UNIVERSITÄT
BERN

Faculty of Business, Economics
and Social Sciences

Department of Economics

Intangible Capital Formation, International Equity Investments, and Output Synchronization

Guido Baldi, André Bodmer

18-10

June 2018

DISCUSSION PAPERS

Schanzeneckstrasse 1
Postfach
CH-3001 Bern, Switzerland
http://www.vwi.unibe.ch

Intangible Capital Formation, International Equity Investments, and Output Synchronization*

Guido Baldi † André Bodmer ‡

June 2018

Abstract

We analyze the effects of intangible investment on international output synchronization. Using a dynamic stochastic general equilibrium model, we find that an increase in the importance of intangible capital leads to a higher degree of output comovement across countries. Therefore, countries in which intangible capital is more important are better suited to economic integration, such as forming a monetary union. This offers an insightful perspective on the potential relation between the considerable differences in intangible capital among Eurozone members and the discussion surrounding the Eurozone as a sub-optimal currency area. A high stock of intangible capital also tends to attract foreign equity investments, in particular foreign direct investments. We find that cross-border equity holdings in tangible and intangible capital further increase the degree of output synchronization. Our results imply that policy reforms to incentivize higher intangible capital formation and cross-border equity investments may not

*The authors would like to thank various seminar participants for useful comments. All remaining errors are the responsibility of the authors. The views expressed in this paper are those of the authors and not necessarily those of the institutions to which the authors are affiliated.

†University of Bern, Department of Economics, Schanzeneckstr. 1, CH-3012 Bern, Switzerland. Email: guido.a.baldi@gmail.com; and German Institute for Economic Research (DIW Berlin), Mohrenstr. 58, D-10108 Berlin, Germany.

‡University of Bern, Department of Economics, Schanzeneckstr. 1, CH-3012 Bern, Switzerland. Email: andre.bodmer@vwi.unibe.ch.

only foster economic growth but also improve the functioning of the monetary policy in the Eurozone.

JEL classification: E22, E32, F41
Keywords: International Business Cycles, Investment, Cross-country Correlations, Intangible Capital

1 Introduction

In this paper, we analyze the effects of intangible capital on output co-movement across countries. To this end, we extend a standard two-country dynamic stochastic general equilibrium (DSGE) model to include a production sector for intangible capital. In our model, the immaterial nature of intangible capital allows a firm to use the same stock of intangible capital simultaneously for different purposes. The existing stock of intangible capital can be used in both the production of tangible output and the augmentation of the stock of intangibles (similar to McGrattan & Prescott (2014) and Baldi & Bodmer (2017)). We interpret intangible capital broadly: Intangibles comprise accumulated investments in research and development, software, brands, organizational capital, and training (see e.g. Corrado et al. (2013)). We also consider the possibility of the non-neutral evolution of technology, which implies that the production of final goods and the production of intangibles may be subject to different shocks.

While it has been shown before that the presence of intangible capital leads to the international co-movement of tangible investments in a real business cycle model (see Baldi & Bodmer (2017)), we use a model with sticky prices and foreign equity investments to demonstrate that the presence of intangible capital also leads to a higher degree of output synchronization. We find that as intangible capital becomes more important to production, the degree to which the international co-movement of investments and output occurs also increases. Because the degree of business cycle synchronization is an important criterion for the economic integration of countries, our findings give rise to important policy conclusions. Countries that have a high degree of intangible capital in production are better suited to economic integration, e.g., forming a monetary union, than do countries in which intangible capital plays a less important role. Because countries in the southern European periphery tend to invest considerably less in intangibles than do other Eurozone countries, this paper offers an insightful perspective, though not an entirely new one, on the debate surrounding optimal and suboptimal currency areas.

This paper is related to the literature on international business cycles. In their influential contribution, Backus et al. (1992) found that cross-country output correlations are generally higher than cross-correlations of consumption and that cross-correlations of output, investment, and employment are generally positive and rather high. These empirical findings have often been called a quantity puzzle or an anomaly because in a standard international business cycle model, the cross-correlations of investment and output are negative and the cross-correlation of consumption is higher than that for output. Negative cross-correlations of output and investment arise as a result of incentives to use inputs where they are most productive. Although the discrepancies between theory and data may not be as large when investigating other countries or time periods (see e.g. Ambler et al. (2004)), the general features and signs of the correlations are fairly robust. By including intangible production in our model, we account for the finding that tangible investment tends to be positively correlated across countries, whereas most theoretical models, including those with non-separable preferences, find a negative correlation (see Raffo (2010)). Papers that (partially) successfully find positive co-movement include those by Canova & Ubide (1998), Heathcote & Perri (2002), Kehoe & Perri (2002), Johri et al. (2011), and Corsetti et al. (2014). In our model with two sectors and non-rivalrous use of intangible capital, tangible inputs can be moved across sectors to where they are most productive. As a result, the relocation of resources across countries is dampened, which renders the cross-country correlations for both tangible investment and output positive.

Our modelling approach uses a broad definition of intangible investment that includes software and research and development expenditures, which were included in the System of National Accounts, 1993 and 2008, respectively and are now part of GDP, as well as organizational capital, business expenditures for market development, and managerial expertise (for an overview, see Corrado et al. (2005), and Corrado et al. (2009)). One may interpret these investments as knowledge creation. Such expenditures for intangibles are strategic investments in the long-term growth of individual companies and the economy as a whole. Corrado et al. (2013) find that when intangibles are defined in such a broad way, businesses in the US and other advanced countries currently invest even more in intangibles than in traditional fixed assets. However, for countries in the southern European periphery, intangible investment has been considerably lower than tangible investment; in fact, it has been lower than in other countries of the Eurozone (see e.g. Veugelers (2016)). It is important to note that several measurement issues arise when determining the extent of intangible investment and capital (see e.g. Corrado et al. (2012)). In particular, determining depreciation rates for intangible capital is associated with many uncertainties and the published depreciation rates vary considerably across intangible investment categories.

A high stock of intangible capital tends to attract foreign equity investments, in particular foreign direct investments. In an extension of our model, we find that cross-border equity holdings in tangible and intangible capital further increase the degree of output synchronization. In many economies, these investments that comprise foreign direct investments (FDI) and portfolio equity investments represent an important financing source for capital investment (for an overview, see Baldi & Miethe (2015)). However, equity investment inflows to the Eurozone and the European Union have been rather weak in recent years, which has likely contributed to the low overall investment levels (see e.g. Baldi et al. (2014)). The shares of equity inflows worldwide to countries in the Eurozone have steadily decreased since 1999, and they fell sharply in the course of the financial crisis and the debt crisis in some countries in the Eurozone. Within the Eurozone, there is strong heterogeneity across the member states with respect to equity investment. The overall level of equity investment was and still is significantly lower in the southern peripheral countries in relation to output than in the rest of the monetary union. In the course of the debt crisis, equity investment from the non-crisis countries in southern European countries further decreased. However, the existing empirical evidence suggests that higher cross-country equity investments, in particular foreign direct investment, can further contribute to synchronizing business cycles (see e.g. Fries & Kappler (2015)).

This paper is organized as follows. Section 2 develops a two-country DSGE model with two sectors of production, one producing tangible goods and the other delivering intangibles. Section 3 outlines the calibration strategy, and in Section 4, we present the results of our simulations and investigate the business cycle properties of our model. Section 5 concludes the paper.

2 Model

Our model contains two sectors of production and two countries of equal size. This two-sector production structure with simultaneous use of the same stock of intangible capital in both sectors is very similar to the closed economy real business cycle model of McGrattan & Prescott (2014) and the real open economy model of Baldi & Bodmer (2017). In our sticky price open economy model with foreign equity investment, we investigate the impact of intangible investment on output synchronization across countries.

2.1 Individuals

There are two countries populated by infinitely lived representative individuals. These individuals derive positive utility from consumption and experience disutility from working. We adopt the preference specification originally proposed by Greenwood et al. (1988), where consumption and labor are not additively separable. This specification has been increasingly used in the international business cycle literature, mainly because hours worked tend to comove across countries. The utility function for an individual living in the domestic economy is then given by $E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{(c_t - \phi_h h_t^{\tau})^{1-\sigma}}{1-\sigma} \right)$.[1] c_t is consumption, h_t is hours worked, $E_0\{\}$ denotes the expectation operator, and the parameters σ, τ and ϕ_h are all positive. The utility function is maximized subject to the budget constraint:

$$\begin{gathered} B_t^h + e_t B_t^f + P_t c_t + P_t x_{T,t} + Q_t x_{I,t} + Pr_t = \\ R_{t-1} B_{t-1}^h + e_t R_{t-1}^* B_{t-1}^f + P_t r_{T,t} k_{T,t} + P_t r_{I,t} k_{I,t} + P_t w_t h_t \end{gathered} \tag{1}$$

where B_t^i, for $i = h, f$, are nominal domestic and foreign bonds, and e_t is the nominal exchange rate. The total net bonds in this two-country world

[1] The foreign country faces analogous functions and the following optimality conditions are identical to those for the domestic economy. Foreign variables are denoted by '*'.

is equal to zero. $x_{T,t}$ and $k_{T,t}$ denote tangible investment and capital, and $x_{I,t}$ and $k_{I,t}$ stand for intangible investment and capital. R_t is the nominal domestic interest rate on bonds and R_t^* is the nominal interest rate on foreign bonds. P_t is the nominal price of tangible output and Q_t is the nominal price of intangible investment $x_{I,t}$. The interest rates on tangible and intangible capital are denoted by $r_{T,t}$ and $r_{I,t}$, respectively. w_t denotes the wage rate for labor. Capital depreciates at rates δ_T and δ_I for tangible and intangible capital, respectively. As the firms are owned by the individuals, its total profits $P_t r_t$ from tangible and intangible production are distributed to the individuals. Adding convex adjustment costs for investments, determined by ψ_{k_T} and ψ_{k_I}, the laws of motion for tangible and intangible capital are:

$$k_{T,t+1} = x_{T,t} - \frac{\psi_{k_T}}{2}\left(\frac{x_{T,t}}{k_{T,t}} - \delta_T\right)^2 k_{T,t} + (1-\delta_T)k_{T,t} \tag{2}$$

$$k_{I,t+1} = x_{I,t} - \frac{\psi_{k_I}}{2}\left(\frac{x_{I,t}}{k_{I,t}} - \delta_I\right)^2 k_{I,t} + (1-\delta_I)k_{I,t} \tag{3}$$

Total hours worked, h_t, is composed of hours worked that are used for tangible output h_t^1 and hours worked to produce intangible investment goods h_t^2. Households choose $\{c_t, h_t, k_{T,t+1}, k_{I,t+1}, x_{T,t}, x_{I,t}, B_t^h, B_t^f\}$ to maximize utility subject to (1)-(3). The associated Lagrange multipliers for these equations are Λ_t^1, Λ_t^2, and Λ_t^3. The first order conditions with respect to these variables are:

$$\frac{\partial U_t}{\partial c_t} = \Lambda_t^1 P_t$$

$$\frac{\partial U_t}{\partial h_t} = \Lambda_t^1 P_t w_t$$

$$\Lambda_t^2 = \beta E_t \left\{ \Lambda_{t+1}^1 P_{t+1} \left[r_{T,t+1} \right] + \Lambda_{t+1}^2 \left[1 - \delta_T + \frac{\psi_{k_T}}{2} \left(\left(\frac{x_{T,t+1}}{k_{T,t+1}} \right)^2 - \delta_T^2 \right) \right] \right\}$$

$$\Lambda_t^3 = \beta E_t \left\{ \Lambda_{t+1}^1 \left[P_{t+1} r_{I,t+1} \right] + \Lambda_{t+1}^3 \left[1 - \delta_I + \frac{\psi_{k_I}}{2} \left(\left(\frac{x_{I,t+1}}{k_{I,t+1}} \right)^2 - \delta_I^2 \right) \right] \right\}$$

$$\Lambda_t^1 P_t = \Lambda_t^2 \left(1 - \psi_{k_T} \left(\frac{x_{T,t}}{k_{T,t}} - \delta_T \right) \right)$$

$$\Lambda_t^1 Q_t = \Lambda_t^3 \left(1 - \psi_{k_I} \left(\frac{x_{I,t}}{k_{I,t}} - \delta_I \right) \right)$$

$$\Lambda_t^1 = \beta R_t E_t \{ \Lambda_{t+1}^1 \}$$

$$\Lambda_t^1 = \beta R_t^* E_t \{ \Lambda_{t+1}^1 \frac{e_{t+1}}{e_t} \}$$

2.2 Firms

There are intermediate goods produced by intermediaries owned by households. As in McGrattan & Prescott (2014) and Baldi & Bodmer (2017), each intermediate firm uses two constant returns to scale technologies to produce tangible and intangible goods. This is the main feature that distinguishes the model used in this paper from conventional models. The production functions are given by:

$$y_t(i) = A_t^1 \left(k_{T,t}^1(i)\right)^{\theta} \left(k_{I,t}(i)\right)^{\phi} \left(h_t^1(i)\right)^{1-\theta-\phi}$$

$$x_{I,t}(i) = A_t^2 \left(k_{T,t}^2(i)\right)^{\theta} \left(k_{I,t}(i)\right)^{\phi} \left(h_t^2(i)\right)^{1-\theta-\phi}$$

In the following, we drop the index (i) whenever feasible to simplify the notation. Firms produce output y_t by using their tangible capital $k_{T,t}^1$, intangible capital $k_{I,t}$, and labor h_t^1. Firms produce intangible investment goods, $x_{I,t}$, - such as R&D, software, brand development, organizational capital, and training -, by using tangible capital $k_{T,t}^2$, intangible capital $k_{I,t}$, and labor h_t^2. The total stock of intangible capital $k_{I,t}$ is an input to both business sectors as in McGrattan & Prescott (2014). The intangible nature of these goods makes it possible to use intangible capital to deliver final goods and develop new intangible capital simultaneously. A_t^1 and A_t^2 denote total factor productivity in the two sectors. In our quantitative analysis, we assume both neutral and non-neutral technology shocks across the two sectors.

The two technology shocks follow AR(1)-processes of the following type:

$$\log A_{t+1}^{1} = \rho_{A^1}\log A_t^1 + (1-\rho_{A^1})\log A^1 + \epsilon_{t+1}^{A^1}$$

$$\log A_{t+1}^{2} = \rho_{A^2}\log A_t^2 + (1-\rho_{A^2})\log A^2 + \epsilon_{t+1}^{A^2}$$

There is a retail firm that combines foreign and domestic goods to produce a non-tradable final good and determines its optimal production by maximizing its profit

$$\max_{y_t^h, y_t^f} P_t Y_t - P_{y,t} y_t^h - e_t P_{y,t}^* y_t^f$$

where $(P_{y,t})$ and $(P_{y,t}^*)$ denote the prices of the domestic and foreign goods respectively, as denominated in terms of the seller's currency. The final good is given by the following CES function

$$Y_t = \left(\kappa^{1-\eta} y_t^{h\eta} + (1-\kappa)^{1-\eta} y_t^{f\eta}\right)^{\frac{1}{\eta}}$$

where $\kappa \in (0,1)$ and $\eta \in (-\infty, 1)$.

Optimal retailer behavior yields the following demand for domestic and foreign goods:

$$y_t^h = \left(\frac{P_{y,t}}{P_t}\right)^{\frac{1}{\eta-1}} \kappa Y_t$$

and

$$y_t^f = \left(\frac{e_t P_{y,t}^*}{P_t}\right)^{\frac{1}{\eta-1}} (1-\kappa) Y_t$$

y_t^h is itself a combination of the domestic intermediate goods according to

$$y_t^h = \left(\int_0^1 y_t^h(i)^{\frac{\nu}{\nu-1}} di\right)^{\frac{\nu}{\nu-1}}$$

Cost minimization by the intermediary is complicated by the fact that the firm uses two different production functions. In addition, the same stock of intangible capital appears in both production functions. Denoting the marginal costs in the two sectors as mc_t^1 and mc_t^2 and defining $p_{y,t} = P_{y,t}/P_t$ and $q_t = Q_t/P_t$, the following equations for the return to production inputs are obtained:

$$r_{T,t} = \theta \frac{p_{y,t} mc_t^1 y_t}{k_{T,t}^1}$$

$$r_{T,t} = \theta \frac{mc_t^2 q_t x_{I,t}}{k_{T,t}^2}$$

$$r_{I,t} = \frac{\phi p_{y,t} mc_t^1 y_t + \phi mc_t^2 q_t x_{I,t}}{k_{I,t}}$$

$$w_t = (1-\theta-\phi)\frac{p_{y,t} mc_t^1 y_t}{h_t^1}$$

$$w_t = (1-\theta-\phi)\frac{mc_t^2 q_t x_{I,t}}{h_t^2}$$

We assume sticky prices following the seminal contribution of Calvo (1983), with price stickiness parameters ϵ and ξ for tangible and intangible prices, respectively. These parameters determine the probabilities that a firm can reset its two output prices. The two probabilities are independent of each other. This implies that, for example, a firm may therefore be able to set a new optimal price for its final output but not for intangible output. The expected profit flow generated by setting new optimal prices $\tilde{P}_{y,t}(i)$, and $\tilde{Q}_t(i)$ in period t is given by:

$$\max_{\tilde{P}_{y,t}(i),\tilde{Q}_t(i)} E_t \sum_{j=0}^{\infty} \Phi_{t,t+j}\left(\epsilon^j \Pi_{t,y}\left(\tilde{P}_{y,t}(i)\right) + \xi^j \Pi_{t,xI}\left(\tilde{Q}_t(i)\right)\right)$$

Profits are determined by the difference between revenue at the new optimal price and the nominal costs of production. The maximization is subject to the total demand the firm faces for its two products:

$$y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\nu} y_t$$

and

$$x_{I,t}(i) = \left(\frac{Q_t(i)}{Q_t}\right)^{-\omega} x_{I,t}$$

$\Phi_{t,t+j}$ is the appropriate discount factor related to the way the household values future as opposed to current consumption:

$$\Phi_{t,t+j} = \beta^j \frac{\Lambda^1_{t+j}}{\Lambda^1_t}$$

Note that all firms that reset their price in period t set it at the same level $\tilde{P}_{y,t}(i) = \tilde{P}_{y,t}$ and $\tilde{Q}_t(i) = \tilde{Q}_t$, for all $i \in (0,1)$. The price indices consist of surviving contracts and newly set prices. Given that in each period, a consumption price contract has a probability $1-\epsilon$ of ending, the probability that a contract signed in period $t-j$ survives until period t and ends at the end of period t is given by $(1-\epsilon)\epsilon^j$.[2]

Therefore, the aggregate price level may be expressed as the average of all surviving contracts:

$$P_{y,t} = \left(\sum_{j=0}^{\infty} (1-\epsilon)\epsilon^j \tilde{P}^{1-\nu}_{y,t-j} \right)^{\frac{1}{1-\nu}}$$

which can be expressed recursively as

$$P_{y,t} = \left((1-\epsilon)\tilde{P}^{1-\nu}_{y,t} + \epsilon P^{1-\nu}_{y,t-1} \right)^{\frac{1}{1-\nu}}$$

[2] For the intangible investment price Q_t, the equivalent expression is $(1-\xi)\xi^j$.

2.3 Monetary policy

The central bank follows a version of the standard Taylor rule that reacts to inflation and, in a tiny extension of the model, also reacts to the output gap:

$$\log(R_t) = \rho_r \log(R_{t-1}) + (1-\rho_r)\log(R) + \gamma_{\pi^P}\left(\log(\pi_t^P) - \log(\pi^P)\right) + \gamma_Y\left(\log(y_t) - \log(y)\right)$$

Variables without time indices are steady-state values.

2.4 Foreign equity investment

As mentioned above, higher intangible capital in an economy may also attract more foreign equity investment. In particular foreign direct investment represents an important financing source for capital investments and may affect the degree of output synchronization. In an extension of our basic model, we capture equity investments by modifying the budget constraint of the household in the following way:

$$\begin{aligned}
&B_t^h + e_t B_t^f + P_t c_t + P_t x_{T,t} + P r_t + Q_t x_{I,t} + e_t P_t^* \mu_{T,t}^f k_{T,t+1}^* \\
&+ \frac{P_t}{2}(\mu_{T,t}^f k_{T,t}^*)^2 + P_t \mu_{T,t-1}^h (1 + r_{T,t}) k_{T,t} + e_t Q_t^* \mu_{I,t}^f k_{I,t+1}^* \\
&+ \frac{P_t}{2}(\mu_{I,t}^f k_{I,t}^*)^2 + Q_t \mu_{I,t-1}^h (1 + r_{I,t}) k_{I,t} = \\
&R_{t-1} B_{t-1}^h + e_t R_{t-1}^* B_{t-1}^f + P_t r_{T,t} k_{T,t} + P_t r_{I,t} k_{I,t} + P_t w_t h_t + P_t \xi_t \\
&+ e_t P_t^* \mu_{T,t-1}^f (1 + r_{T,t}^*) k_{T,t}^* + P_t \mu_{T,t}^h k_{T,t+1} + e_t Q_t^* \mu_{I,t-1}^f (1 + r_{I,t}^*) k_{I,t}^* + Q_t \mu_{I,t}^h k_{I,t+1}
\end{aligned}$$

where $\mu_{T,t}^f$ is the share of foreign tangible capital held by domestic households, which is optimally chosen each period.[3] $e_t P_t^* \mu_{T,t}^f k_{T,t+1}^*$ is the equity

[3] For the foreign country, we add equivalent terms to the budget constraint.

investment of the domestic economy in the foreign country's tangible capital stock valued at current prices and expressed in domestic currency. Similarly, $P_t \mu^h_{T,t} k_{T,t+1}$ indicates the share of domestic tangible capital acquired by foreign households. There are quadratic costs associated with holding equity capital in a foreign country given by: $\frac{P_t}{2}(\mu^f_{T,t} k^*_{T,t})^2$. This assumption is needed to ensure a stable solution and can be justified by the idea that foreign lenders usually have only partial knowledge and experience in the local market. Finally, the return of domestic households' equity holdings in the foreign economy is derived from $e_t P^*_t \mu^f_{T,t-1}(1 + r^*_{T,t})k^*_{T,t}$, and the return of foreign households' equity holdings in the domestic economy is obtained from $P_t \mu^h_{T,t-1}(1 + r_{T,t})k_{T,t}$. There are equivalent expressions for intangible capital. Maximizing utility with respect to this new budget constraint leads to two new optimality conditions, where rer_t denotes the real exchange rate:

$$\Lambda^1_t rer_t k^*_{T,t+1} + \Lambda^1_t \mu^f_{T,t} \left(k^*_{T,t}\right)^2 = \beta E_t \left\{\Lambda^1_{t+1} rer_{t+1}(1 + r^*_{T,t+1})k^*_{T,t+1}\right\}$$

$$\Lambda^1_t rer_t q^*_t k^*_{I,t+1} + \Lambda^1_t \mu^f_{I,t} \left(k^*_{I,t}\right)^2 = \beta E_t \left\{\Lambda^1_{t+1} rer_{t+1} q^*_{t+1}(1 + r^*_{I,t+1})k^*_{I,t+1}\right\}$$

In addition, the two optimality conditions related to the choice of the domestic capital stock are modified:

$$\begin{aligned}
&\Lambda^2_t - \Lambda^1_t \mu^h_{T,t} \\
&= \beta E_t \left\{ \lambda^1_{t+1} \left[r_{T,t+1} - \mu^h_{T,t}(1 + r_{T,t+1}) \right] + \Lambda^2_{t+1} \left[1 - \delta_T + \frac{\psi_{k_T}}{2} \left(\left(\frac{x_{T,t+1}}{k_{T,t+1}} \right)^2 - \delta^2_T \right) \right] \right\}
\end{aligned}$$

$$\begin{aligned}
&\Lambda^3_t - \lambda^1_t q_t \mu^h_{I,t} \\
&= \beta E_t \left\{ \lambda^1_{t+1} \left[r_{I,t+1} - q_{t+1} \mu^h_{I,t}(1 + r_{I,t+1}) \right] + \Lambda^3_{t+1} \left[1 - \delta_I + \frac{\psi_{k_I}}{2} \left(\left(\frac{x_{I,t+1}}{k_{I,t+1}} \right)^2 - \delta^2_I \right) \right] \right\}
\end{aligned}$$

3 Choice of parameter values

Table 1 depicts the chosen parameter values for the simulation of our model. Note that one period corresponds to one quarter and that the domestic and foreign economies share the same parameter values. For the shares of tangible and intangible capital in production, we draw from the values used by McGrattan & Prescott (2012) and Corrado et al. (2009). We set the share of tangible capital θ at 0.2 and the share of intangible capital ϕ at 0.15. In a variant of the model, we assume $\theta = 0.25$ and $\phi = 0.1$. This leaves 0.65 for the labor income share of total output. Following McGrattan & Prescott (2012), we set the depreciation rate of intangible capital equal to that of tangible capital. We assume that both depreciation rates are 0.025, which is a standard value in the DSGE literature. This allows us to analyze the pure effect of intangible production and to abstract from differences in the depreciation rates across investment categories.

The trade share, $1 - \kappa$, is set at 0.15 and the elasticity of trade, η, is equal to 0.5. These values lie in the range of values that are commonly used in the literature (see e.g. Kehoe & Perri (2002) and Raffo (2010)). The adjustment cost parameter for capital is set to match the standard deviation of investment relative to GDP in US data for the period 1970 to 2007 and varies across the different versions of the model. The standard deviation of the technology shocks is set to achieve the volatility of output over the same period of time. The calibration assumes that both sector-specific technology shocks are persistent with moderate cross-country spillovers of 0.25, which is similar to the findings in related papers in the international business cycle literature (see e.g. Kehoe & Perri (2002) and Raffo (2010)). The price stickiness parameters are set at 0.5. The Taylor rule coefficients also take standard values, specifically, $\rho_r = 0.8$, $\gamma_\pi = 1.5$, and $\gamma_y = 0.25$.

Table 1: Choice of parameter values

Parameter	Value	Parameter	Value
β	0.990	ρ^{A^1}	0.950
σ	2.000	ρ^{A^2}	0.950
θ	0.200	κ	0.850
ϕ	0.150	η	0.500
τ	1.600	δ_T	0.025
ν	6.000	δ_I	0.025
ω	6.000	ρ_r	0.800
ξ	0.500	γ_π	1.500
ϵ	0.500	γ_y	0.250

4 Quantitative results

4.1 Impulse response functions

This section presents impulse response functions for the basic version of the model.[4] We illustrate the most important qualitative effects of our intangibles model by assuming flexible prices and no capital adjustment costs. The impulse response functions of our basic model are compared to those obtained from a standard model that only includes tangible capital. We depict the domestic and cross-border effects of neutral and sector-specific technology shocks.

4.2 Neutral technology shock

Figure 1 presents the effects of a neutral technology shock to the tangible and intangible production sectors. Figure 2 depicts the reactions of the standard model with only tangible capital. As shown, there are a few notable differences between the two models. Interestingly, when intangible investment is included in the analysis, the increase in domestic tangible investment also leads to a considerable increase in foreign tangible investment. This is a significant qualitative difference to the model that includes only tangible capital, where such a co-movement is not observed. Regarding intangible capital, however, the increase in domestic production is associated with only a minor increase in foreign intangible production.

[4]The model can be linearized and simulated using standard methods. For all simulations, the Dynare software version 4.4.3 is used.

Figure 1: Domestic neutral technology shock (Intangible model)

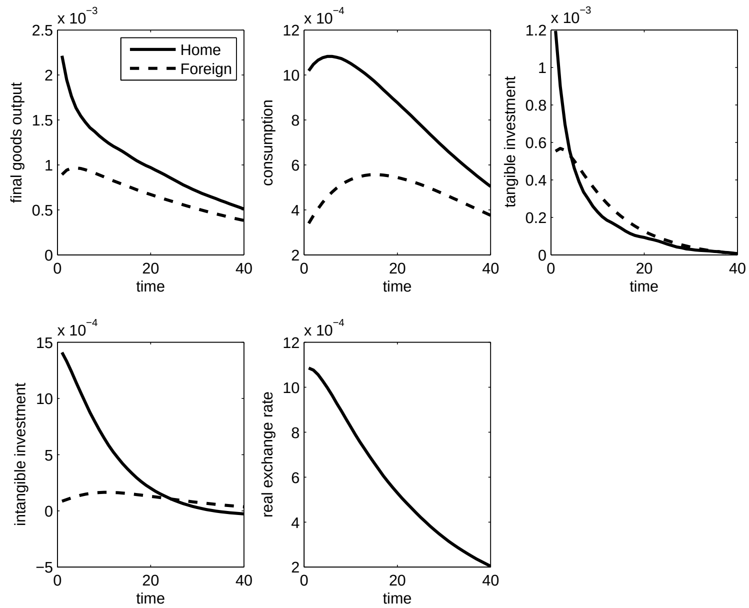
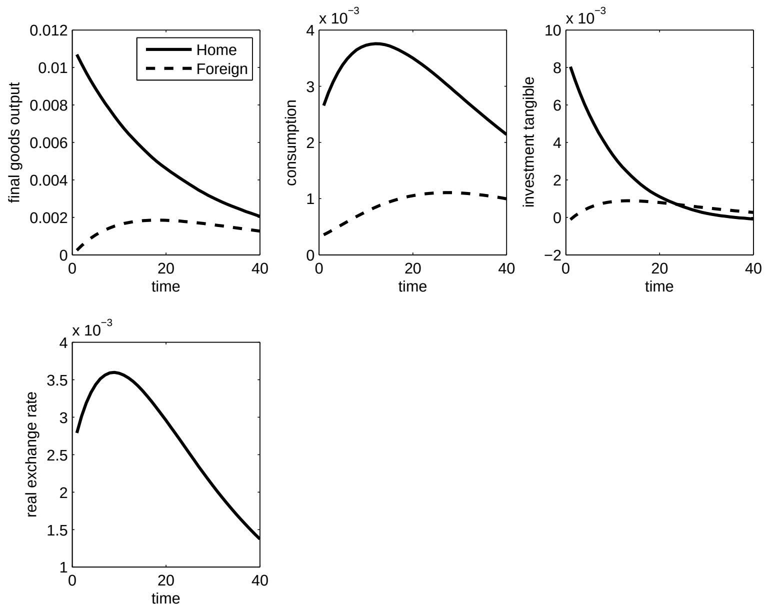


Figure 2: Domestic neutral technology shock (Tangible model)



4.3 Sector-specific technology shocks

Figure 3 displays the impulse response functions for a technology shock to the final goods sector. An important difference compared with a neutral technology shock is that after this sector-specific shock, the output in the final goods sector increases and the production in the intangible sector decreases, because the latter sector does not experience a technology shock and more resources are devoted to the production of goods, which has become relatively more productive. With respect to tangible investments, there is a strong co-movement between the domestic and foreign variables. Finally, figure 4 reveals the reaction of the model variables to a sector-specific productivity shock to the intangible production sector. A technology shock to the production function for intangibles has considerably different implications than a technology shock to the final goods sector. Most importantly, however, the output in the final goods sector initially decreases and only increases again in the medium term. This reflects the fact that there is an initial inter-sectoral shift and that more resources are thus devoted to the sector that has become relatively more productive. After several periods, the increase in intangible investment increases the intangible capital stock sufficiently, which then yields an increase in final goods production. In addition, one can observe a strong co-movement of tangible investment.

Figure 3: Domestic technology shock to final goods production

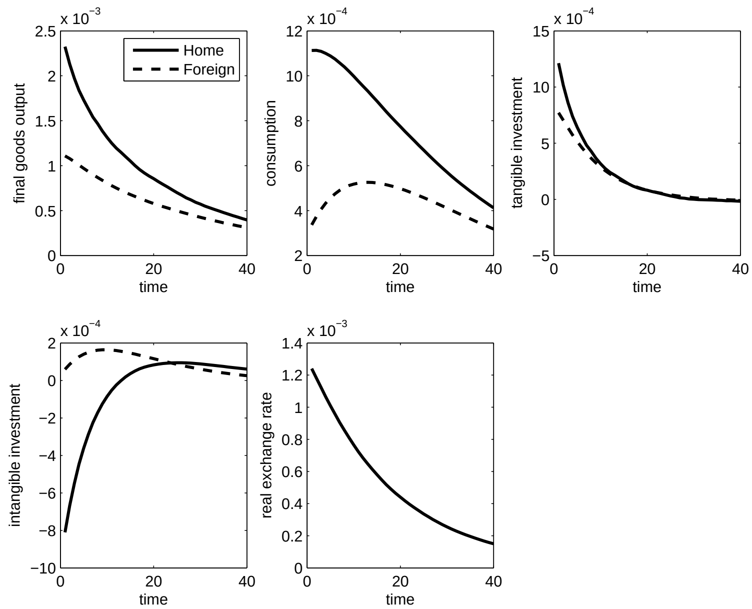
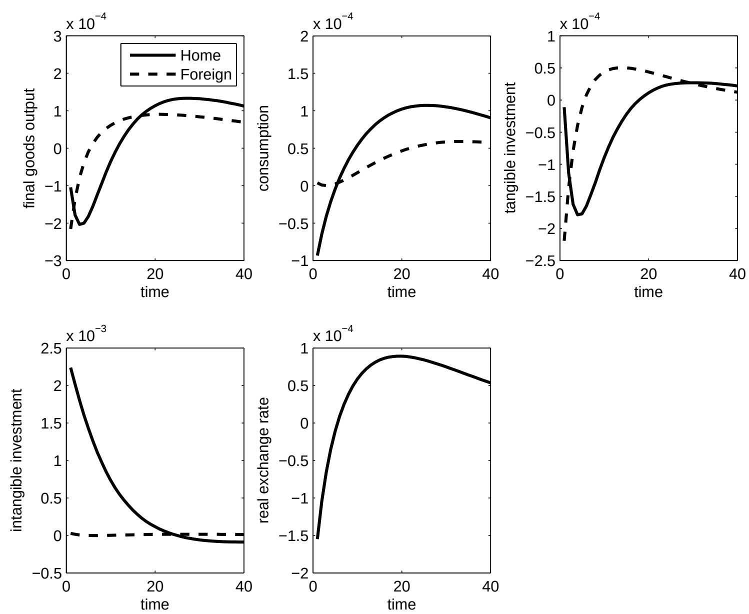


Figure 4: Domestic technology shock to intangible production sector



4.4 Moments

Tables 2-4 present the HP-filtered statistics for the data and the results of our model simulations. The moments for the data in the first column are taken from Raffo (2010) and are within the range of moments reported for quarterly data in other studies. The data refer to the US economy and an aggregate consisting of EU15, Canada and Japan for the period 1970:1-2007:3. Consumption and investment are defined as the sum of the respective private and public components. In all models, we add adjustment costs for investment to match the standard deviations of tangible investment generated by the model to those found in the data. We compare our results of the baseline model to the results obtained from a version with only tangible capital (Only tangible), a lower share of intangible capital by assuming $\phi = 0.1$ (Low intangible), an augmented Taylor rule (Taylor output), non-neutral technology shocks by assuming that the correlation coefficient across the two shocks is -0.5 (Non-neutral), and our augmented model with foreign equity investment (Equity).

As presented in tables 2-4, the model performs fairly well in reproducing the main features of the business cycle.[5] In particular, the model simulations yield a positive co-movement for domestic and foreign tangible investment (Table 4). While the cross-correlation between domestic and foreign tangible investment is only 0.02 in the *Only tangible* case, it increases to 0.51 in the *Baseline* case, respectively. In the same way, the degree of output synchronization increases from 0.38 in the model with only tangible capital to 0.57 in the full model with intangible capital. As mentioned above, these results are consistent with empirical findings and are not obtained by conventional

[5] Similar to many other models, our model does not successfully solve international price puzzles. Because our study does not focus on these issues, the respective moments are not reported.

models. Because of the two-sector structure, tangible capital can move between the two sectors and can thus be used where it is most productive. Therefore, the need to relocate capital across countries present in standard models is reduced in our model. Importantly, a higher share of intangible capital increases the co-movement of both tangible investment and output. For tangible investment, the cross-correlation increases from 0.35 to 0.51 when the share of intangible investment increases. For output, the degree of synchronization increases from 0.48 to 0.57. Therefore, our model predicts that the growing importance of intangible capital in advanced economies will increase the degree of output co-movement, which has implications for economic integration. In particular, because a crucial criterion for a monetary union is the degree of business cycle synchronization, our model implies that countries with a relatively high share of intangible capital are well suited to form a monetary union, while this is less true for countries with a relatively low share of intangible capital.

In addition, our results imply that including cross-border equity investments in our model further increase the degree of output and tangible investment co-movement across countries. The correlation coefficient increases to 0.72 for tangible investment and to 0.78 for output. The degree of co-movement of tangible investment increases slightly when the central bank reacts not only to inflation, but also to the output gap with the augmented Taylor rule. However, the co-movement of output is lower under this version of the Taylor rule. In a similar way, non-neutral technology shocks lead to an increase in the cross-correlation of tangible investment, but to a lower coefficient for output.

Table 2: Standard deviations relative to GDP

	US Data	Baseline	Only tangible	Low intangible
Tangible investment	2.87	2.87	2.87	2.87
Consumption	0.81	0.70	0.61	0.65
Hours worked	0.87	0.71	0.62	0.65
		Non-neutral	Taylor output	Equity
Tangible investment		2.87	2.87	2.87
Consumption		0.68	0.65	0.69
Hours worked		0.61	0.60	0.66

Table 3: Cross-correlations between GDP and selected variables

	US Data	Baseline	Only tangible	Low intangible
Tangible Investment	0.91	0.93	0.92	0.90
Consumption	0.85	0.86	0.87	0.86
		Non-neutral	Taylor output	Equity
Tangible Investment		0.89	0.92	0.90
Consumption		0.81	0.84	0.94

Table 4: Cross-correlations between foreign and domestic variables

	US Data	Baseline	Only tangible	Low intangible
Output	0.60	0.57	0.38	0.48
Tangible Investment	0.46	0.51	0.02	0.35
Consumption	0.50	0.95	0.70	0.92
		Non-neutral	Taylor output	Equity
Output		0.53	0.52	0.78
Tangible Investment		0.80	0.63	0.72
Consumption		0.97	0.94	0.98

5 Conclusion

This paper analyzes intangible capital using an international business cycle model. We find that the greater the importance of intangible capital to the production function is, the greater the international co-movement of output and tangible investment is. The positive correlation of tangible investment and output across countries is a result that many conventional models fail to produce. In addition, we find that cross-border equity investments further increase international co-movement of both output and tangible investment. Because the degree of output synchronization is an important condition for the functioning of a monetary union, one may conclude from our results that countries in which intangible capital and foreign equity investments are more important are best suited to forming a monetary union. This offers an important policy conclusion for the Eurozone. Specifically, fostering intangible investment and foreign equity investment in the Eurozone may not only increase economic growth rates, but also improve the functioning of the monetary policy in the Eurozone.

References

Ambler, S., Cardia, E. & Zimmermann, C. (2004), 'International Business Cycles: What are the Facts?', *Journal of Monetary Economics* **51**(2), 257–276.

Backus, D. K., Kehoe, P. J. & Kydland, F. E. (1992), 'International Real Business Cycles', *Journal of Political Economy* **100**(4), 745–775.

Baldi, G. & Bodmer, A. (2017), 'Intangible Investments and International Business Cycles', *International Economics and Economic Policy* **14**(2), 211–219.

Baldi, G., Fichtner, F., Michelsen, C. & Rieth, M. (2014), 'Weak Investment Dampens Europe's Growth', *DIW Economic Bulletin* **4**(7), 8–21.

Baldi, G. & Miethe, J. (2015), Foreign Direct Investment and Economic Growth, DIW Roundup: Politik im Fokus 71, Berlin.

Calvo, G. A. (1983), 'Staggered Prices in a Utility-Maximizing Framework', *Journal of Monetary Economics* **12**(3), 383–398.

Canova, F. & Ubide, A. J. (1998), 'International Business Cycles, Financial Markets and Household Production', *Journal of Economic Dynamics and Control* **22**(4), 545–572.

Corrado, C. A., Haskel, J., Iommi, M. & Jona, C. (2012), Intangible Capital and Growth in Advanced Economies: Measurement and Comparative Results, Working Paper DP9061, Centre for Economic Policy Research.

Corrado, C., Haltiwanger, J. & Sichel, D. (2005), *Measuring Capital and Technology: An Expanded Framework*, University of Chicago Press, Chicago.

Corrado, C., Haskel, J., Jona-Lasinio, C. & Iommi, M. (2013), 'Innovation and Intangible Investment in Europe, Japan, and the United States', *Oxford Review of Economic Policy* **29**(2), 261–286.

Corrado, C., Hulten, C. & Sichel, D. (2009), 'Intangible Capital and U.S. Economic Growth', *Review of Income and Wealth* **55**(3), 661–685.

Corsetti, G., Dedola, L. & Leduc, S. (2014), 'The International Dimension of Productivity and Demand Shocks in the US Economy', *Journal of the European Economic Association* **12**(1), 153–176.

Fries, C. & Kappler, M. (2015), Does Foreign Direct Investment Synchronise Business Cycles? Results from a Panel Approach, Discussion Paper 15-031, ZWE - Centre for European Economic Research.

Greenwood, J., Hercowitz, Z. & Huffman, G. W. (1988), 'Investment, Capacity Utilization, and the Real Business Cycle', *American Economic Review* **78**(3), 402–417.

Heathcote, J. & Perri, F. (2002), 'Financial Autarky and International Business Cycles', *Journal of Monetary Economics* **49**(3), 601–627.

Johri, A., Letendre, M.-A. & Luo, D. (2011), 'Organizational Capital and the International Co-Movement of Investment', *Journal of Macroeconomics* **33**(4), 511–523.

Kehoe, P. J. & Perri, F. (2002), 'International Business Cycles with Endogenous Incomplete Markets', *Econometrica* **70**(3), 907–928.

McGrattan, E. R. & Prescott, E. C. (2012), *The Labor Productivity Puzzle*, Hoover Institution Press.

McGrattan, E. R. & Prescott, E. C. (2014), 'A Reassessment of Real Business Cycle Theory', *American Economic Review* **104**(5), 177–187.

Raffo, A. (2010), *Technology Shocks: Novel Implications for International Business Cycles*, Diane Publishing.

Veugelers, R. (2016), The European Union's Growing Innovation Divide, Bruegel Policy Contribution 2016/08, Brussels.