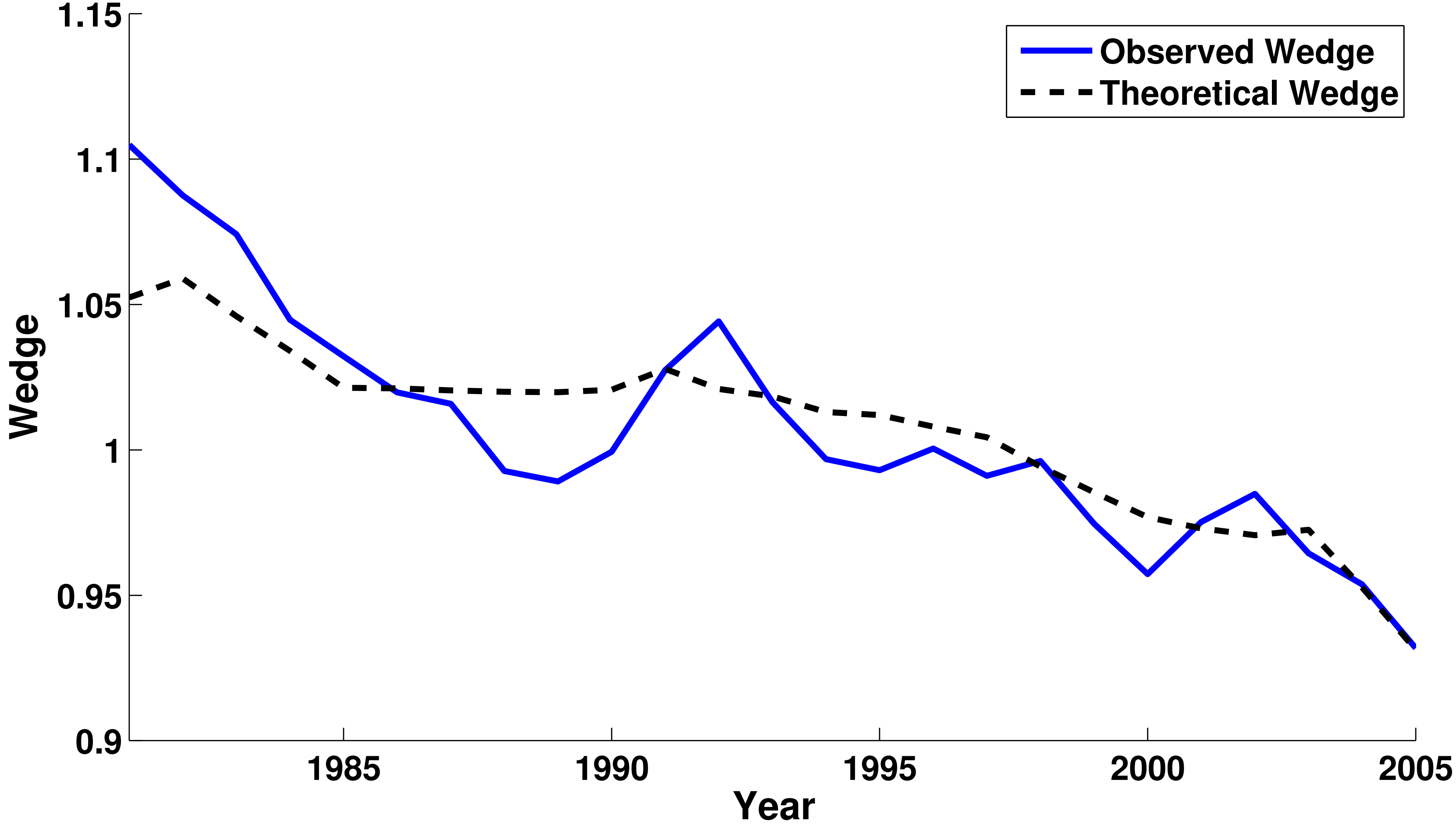
Notes: The Figure compares the observed labor wedge constructed according to equation (16) with the theoretical labor wedge constructed according to equation (19) when taxes are zero ($\pi_t = 0$). See the main text of the paper for the construction of the series. In both cases I fix $\chi = 1$. In the red line the offset rate is set equal to $\alpha = 0.75$. In the black line the offset rate is set equal to $\alpha = 0.99$. In both cases I optimally chose $(a_h, \epsilon_H) = (0.19, 1.38)$.

Figure 10: US Observed Wedge vs. Theoretical Labor Wedge with US Data: Taxes



Notes: The Figure compares the observed labor wedge constructed according to equation (16) with the theoretical labor wedge constructed according to equation (19) without (black line) and with taxes (red line). In both cases the offset rate is set equal to $\alpha = 0.75$. In the black line I optimally chose $(a_h, \epsilon_H, \chi) = (0.26, 1.17, 13.58)$. In the red line I optimally chose $(a_h, \epsilon_H, \chi) = (0.02, 2.98, 8.01)$.

Figure 11: US Observed Wedge vs. Theoretical Labor Wedge with Ramey-Francis Data



Notes: The Figure compares the observed labor wedge constructed according to equation (16) with the theoretical labor wedge constructed according to equation (19). The market hours ("Implied Average Hours per Worker") and home hours variables ("htw14") are taken from Ramey and Francis (2009; Online Appendix, Main Data.xls). I fix the elasticity of substitution at the value suggested in Benhabib, Rogerson and Wright (1991), $\epsilon_H = 5$. I optimally chose $(a_h, \alpha_n) = (0.07, 2.08)$.