# The International Propagation of News Shocks

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**Abstract**

We address the question of business cycle co-movements within and between countries. We first show that for the U.S. and Canada as well as for Germany and Austria, a stock market innovation in the large country, that does not affect TFP in the short run, does indeed explain the large TFP in tho long run. We therefore label such a shock a news about TFP of the large country. This shocks is shown to act as a demand shock in the data, creating a boom in the large country as well as in the small one. Second, we show that a canonical RBC two-country model can account for national and international business cycles only when the technological shocks are common and surprises, which does not fully map our empirical evidence. We then propose an enrichment of the productive structure of this canonical model that theoretically allows for news shocks to propagate as they do in the data. Finally, we propose a specific quantitative model that is shown to give realistic quantitative predictions.

**Key Words :** Business Cycles, Expectations, International Fluctuations

**JEL Classification : E3**

## Introduction

Since A.C. Pigou and J.M Keynes, the macroeconomic literature has emphasize the role of expectations in affecting business cycles. The newest embodiment of the literature stresses on the role of expectations regarding future productivity growth in creating fluctuations. Beaudry and Portier [2006], Beaudry and Portier [2005] and Haertel and Lucke [2007]have shown that Total Factor Productivity permanent improvements can be spotted in stock prices fluctuations before they actually increase TFP. The effect of those news shocks on economic activity have been investigated in a set of recent papers ((Beaudry and Portier [2004a], Christiano, Motto, and Rostagno [2005], Jaimovich and Rebelo [2006], Beaudry, Collard, and Portier [2006], Den Haan and Kaltenbrunner [2007])

In this paper, we show that considering such changes in expectation can also help reproducing international business cycle fluctuations, and that the data supports the existence of such shocks.

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Business Cycles display two distinctive features. The first one, that we label "National Business Cycles" (*NBC)* is the fact that macroeconomic aggregates (consumption, investment, output, worked hours) are positively correlated. The second one, that we label "International Business Cycles" (*IBC*) is that those aggregates are pairwise correlated across countries. Those two set of facts are well documented in the literature (see Ambler, Cardia, and Zimmermann [2004]).

Can standard business cycle models reproduce those facts? Standard closed economy Real Business Cycle models in the line of Kydland and Prescott [1982] do display NBC when perturbed by technological surprises. Standard two-country economy Real Business Cycle models in the line of Backus, Kehoe, and Kydland [1995] do when perturbed by common technological shocks. Is it therefore the end of the story? No, because the previous results crucially rely on two assumptions: first the fact that technological shocks are surprises and second the fact that they are common across countries. Those two assumptions, which are needed to generate NIC and IBC are at odd with the data. As for the first assumption, Beaudry and Portier [2006] have shown that (permanent) technology improvements diffuse slowly over time, and are forecastable to a large extent. Beaudry and Portier [2004b] have shown that standard neoclassical models generate negative correlation of consumption with investment, output and hours, which is highly counterfactual. In this paper, we extend the result to standard two-country economies: they cannot display business cycle fluctuations when news about future technological improvements occur. Given this challenge, we propose a two-country two-sector model inspired from Beaudry and Portier [2004a], in which good technological news create aggregate booms. The second assumptions is that technological shocks are common across countries, or at least very correlated. This assumption is not strongly supported by the data, as also shown in Ambler, Cardia, and Zimmermann [2004]. But such an assumption is needed for the standard model RBC model, as local technological shocks lead to dramatic reallocation of capital, and therefore negatively correlated cycles across countries. In this paper, we show that news shocks, because the information is common to all the countries although the realization might be in only one country, act as common shocks, and therefore tend to synchronize business cycles.

In the first section, we show that news about future increases in TFP are creating both NBC and IBC. More precisely, we show that innovations in the U.S. stock price that are orthogonal to current U.S. TFP are increasing U.S. TFP in the long run, are associated with an increase in output, consumption, investment and hours in the U.S. and in one of the closest U.S. trade partner, Canada. We repeat the same exercise with German stock price and show that they create German business cycle, but also Austrian one. We also show that macroeconomic aggregates also increase in Great Britain, Italy and France. A second section investigate the properties of a canonical neoclassical two-country model, and show that technological shocks cannot produce both NBC and IBC, unless they are at the same time surprises and common. We then show that allowing for a richer productive structure that allows for joint production of consumption and investment is a way to produce NBC and IBC with technological news. The key insight is that, because news shocks are common knowledge, they act as a common shock although the news is about a technological improvement in one country only. Section 3 then proposes a quantitative assessment in a two-country model with a rich productive structure. The model is a two-country version of Beaudry and Portier [2004a] . We show that the model responses to a local technological news shocks display a aggregate boom at home, and that this boom is also transmitted to the foreign country. We then perform some stochastic simulations of the model, and apply our VAR empirical strategy to simulated data. Results are qualitatively in line with what we found in the data

# 1 Facts on the International Propagation of News Shocks

In this section, we assess the empirical propagation of news shocks across countries, namely of U.S. TFP news on Canadian business cycle and German TFP news on Austrian, French, Italian and British business cycles.

## 1.1 Identification

Beaudry and Portier [2006] identify news shock to productivity estimating a bivariate VAR[1] and recovering the following Wold representation, where $TFP$ is the log of Total Factor productivity, $SP$ is a stock price index and $B(L)$ a matrix of lag polynomials:

$$\begin{pmatrix} \Delta TFP_t \\ \Delta SP_t \end{pmatrix} = B(L) \begin{pmatrix} u_{1,t} \\ u_{2,t} \end{pmatrix}. \tag{1}$$

$u_1$ and $u_2$ are two white noise with covariance matrix $\widehat{\Omega}$, and $B(L) = I + \sum_{i=1}^{\infty} B_i L^i$

Identification amounts at choosing a matrix $\widehat{A}_0$ that maps "reduced-form" residuals $u$ into "structural" ones $\varepsilon$: $u_t = \widehat{A}_0 \varepsilon_t$. Imposing that the covariance matrix of $\varepsilon$ is identity, the matric $\widehat{A}_0$ shall verify $\widehat{A}_0 \widehat{A}_0' = \widehat{\Omega}$, which imposes 3 constraints ont the four elements of $A_0$. One extra restriction is therefore needed to uncover the following "structural" representation:

$$\begin{pmatrix} \Delta TFP_t \\ \Delta SP_t \end{pmatrix} = \widehat{A}(L) \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{pmatrix}. \tag{2}$$

with $\widehat{A}(L) = \sum_{i=0}^{\infty} \widehat{A}_i L^i$ and $\widehat{A}_i = B_i \widehat{A}_0$ for $i > 0$.

[1] For simplicity, we assume away constants and cointegration in this presentation, although we do consider those issues in the estimation.

Beaudry and Portier [2006] successively impose a long run and a short run restriction to identify *(i)* a short–run TFP shock and *(ii)* a long–run TFP shock. They show that the shock which is orthogonal to the short–run TFP shock is almost perfectly correlated with the long–run TFP shock. In other words, a shock which has no instantaneous impact on TFP explains virtually 100% of its long–run variance. This shock is interpreted as a news on future TFP improvements which shows up instantaneously in stock market capitalization but only affects measured TFP with a delay. This shock, that we denote $\varepsilon_1$, is obtained by imposing the extra constraint $\widehat{A}_0(1,1) = 0$.

We want to build on the empirical identification presented above to recover the responses of different macroeconomic aggregates in country $J$ to a news about total factor productivity in country $I$. Let $X$ be any macroeconomic variable. We consider trivariate structural processes of the type:

$$\begin{pmatrix} \Delta TFP_{I,t} \\ \Delta SP_{I,t} \\ \Delta X_{J,t} \end{pmatrix} = A(L) \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \varepsilon_{3,t} \end{pmatrix} = \left[\sum_{k=0}^{+\infty} A_k L^k\right] \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \varepsilon_{3,t} \end{pmatrix}. \tag{3}$$

Here, $\varepsilon_{1,t}$ denotes the news shock, while $\varepsilon_{2,t}$ and $\varepsilon_{3,t}$ denote the two remaining shocks in this three-variables setup. These three shocks are independent, have zero mean and unit variance.

We choose here to identify $\varepsilon_1$ so that the news shock does not depend on the third variable of the system, inn order to compare responses of different $X_I$ to the same object[2]. To do so, we constrain the estimation of (3) and impose $A_{k,13} = A_{k,23} = 0\,\forall k$. The constrained VAR($q$) model we estimate writes

$$\begin{aligned} \begin{pmatrix} \Delta TFP_{I,t} \\ \Delta SP_{I,t} \\ \Delta X_{J,t} \end{pmatrix} = & \begin{bmatrix} c_{1,11} & c_{1,12} & 0 \\ c_{1,21} & c_{1,22} & 0 \\ c_{1,31} & c_{1,32} & c_{1,33} \end{bmatrix} \cdot \begin{pmatrix} \Delta TFP_{I,t-1} \\ \Delta SP_{I,t-1} \\ \Delta X_{J,t-1} \end{pmatrix} + \ldots \\ & + \begin{bmatrix} c_{q,11} & c_{q,12} & 0 \\ c_{q,21} & c_{q,22} & 0 \\ c_{q,31} & c_{q,32} & c_{q,33} \end{bmatrix} \cdot \begin{pmatrix} \Delta TFP_{I,t-q} \\ \Delta SP_{I,t-q} \\ \Delta X_{J,t-q} \end{pmatrix} + \begin{pmatrix} u_{1,t} \\ u_{2,t} \\ u_{3,t} \end{pmatrix} \end{aligned} \tag{4}$$

with $\Omega$ the variance–covariance matrix of residuals $u$.

This constrained VAR equation is estimated following a SUR estimation (Zellner, A. (1962). "An efficient method of estimating seemingly unrelated regression equations and tests for aggregation bias". Journal of the American Statistical Association 57: 348–368). To identify the news shock of (3), we impose $A_0 A_0' = \Omega$ and $A_0(1,1) = 0$ (the news shock has no impact on TFP in country $I$). Another restriction would ne needed to disentangle $\varepsilon_2$ from $\varepsilon_3$, but we do not need to do so here.

We now turn to the data.

## 1.2 News on US TFP and Their Impact on US and Canadian Business Cycle

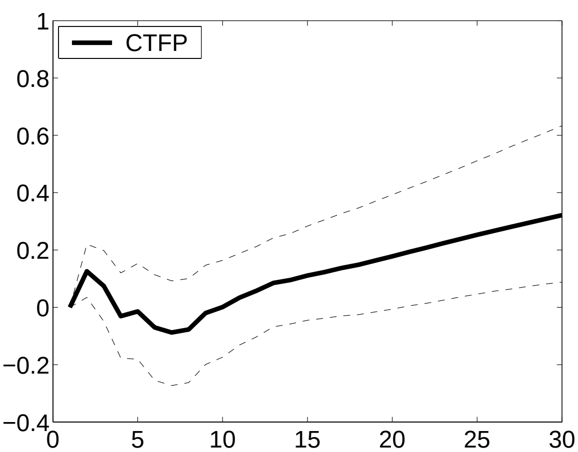
We identify news about U.S. TFP and estimate their impact on US and Canadian business cycle. Canada is a good country candidate to asses the international propagation of news shocks. The U.S.

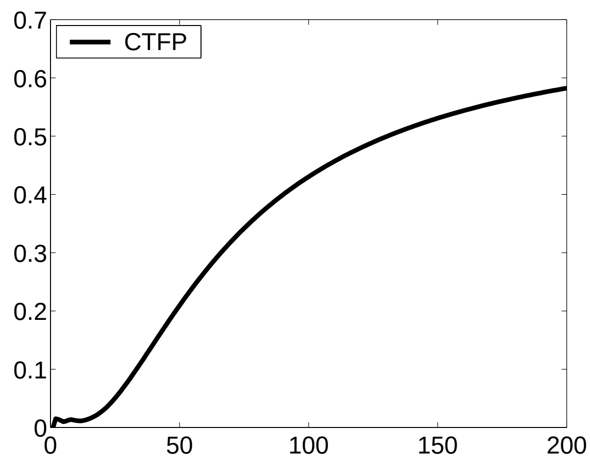
[2]In the appendix, we show that our results are not affected estimating

is the main trade partner of Canada, and Canadian economy is about one-fifth of U.S. one, so that any changes affecting the US.S is likely to have a consequence in Canada. We therefore estimate model (3) on quarterly U.S. and Canadian data[3].

Figure 1 displays the response on U.S. TFP to the $\varepsilon_1$ shock (the shock that is orthogonal to contemporaneous TFP) (left panel) together with the share of the forecast error variance of TFP associated to this shock at horizons 1 to 200 quarters (right panel). Two features emerge. First, the news shock has a significant long–run effect on TFP and explains a large share of the forecast error. Second, it has almost no impact on TFP during the first five years. This favors an interpretation of $\varepsilon_1$ as a news about future U.S. TFP. The three–variables systems evaluates the response of selected macro aggregates to the very same news shock realizations. We see on Figure 2 that a positive news shock (*i.e.* a positive increase in market capitalization independent of any current TFP increase but which forecasts a future TFP increase) triggers an expansion. Output, employment, consumption and investment exhibit sizeable increases in the years that follow the shock. This expansion is an episode of expectation–driven national business cycle (NBC).

Figure 1: Identification of the US News Shock




*This Figure ... (Corrected TFP, SP) VECM with 5 lags.*

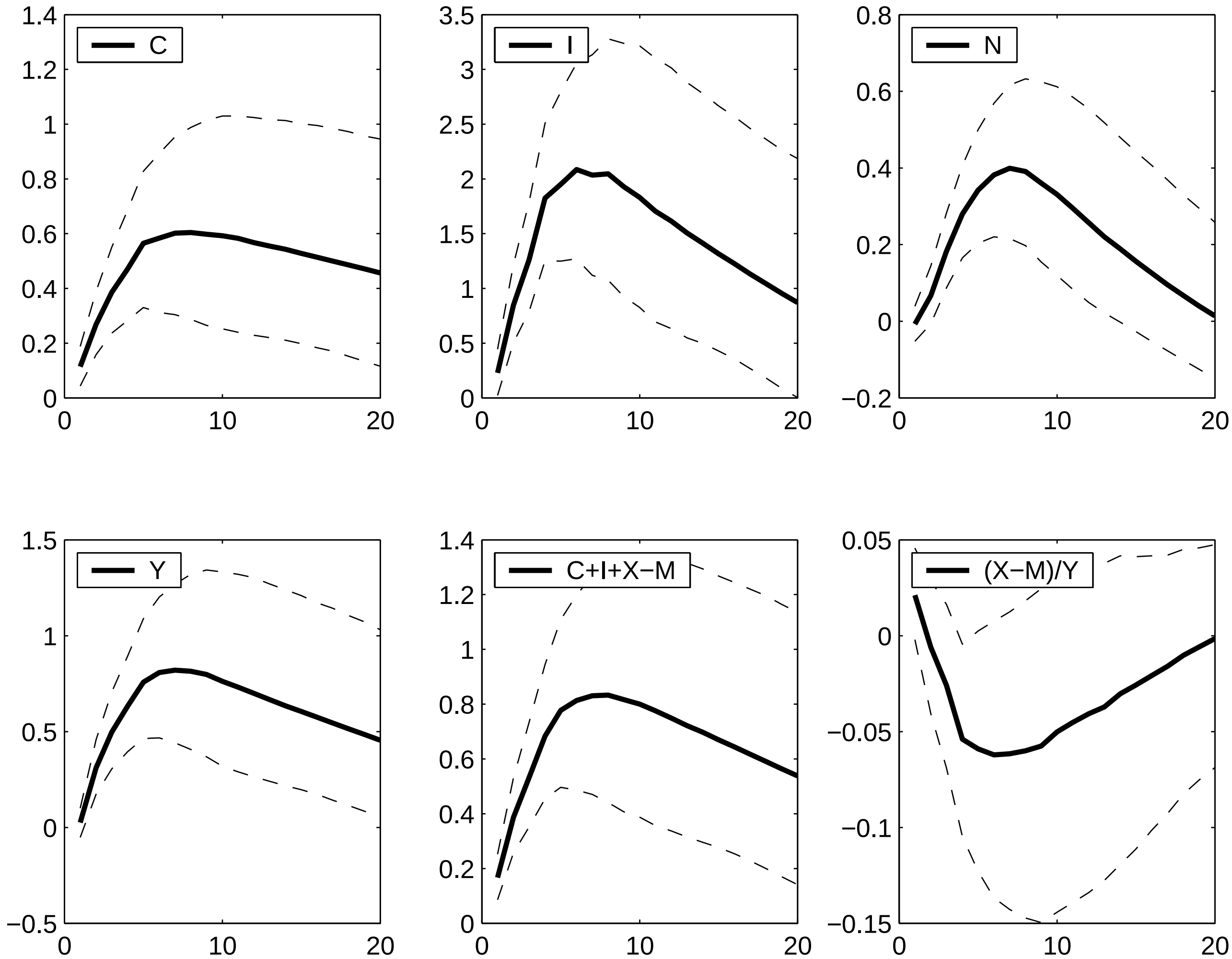
Both US exports and US imports respond positively to the US news shock. Overall, net exports tend to decrease (though not positively). This is in line with the demand–side interpretation of news shock.

Does this US expansion channels to Canada countries? Estimations of the three variables model with Canadian series for the third variable are displayed on Figure 3

The overall picture is similar to the US one, and the orders of magnitude are the same. The US news shock creates an expansion in Canada, which is an episode of expectation–driven international business

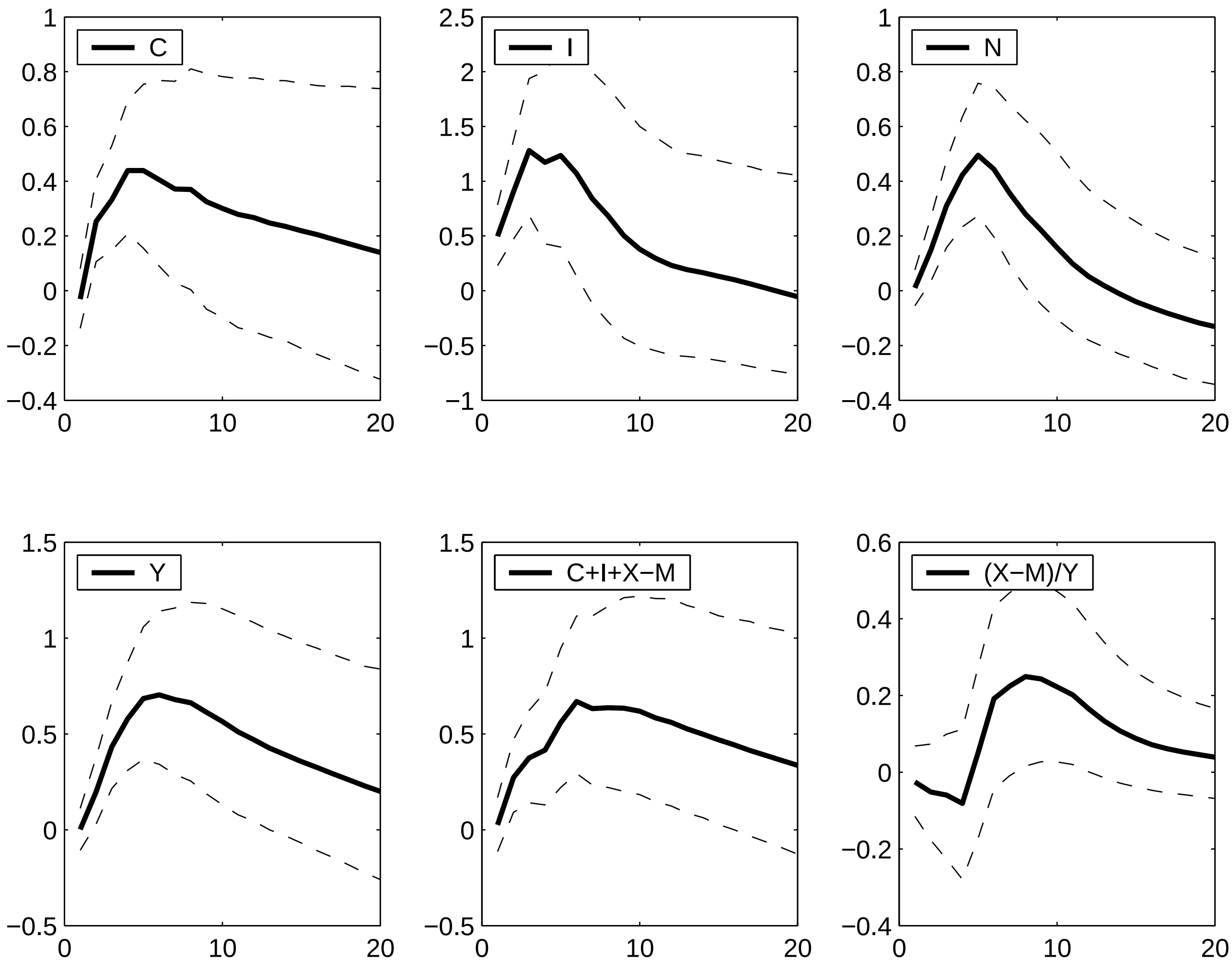
[3]See the appendix for an extensive description of the data.

Figure 2: Response to a US News Shock, USA




*This Figure ... (Corrected TFP, SP, macroeconomic aggregate) VECM with 5 lags. Sample: 1960Q1 to 2000Q4.*

Figure 3: Response of Canadian Aggregates to a News on US TFP




*This Figure ... (Corrected US TFP, US SP, Canadian macro aggregate) VECM with 5 lags. Sample: 1965Q1 to 2000Q4.*

cycle (IBC). Interestingly, Canadian net exports tend to rise in the medium–run. Quantitatively, the increase in consumption is relatively similar in both countries while US investment raises substantially more than its Canadian counterpart.

This exercise reveals that permanent U.S. TFP improvements diffuse slowly, while they are immediately incorporated in agents expectations. Such news create an aggregate boom at home, but also in Canada, which is a close trade partner.

### 1.3 News on German TFP and Their Impact on German and Austrian Business Cycle

We extend our previous result to a second couple of countries with similar characteristics, namely the German-Austrian couple. As for U.S.A-Canada, Austria GDP is about one fifth of German one, and Germany is the main Austrian trade partner. We identify a news shock to German TFP using data presented in Haertel and Lucke [2007], and estimate its dynamic impact on German and Austrian aggregates.

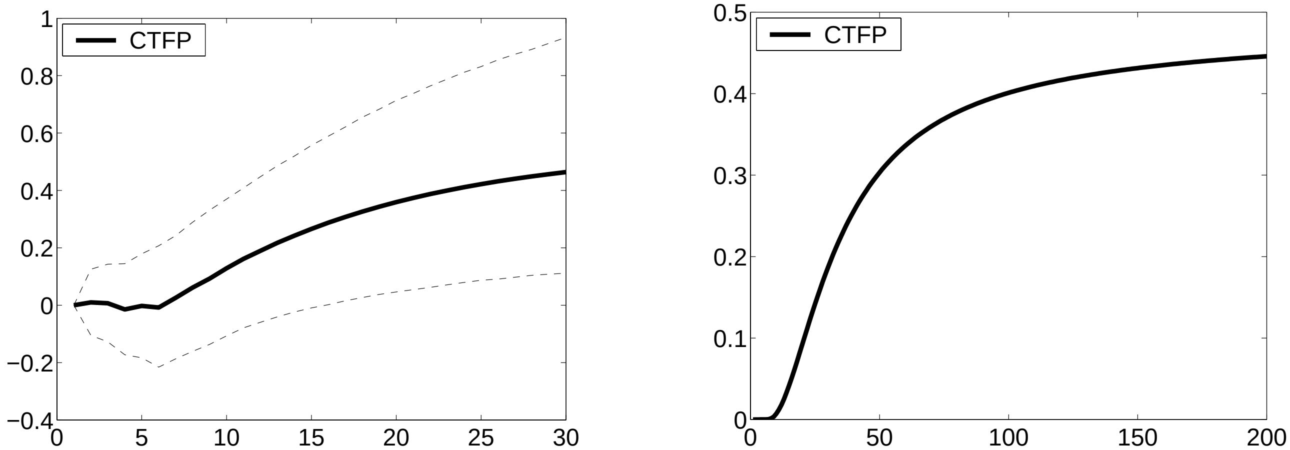
Figure 4 displays the IRF of TFP to the news shock (left panel) and the forecast–error variance decomposition (right panel). Results are similar to the U.S. ones. The impact on TFP remains insignificant for more than twenty quarters and a large part of the long–run forecast–error variance is attributable to the shock with no instantaneous impact on corrected TFP. We then compute the dynamic responses of several German macroeconomic aggregates. The results of these estimations are reported in Figure 5. German consumption, investment and output rise in the quarters following a news shock. Employment is more sluggish, and slightly increases two years after the shock.

The shock stimulates both exports and imports. Overall, net exports tend do drop on impact and exhibit a non–monotonic pattern afterwards.

Figure 6 displays the IRF of Austrian aggregates to the German news shock. Consumption and output rise in the quarters following the news. The increase in employment takes longer, as it does in Germany. The confidence interval for the response of investment are very large, hence we cannot reject that investment is left unaffected. However, the point estimates exhibit a strong increase. Finally, the response of net exports are very small at all horizons.

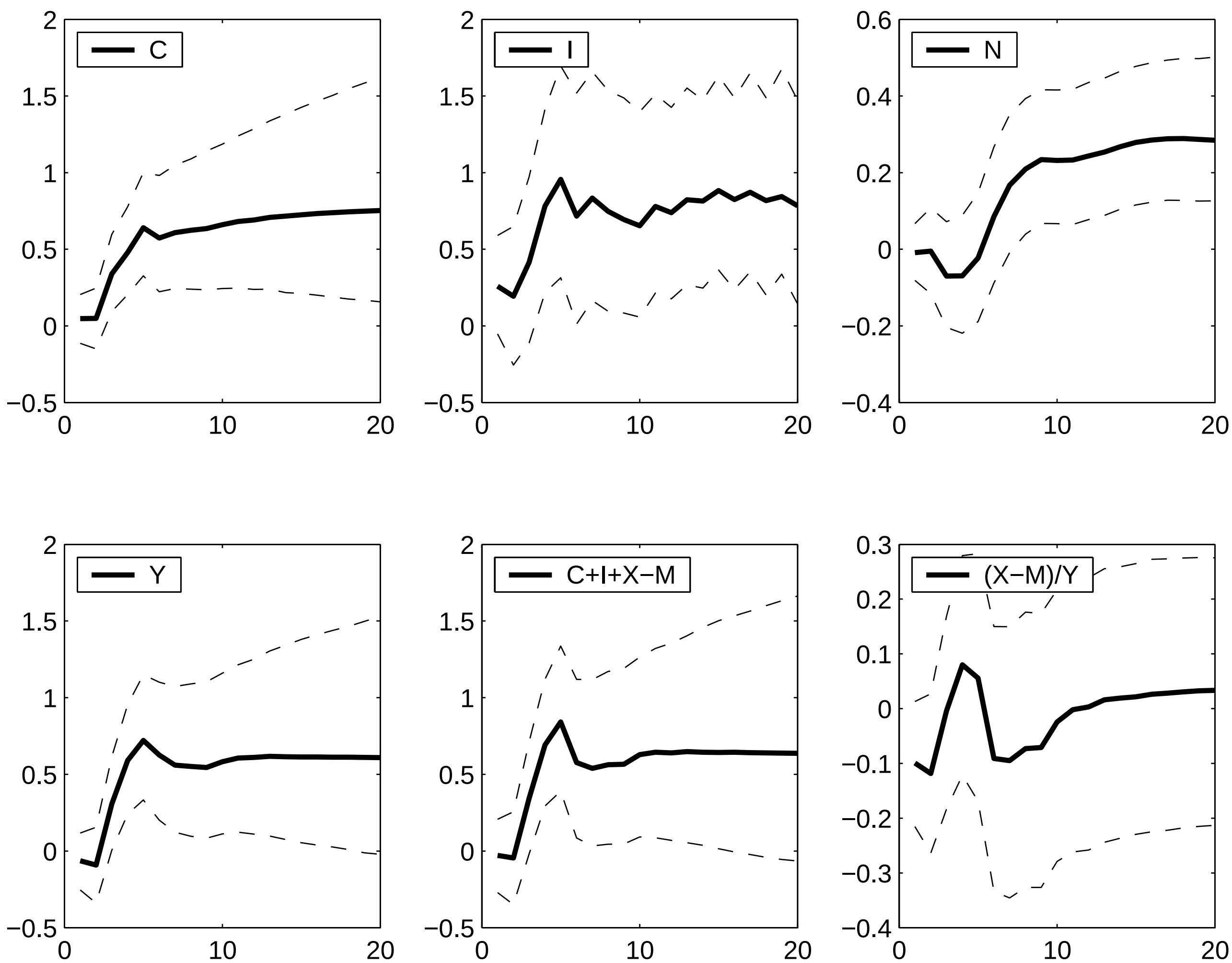
In the appendix, we repeat the exercise by estimating the responses of French, British and Italian aggregates to the German news, and obtain convincing evidence of an international propagation of the German news shock.

Figure 4: Identification of the German News Shock




*This Figure ... (Corrected TFP, SP) VECM with 5 lags. Sample: 1970Q1 to 2004Q3.*

Figure 5: Response to a German News Shock, Germany




*This Figure ... (Corrected TFP, SP, macroeconomic aggregate) VECM with 5 lags. Sample: 1970Q1 to 2004Q3.*

Figure 6: Response of Austrian aggregates to a News on German TFP

*This Figure ... (Corrected TFP, SP, Austrian macro aggregate) VECM with 5 lags. Sample: 1969Q1 to 2005Q2.*

# 2 The International Propagation of Technological Shocks in real Business Cycle Models

In this section, we first formally show that in a standard BKK-type international real business cycle model, technological shocks can display NBC and IBC if and only if those shocks are common and surprises. We then show that allowing for a richer sectorial structure of the economy makes it possible for technological news to create NBC and IBC.

## 2.1 A Standard BKK-type Model

We consider a two-country, one final good economy. In period $t$, The final good $Y$ is produced in quantities $Y_{A,t}$ in country $A$ and $Y_{B,t}$ in country $B$, using capital ($K$) and labor ($H$) services. The good can be then used to invest ($I$) or consume ($C$), in country $A$ of $B$. The economy is hit by technology shocks $\theta_{A,t}$ and $\theta_{B,t}$. Capital quantity and location is predetermined.

A benevolent planner assigning equal weights to country $A$ and $B$ maximizes the objective function

$$\max_{\{C_{J,t},H_{J,t},I_{J,t},K_{J,t+1}\}_{J=A,B}} E_0 \sum_{t=0}^{+\infty} \beta^t \left[U\left(C_{A,t},1-H_{A,t}\right)+U\left(C_{B,t},1-H_{B,t}\right)\right]$$

subject to the following constraints

$$\begin{cases} K_{A,t+1} \leq (1-\delta)K_{A,t}+I_{A,t} & (\eta_{A,t}\geq 0) \\ K_{B,t+1} \leq (1-\delta)K_{B,t}+I_{B,t} & (\eta_{B,t}\geq 0) \\ C_{A,t}+C_{B,t}+I_{A,t}+I_{B,t} \leq F\left(K_{A,t},H_{A,t};\theta_{A,t}\right)+F\left(K_{B,t},H_{B,t};\theta_{B,t}\right) & (\lambda_t \geq 0). \end{cases}$$

Functions $U$ and $F$ fulfill all the usual assumptions (convexity of preferences, normality of both consumption and leisure, concavity and homogeneity of degree one for technology). We make the further simplifying assumption that preferences are separable in consumption and leisure ($U_{12}=0$). Without loss of generality, we assume symmetric initial endowments: $K_{A,t}=K_{B,t}>0$.

The first-order conditions of this program imply:

$$U_1\left(C_{A,t},1-H_{A,t}\right) = U_1\left(C_{B,t},1-H_{B,t}\right) \tag{5}$$

$$U_2\left(C_{A,t},1-H_{A,t}\right) = U_1\left(C_{A,t},1-H_{A,t}\right)\cdot F_2\left(K_{A,t},H_{A,t};\theta_{A,t}\right) \tag{6}$$

$$U_2\left(C_{B,t},1-H_{B,t}\right) = U_1\left(C_{B,t},1-H_{B,t}\right)\cdot F_2\left(K_{B,t},H_{B,t}\right) \tag{7}$$

$$U_1\left(C_{A,t},1-H_{A,t}\right) = \beta E_t\Big\{\left[1-\delta+F_1\left(K_{A,t+1},H_{A,t+1};\theta_{A,t+1}\right)\right]$$

$$
\begin{aligned}
& \times U_1\left(C_{A,t+1}, 1-H_{A,t+1}\right)\Big\} & (8)\\
U_1\left(C_{B,t}, 1-H_{B,t}\right) \;=\; & \beta E_t \Big\{ \left[1-\delta+F_1\left(K_{B,t+1}, H_{B,t+1}; \theta_{B,t+1}\right)\right] \\
& \times U_1\left(C_{B,t+1}, 1-H_{B,t+1}\right)\Big\} & (9)\\
C_{A,t}+C_{B,t}+I_{A,t}+I_{B,t} \;=\; & F\left(K_{A,t}, H_{A,t}; \theta_{A,t}\right)+F\left(K_{B,t}, H_{B,t}; \theta_{B,t}\right) & (10)\\
K_{A,t+1} \;=\; & (1-\delta) K_{A,t}+I_{A,t} & (11)\\
K_{B,t+1} \;=\; & (1-\delta) K_{B,t}+I_{B,t}. & (12)
\end{aligned}
$$

together with the usual transversality conditions.

## 2.2 Technological Shocks

We first study the impact of technological shocks.

Result 1 ***(World Technological Surprises)*** *If technology shocks are global and surprises (i.e. $\theta_{A,t} = \theta_{B,t} = \theta_t \, \forall t$), allocations are always symmetrical. The model displays IBC. Under functional and parameters restrictions, the model also displays NBC.*

Proof and Discussion of Result 1 **(World Technological Surprises)** : Optimal (and equilibrium) allocations are given by equations (5) to (12). Under world surprises, $\theta_{A,t} = \theta_{B,t} = \theta_t \, \forall t$. A symmetric allocation, such that $C_{A,t} = C_{B,t} = C_t$, $H_{A,t} = H_{B,t} = H_t$ and $I_{A,t} = I_{B,t} = I_t \, \forall t$, fulfills these conditions if and only if

$$
\begin{aligned}
U_2\left(C_t, 1-H_t\right) \;=\; & U_1\left(C_t, 1-H_t\right) \cdot F_2\left(K_t, H_t; \theta_t\right) & (13)\\
U_1\left(C_t, 1-H_t\right) \;=\; & \beta E_t \Big\{ \left[1-\delta+F_1\left(K_{t+1}, H_{t+1}; \theta_{t+1}\right)\right] \\
& \times U_1\left(C_{t+1}, 1-H_{t+1}\right)\Big\} & (14)\\
C_t+I_t \;=\; & F\left(K_t, H_t; \theta_t\right). & (15)
\end{aligned}
$$

These are the optimality conditions of a standard closed economy. Under the usual concavity conditions for the utility and production function, the optimal allocation exists and is unique. It also corresponds to an optimal symmetrical two-country model allocation. One has therefore IBC.

To obtain NBC, one needs consumption, investment and hours to move in the same direction following a change in $\theta_t$. Allocations being symmetrical, one can again work with the system of equations (13) to (15). As consumption is a normal good, it will increase following a positive $\mathrm{d}\theta$. Leisure being also a normal good, hours worked are likely move in opposite direction with respect to consumption because of this wealth effect. On the other hand, the increase in $\theta$ increasing the opportunity cost of leisure, and pushing hours worked upwards through a substitution effect. Those two conflicting effects can be seen from the total differentiation of equation (13):

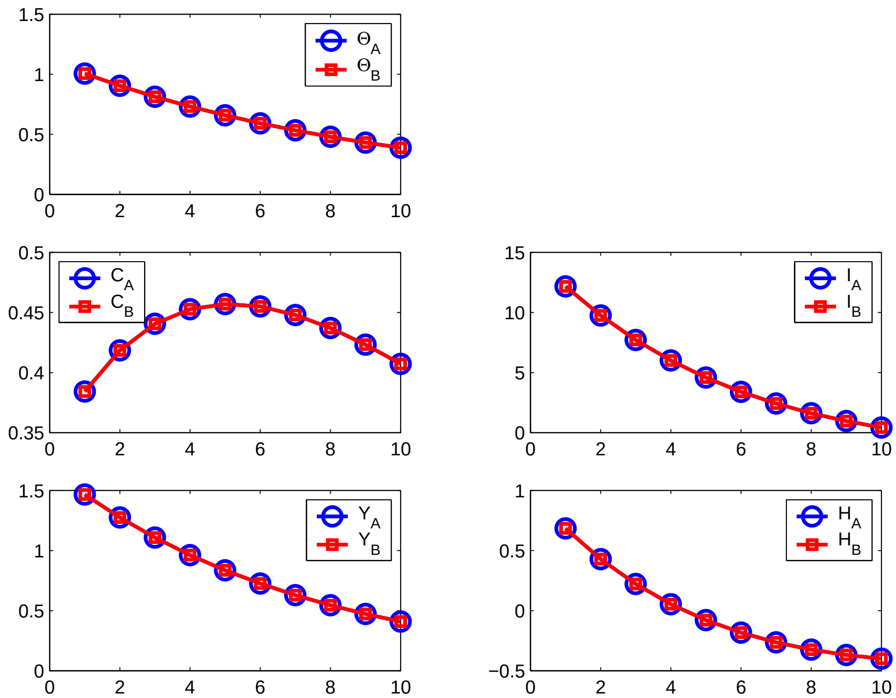
$$\mathrm{d}H = \kappa_1(\kappa_2\ \mathrm{d}\theta - \kappa_3\ \mathrm{d}C)$$

where $\kappa_1 = -(U_{22} + U_1F_{22})^{-1}$, $\kappa_2 = U_{11}F_2$ and $\kappa_3 = -U_1F_{23}$ are positive constants. For standard functional forms and calibration, it is well known in the RBC literature that the substitution effect dominates, so that $\mathrm{d}H > 0$. The evolution of investment depends on the relative strength of these substitution and wealth effects. This can be seen from the total differentiation of (15):

$$\mathrm{d}I = -(1 + F_2\kappa_1\kappa_3)\ \mathrm{d}C + (F_2\kappa_1\kappa 2 + F_3)\ \mathrm{d}\theta$$

Again, under suitable calibration, one obtains $\mathrm{d}I > 0$. In that case, the model displays NBC. As an illustration, Figure 7 displays the response to a world technology shock for what we consider as a "standard" calibration.

Figure 7: Typical BKK Model, Response to a World Technology Shock

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RESULT 2 ***(Local Technological Surprise)*** *If technology shocks are local and surprises (i.e.* $d\theta_{A,t} > 0$*,* $d\theta_{B,t} = 0$ *for some* $t$*), then hours worked are not perfectly correlated across countries. For realistic settings, hours and investments are negatively correlated. There is therefore no IBC and no NBC in the foreign country*

Proof and Discussion of Result 2 **(Local Technological Surprises)** :

We consider small deviations from the symmetric steady-state of the economy. Assume $\theta_{A,t} = \overline{\theta} + d\theta_{A,t} \neq \theta_{B,t} = \overline{\theta}$.

From equation (5), we know that perfect risk-sharing requires consumption in both countries to be perfectly correlated.

Differentiation of equation (6) and (7) implies

$$\begin{aligned} & [U_1(\cdot)\ F_{22}(\cdot) + U_{22}(\cdot)]\,(dH_A - dH_B) \\ = & -U_{11}(\cdot)\ F_2(\cdot)\,(dC_A - dC_B) - [U_1(\cdot)\ F_{23}(\cdot)]\,d\theta_A \\ = & -[U_1(\cdot)\ F_{23}(\cdot)]\,d\theta_A \end{aligned}$$

Finally,

$$\frac{dH_A - dH_B}{d\theta_A} = \frac{U_1(\cdot)\ F_{23}(\cdot)}{-U_1(\cdot)\ F_{22}(\cdot) - U_{22}(\cdot)} > 0.$$

We see from this last equation that hours worked are not perfectly correlated. In country A, they increase more than in country B following a technological surprise in A, therefore amplifying productivity differentials and breaking the perfect correlation of outputs. It is hard to obtain more unambiguous analytical results. Results from calibrated examples show that for standard calibration, hours actually move in opposite direction, creating a negative correlation between output on impact. As investments are also negatively correlated, the negative correlation between output persists. This is illustrated in Figure 8

Result 3 ***(Technological News)*** *If technology shocks are announced $N$ periods in advance, then allocations are symmetrical in the $N-1$ first periods of the interim period, for both world and local news. News are therefore creating IBC. In the interim period, consumption and hours always move in opposite directions There are therefore no NBC.*

Proof and Discussion of Result 3 **(Technological News)** :

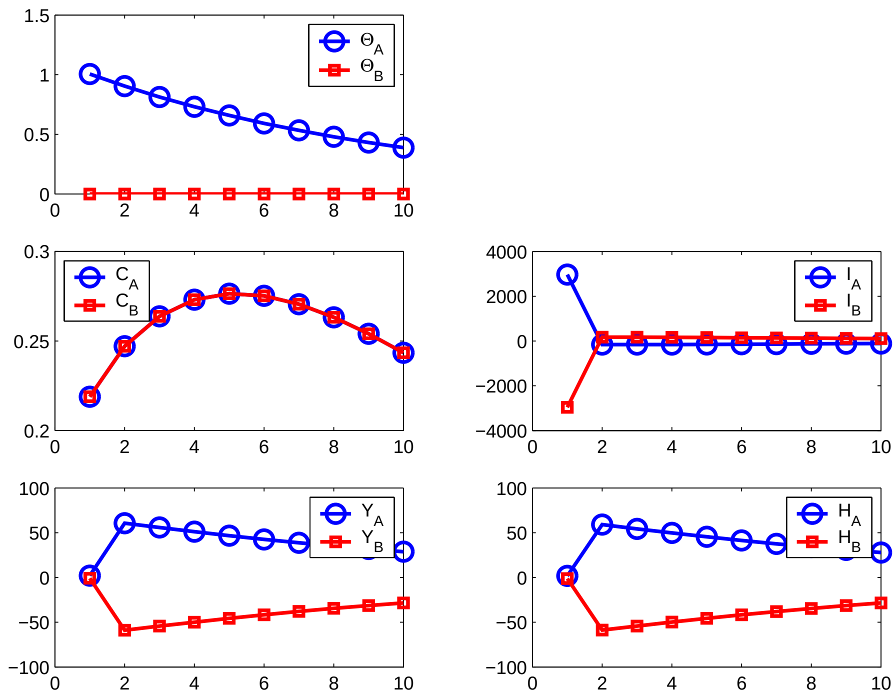
When the economy is hit by a news shock, no current fundamental is affected, so that allocations $(C_A, C_B, H_A, H_B, I_A, I_B)$ are moving along the hyper surface defined by equations (5), (6), (7) and (10), for given expectations. From (5), we know that consumptions allocations will be symmetrical. The conditions defining the set of temporary equilibria write

$$U_2(C_t, 1 - H_{A,t}) = U_1(C_t, 1 - H_{A,t}) \cdot F_2\left(K_t, H_{A,t}; \overline{\theta}\right) \tag{16}$$

$$U_2(C_t, 1 - H_{B,t}) = U_1(C_t, 1 - H_{B,t}) \cdot F_2\left(K_t, H_{B,t}; \overline{\theta}\right) \tag{17}$$

$$2\,C_t + I_{A,t} + I_{B,t} = F\left(K_t, H_{A,t}; \overline{\theta}\right) + F\left(K_t, H_{B,t}; \overline{\theta}\right) \tag{18}$$

Figure 8: Typical BKK Model, Response to a Local Technology Shock




*This Figure ...*

$$
\begin{aligned}
K_{A,t+1} &= (1-\delta) K_t + I_{A,t} && (19) \\
K_{B,t+1} &= (1-\delta) K_t + I_{B,t}. && (20)
\end{aligned}
$$

Full differentiation of (16) and (17) implies

$$[U_1(\cdot)\ F_{22}(\cdot) + U_{22}(\cdot)](dH_A - dH_B) = 0.$$

Hence, $dH_A = dH_B$.

*A priori*, condition (18) does not determine the breakout of investment at the temporary equilibrium. However, if expectations regarding future technology and preference are common to both countries, the Euler equations write:

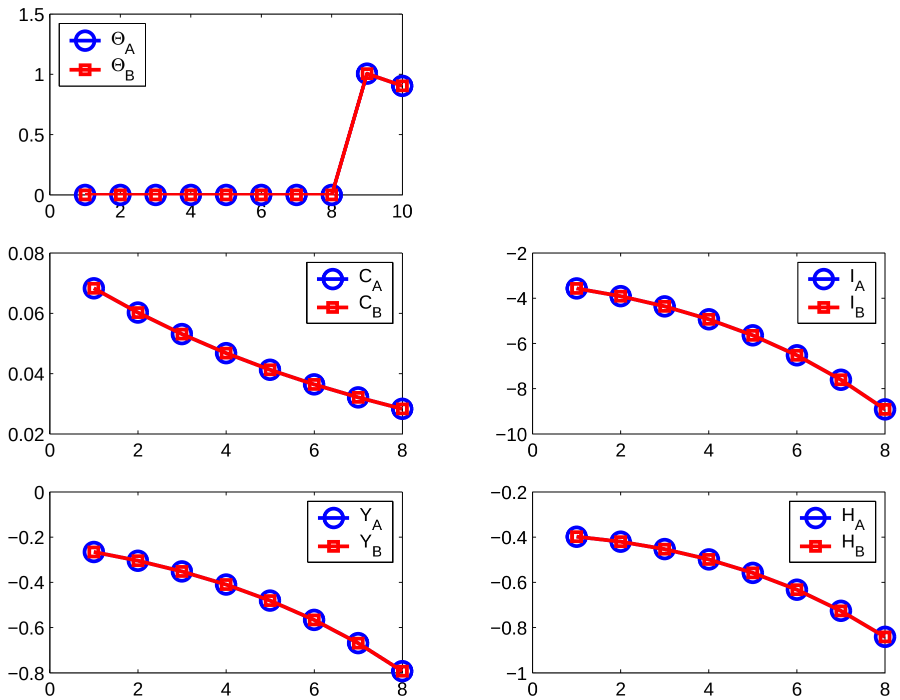
$$
\begin{aligned}
U_1(C_t, 1-H_t) &= \beta E_t \left\{ [1-\delta + F_1(K_{A,t+1}, H_{t+1}; \theta_{t+1})] \times U_1(C_{t+1}, 1-H_{t+1}) \right\} \\
U_1(C_t, 1-H_t) &= \beta E_t \left\{ [1-\delta + F_1(K_{B,t+1}, H_{t+1}; \theta_{t+1})] \times U_1(C_{t+1}, 1-H_{t+1}) \right\}.
\end{aligned}
$$

If $N > 1$, technology does not change in $t+1$. Therefore $K_{A,t+1} = K_{B,t+1}$, hence $I_{A,t} = I_{B,t}$. All variables are therefore equal in both countries: expectations-driven business cycles embed strong cross-country synchronizing forces that create IBC.

We now show that such news shocks do not create NBC. we concentrate on country $A$. Fully differentiating (16), by normality of consumption and leisure, one can show that $dC_A$ and $dH_A$ are of opposite signs. As allocations are symmetrical, it is also true for $dC_B$ and $dH_B$. Then, using (10), one obtains that $dI_A$ and $dI_B$ are of the same sign that $dH_A$. Therefore, one do not have NBC. $\square$

Result 3 is illustrated in Figure 9

Figure 9: Typical BKK Model, Response to a Global Technology News




*This Figure ...*

## 2.3 News Shocks in an Extended Model

Those results show the impossibility of having both NBC and IBC following news shocks of the type we have identified in the data in standard Neoclassical settings. We now extend the model by introducing a richer technological structure, and assume that investment and consumption goods are jointly produced in each country. We show that when the joint production function exhibits economies of scope, one can obtain NBC and IBC following a technological shock.

RESULT 4 ***(Technological News II)*** *In a "rich productive structure" model, allocations are symmetrical in the interim period, for both world and local news, and investment, consumption and hours comove across countries. News are therefore creating IBC and NBC.*

PROOF AND DISCUSSION OF RESULT 4 **(Technological News II)** :

A benevolent planner assigning equal weights to country $A$ and $B$ maximizes the objective function

$$\max_{\{C_{J,t}, H_{J,t}, I_{J,t}, X_{J,t}\}_{J=A,B}} E_0 \sum_{t=0}^{+\infty} \beta^t \left[U\left(C_{A,t}, 1 - H_{A,t}\right) + \mathcal{U}\left(C_{B,t}, 1 - H_{B,t}\right)\right]$$

subject to the following constraints

$$\left\{\begin{array}{rcll} C_{A,t}+C_{B,t} & \leq & G\left(K_{A,t},H_{A,t},X_{A,t};\theta_{A,t}\right)+G\left(K_{B,t},H_{B,t},X_{B,t};\theta_{B,t}\right) & \left(\mu_t\geq 0\right) \\ K_{A,t+1} & \leq & \left(1-\delta\right)K_{A,t}+I_{A,t} & \\ K_{B,t+1} & \leq & \left(1-\delta\right)K_{B,t}+X_{A,t}+X_{B,t}-I_{A,t} & \left(\lambda_t\geq 0\right). \end{array}\right.$$

An example of the $G$ function is

$$G\left(K_{A,t},H_{A,t},X_{A,t};\theta_{A,t}\right)=F\left(K_{A,t},H_{A,t};\theta_{A,t}\right)-X_{A,t}$$

with $F$ a standard aggregate production function.

The temporal equilibrium implied by the first-order conditions of this program verifies the following properties:

$$\begin{array}{rcl} U_1\left(C_{A,t},1-H_{A,t}\right) & = & U_1\left(C_{B,t},1-H_{B,t}\right)=\mu_t \\ U_2\left(C_{A,t},1-H_{A,t}\right) & = & U_1\left(C_{A,t},1-H_{A,t}\right)\cdot G_2\left(K_{A,t},H_{A,t},X_{A,t};\theta_{A,t}\right) \\ U_2\left(C_{B,t},1-H_{B,t}\right) & = & U_1\left(C_{B,t},1-H_{B,t}\right)\cdot G_2\left(K_{B,t},H_{B,t},X_{B,t};\theta_{B,t}\right) \end{array}$$

In the separable utility case, full differentiation of the static first–order conditions yields (given $dK_A=dK_B=d\theta_A=d\theta_B=0$):

$$\left\{\begin{array}{rcl} U_{11}^A\left(\cdot\right)\,dC_A & = & U_{11}^B\left(\cdot\right)\,dC_B \\ dH_A & = & a_1^A\left(-a_2^A\,dC_A+a_3^A\,dX_A\right) \\ dH_B & = & a_1^B\left(-a_2^B\,dC_B+a_3^B\,dX_B\right) \\ G_{23}^A\left(\cdot\right)\,dH_A+G_{33}^A\left(\cdot\right)\,dX_A & = & G_{23}^B\left(\cdot\right)\,dH_B+G_{33}^B\left(\cdot\right)\,dX_B \\ dC_A+dC_B & = & G_2^A\left(\cdot\right)\,dH_A+G_3^A\left(\cdot\right)\,dX_A+G_2^B\left(\cdot\right)\,dH_B+G_3^B\left(\cdot\right)\,dX_B \\ dI_A+dI_B & = & dX_A+dX_B \end{array}\right.$$

with $\left\{\begin{array}{rcl} a_1^j & = & -\left[U_1^j\left(\cdot\right)\,G_{22}^j\left(\cdot\right)+U_{22}^j\left(\cdot\right)\right]^{-1}>0 \\ a_2^j & = & -U_{11}^j\left(\cdot\right)\,G_2^j\left(\cdot\right)>0 \\ a_3^j & = & U_1^j\left(\cdot\right)\,G_{23}^j\left(\cdot\right)\gtreqless 0. \end{array}\right.$

Symmetry implies

$$\left\{\begin{array}{rcl} dH_A & = & a_1\left(-a_2\,dC+a_3\,dX_A\right) \\ dH_B & = & a_1\left(-a_2\,dC+a_3\,dX_B\right) \\ G_{23}\left(\cdot\right)\,dH_A+G_{33}\left(\cdot\right)\,dX_A & = & G_{23}\left(\cdot\right)\,dH_B+G_{33}\left(\cdot\right)\,dX_B \\ 2\,dC & = & G_2\left(\cdot\right)\,dH_A+G_3\left(\cdot\right)\,dX_A+G_2\left(\cdot\right)\,dH_B+G_3\left(\cdot\right)\,dX_B. \end{array}\right.$$

From the first three equations, we get

$$\begin{array}{rcl} dH_A-dH_B & = & a_1a_3\,\left(dX_A-dX_B\right) \\ G_{23}\left(\cdot\right)\,\left(dH_A-dH_B\right) & = & G_{33}\left(\cdot\right)\,\left(dX_B-dX_A\right). \end{array}$$

Hence,

$$\begin{aligned}
\left[a_1 a_3 G_{23}(\cdot) + G_{33}(\cdot)\right](dH_A - dH_B) &= 0 \\
\left[-\frac{U_1(\cdot)\ G_{23}(\cdot)}{U_1(\cdot)\ G_{22}(\cdot) + U_{22}(\cdot)} G_{23}(\cdot) + G_{33}(\cdot)\right](dH_A - dH_B) &= 0. \qquad (21)
\end{aligned}$$

When the utility function is separable in consumption and leisure, in a symmetrical world, equation (21) provides a sufficient condition for the synchronization of labor input.

Lemma 1 ***(Synchronization)***

*If*

$$\frac{U_1(\cdot)\ G_{23}(\cdot)}{U_1(\cdot)\ G_{22}(\cdot) + U_{22}(\cdot)} G_{23}(\cdot) \neq G_{33}(\cdot) \qquad (22)$$

*and* $G_{23}(\cdot) \neq 0$, *labor input, consumption and output in both countries are perfectly synchronized.*

If condition (22) holds, $dH_A - dH_B = 0$. If $G_{23}(\cdot) \neq 0$, $dX_B - dX_A = dH_A - dH_B = 0$: the production of investment goods in both countries is perfectly synchronized.

If condition (22) holds, $G_{23}(\cdot) \geq 0$ is a necessary condition for international expectations driven business cycles.

If $G(K_{J,t}, H_{J,t}, X_{J,t}; \theta_{J,t}) = \theta_{J,t} F(K_{J,t}, H_{J,t}) - X_{J,t}$ for $J = A, B$, $G_3(K_{J,t}, H_{J,t}, X_{J,t}; \theta_{J,t}) = -1$ and $G_{23}(\cdot) = G_{33}(\cdot) = 0$. Hence, labor inputs need not be synchronized during expectation driven business cycles.

If $G(K_{J,t}, H_{J,t}, X_{J,t}; \theta_{J,t}) = \left\{\frac{\left[\theta_{J,t} F\left(K_{J,t}, H_{J,t}\right)\right]^{\sigma} - b X_{J,t}^{\sigma}}{a}\right\}^{\frac{1}{\sigma}}$ for $J = A, B$,

$$\left\{\begin{aligned}
G_3(\cdot) &= -\tfrac{b}{a} X_{J,t}^{\sigma-1}\left\{\frac{\left[\theta_{J,t} F\left(K_{J,t}, H_{J,t}\right)\right]^{\sigma} - b X_{J,t}^{\sigma}}{a}\right\}^{\frac{1}{\sigma}-1} \\
G_{23}(\cdot) &= -(1-\sigma)\tfrac{b}{a^2}\theta_{J,t} F_2(\cdot) X_{J,t}^{\sigma-1}\left\{\frac{\left[\theta_{J,t} F(\cdot)\right]^{\sigma} - b X_{J,t}^{\sigma}}{a}\right\}^{\frac{1}{\sigma}-1} \\
G_{33}(\cdot) &= (1-\sigma)\tfrac{b}{a} X_{J,t}^{\sigma-2}\left\{\frac{\left[\theta_{J,t} F(\cdot)\right]^{\sigma} - b X_{J,t}^{\sigma}}{a}\right\}^{\frac{1}{\sigma}-1} + (1-\sigma)\left(\tfrac{b}{a}\right)^2 X_{J,t}^{2(\sigma-1)}\left\{\frac{\left[\theta_{J,t} F(\cdot)\right]^{\sigma} - b X_{J,t}^{\sigma}}{a}\right\}^{\frac{1}{\sigma}-2}.
\end{aligned}\right.$$

$G_{23}(\cdot)$ and $G_{33}(\cdot)$ have opposite signs if $\sigma > 1$. Hence, condition (22) holds and business cycles are synchronized.

In that case, we have both NBC and IBC.

Result 5 ***(News)*** *Results 3 and 4 apply for any news, not only technological ones.*

Proof and Discussion of Result 5 **(News)** : The previous result can be easily extended to news about any future changes in fundamentals (taxes, preferences, etc...).

## 3 Quantitative Analysis

Theoretically, we have shown that news are a potential source of synchronization across countries. Here we provide explicit and numerical examples of economies in which news create NBC and IBC.

### 3.1 A Two-Country Pigou Model

Here we propose a two-country version of the Beaudry and Portier [2004a] "Pigou" model, that has been shown to have good quantitative properties with news shocks. The building blocks of the model are the following :

1. two sectors for final use goods in each countries (Consumption and Investment (structures)),
2. two sectors of intermediate goods in each countries,
3. capital and labor are complementary in the consumption-oriented intermediate good sector,
4. there are static gains to trade, as consumption and investment are produced in each country with a CES aggregator of home and foreign intermediate goods,
5. investment is produced with labor only, with decreasing returns to scale.

This set of assumptions is such that the economy satisfies the condition

We consider a stylized economy composed of two countries, $A$ and $B$, which are symmetrical except for the population, which we denote $N_A$ and $N_B$. We describe here country $A$ economy.

**Final goods.** There are two final-use sectors: a consumption goods sector and an investment one. The consumption good sector of country $A$ combines two intermediate goods, $Z_{AA}$ which is produced home and $Z_{BA}$ which is imported from country $B$[4], to produce the consumption good, according to the following constant returns CES aggregator:

$$C_{A,t} = \left[ bZ_{AA,t}^{\nu_C} + (1-b)Z_{BA,t}^{\nu_C} \right]^{\frac{1}{\nu_C}}$$

Similarly, the final investment good is produced by combining two intermediate goods, $X_{AA}$ which is produced home and $X_{BA}$ which is imported from country $B$, according to

$$I_{A,t} = \left[ bX_{AA,t}^{\nu_I} + (1-b)X_{BA,t}^{\nu_I} \right]^{\frac{1}{\nu_I}}$$

Investment is then used to increment the stock of capital:

$$K_{A,t+1} = (1-\delta)\, K_{A,t} + I_{A,t}$$

Capital is here best thought as plant and housing infrastructure, which are not directly traded.

[4]We adopt here the following notation: $Z_{IJ}$ means good $Z$ produced in $I$ and used in $J$.

**Intermediate goods.** Country $A$ produces a consumption-oriented intermediate good $Z_A$ using capital and labor $H_A$ according to the following CES technology:

$$Z_{A,t} = \left[a\left(\Theta_{A,t}H_{A,t}^{\varphi}\right)^{\nu} + K_{A,t}^{\nu}\right]^{\frac{1}{\nu}}$$

We will restrict attention to cases where the elasticity of substitution between $K$ and labor in the final goods sector is no greater that one (which seems reasonable given our interpretation of $K$ as infrastructure). This intermediate good is then either used at home ($Z_{AA}$) or exported ($Z_{AB}$).

Country $A$ also produces a investment-oriented intermediate good $X_A$ using labor $\widetilde{H}_A$ according to the following technology:

$$X_{A,t} = \widetilde{\Theta}_{A,t}\widetilde{K}_A^{1-\alpha_X}\widetilde{H}_{A,t}^{\alpha_X}$$

Here we assume that the capital used in this sector $\widetilde{K}_A$ is in fixed quantity. The absence of possibility of reallocating capital between the two-sectors is crucial to obtain news-driven business cycles. A less extreme assumption would be to introduce adjustment cost of capital reallocation. because the model is already quite large, we have preferred to make this quite strong assumption

**Preferences.** The representative household of country $A$ has preferences over individual consumption and hours worked at all periods, and we assume that the period felicity is of the Hansen-Rogerson type:

$$\mathcal{U}_A = \left[\ln c_{A,t} - \chi\left(h_{A,t} + \widetilde{h}_{A,t}\right)\right]$$

### 3.1.1 Equilibrium Allocations

The two theorems of welfare apply in this setup and we solve for an optimal allocation. The Social Planner chooses $\left\{c_{j,t},\, h_{j,t},\, \widetilde{h}_{j,t},\, I_{j,t},\, K_{j,t+1}\right\}_{j=A,B}$ in order to

$$\max E_0 \sum_{t=0}^{+\infty}\beta^t \left[N_A\left(\ln c_{A,t} - \chi\left(h_{A,t}+\widetilde{h}_{A,t}\right)\right) + N_B\left(\ln c_{B,t} - \chi\left(h_{B,t}+\widetilde{h}_{B,t}\right)\right)\right]$$

subject to

$$
\begin{cases}
K_{A,t+1} & \leq & (1-\delta)\, K_{A,t} + I_{A,t} \\
K_{B,t+1} & \leq & (1-\delta)\, K_{B,t} + I_{B,t} \\
X_{A,t} & \leq & \widetilde{\Theta}_{A,t} \widetilde{K}_{A}^{1-\alpha_X}\, \widetilde{H}_{A,t}^{\alpha_X} \\
X_{B,t} & \leq & \widetilde{\Theta}_{B,t} \widetilde{K}_{B}^{1-\alpha_X}\, \widetilde{H}_{B,t}^{\alpha_X} \\
Z_{A,t} & \leq & \left[ a \left( \Theta_{A,t} H_{A,t}^{\varphi} \right)^{\nu} + K_{A,t}^{\nu} \right]^{\frac{1}{\nu}} \\
Z_{B,t} & \leq & \left[ a \left( \Theta_{B,t} H_{B,t}^{\varphi} \right)^{\nu} + K_{B,t}^{\nu} \right]^{\frac{1}{\nu}} \\
Z_{A,t} & \geq & Z_{AA,t} + Z_{AB,t} \\
Z_{B,t} & \geq & Z_{BA,t} + Z_{BB,t} \\
X_{A,t} & \geq & X_{AA,t} + X_{AB,t} \\
X_{B,t} & \geq & X_{BA,t} + X_{BB,t} \\
C_{A,t} & \leq & \left[ b Z_{AA,t}^{\nu_C} + (1-b) Z_{BA,t}^{\nu_C} \right]^{\frac{1}{\nu_C}} \\
I_{A,t} & \leq & \left[ b X_{AA,t}^{\nu_I} + (1-b) X_{BA,t}^{\nu_I} \right]^{\frac{1}{\nu_I}} \\
C_{A,t} & = & N_A c_{A,t} \\
C_{B,t} & = & N_B c_{B,t} \\
H_{A,t} & = & N_A h_{A,t} \\
H_{B,t} & = & N_B h_{B,t} \\
\widetilde{H}_{A,t} & = & N_A \widetilde{h}_{A,t} \\
\widetilde{H}_{B,t} & = & N_B \widetilde{h}_{B,t} \\
K_{A,0} & = & K_{B,0} \text{ given,}
\end{cases}
$$

where small letters denote per capital variables.

Because the model has no analytical solution, we turn to numerical analysis.

### 3.1.2 Numerical Responses

We calibrate parameters to match the following steady-state values. Consumption to output ratio is 80% in each country, ... [TO BE COMPLETED].

We choose low elasticity of substitution between domestic and foreign intermediate goods (0.25), and also low elasticity between capital and labor in the production of the consumption specific intermediate goods (0.2).

The stochastic processes of the shocks are specified as follow. In order to obtain a well behaved balanced growth path, we need the technological levels $\theta_A$, $\theta_B$, $\widetilde{\theta}_A$ and $\widetilde{\theta}_B$ to be stationary of to cointegrate. If we assume that they are non-stationary, we then need to specify the speed of convergence to the cointegrating relation. If the speed of convergence is high, then a local technological increase in one sector is also a news about technological increase in the other sector and int he two sectors abroad. In order to make a clear distinction between local and global news, we proceed as follow. Technology is assumed to be constant in the investment specific intermediate good sector ($\widetilde{\theta}_{A,t} = \widetilde{\theta}_{B,t} = \widetilde{\theta}$), while it is stationary but very persistent in the consumption specific intermediate good sector of the two

Table 1: Parameters Values

| | | |
|---|---|---|
| $a$ | : | .01 |
| $b$ | : | .8 |
| $\phi$ | : | .6 |
| $\nu$ | : | -3.78 |
| $\nu_C$ | : | -3 |
| $\nu_I$ | : | -3 |
| $\alpha_X$ | : | .97 |
| $\chi$ | : | .1225 |
| $\delta$ | : | .05 |
| $\beta$ | : | .999 |
| $\theta$ | : | 1 |
| $\widetilde{\theta}$ | : | 3 |

countries:

$$\theta_{A,t} = (\theta_{A,t-1})^{\rho} + e^{\varepsilon_{A,t}} \tag{23}$$

$$\theta_{B,t} = (\theta_{B,t-1})^{\rho} + e^{\varepsilon_{B,t}} \tag{24}$$

with $\rho = .99$. Finally, we assume that agents receive perfectly informative news about future increases in technology one to four quarters ahead:

$$\varepsilon_{A,t} = \varepsilon^0_{A,t} + \varepsilon^1_{A,t-1} + \varepsilon^2_{A,t-2} + \varepsilon^3_{A,t-3} + \varepsilon^4_{A,t-4} \tag{25}$$

$$\varepsilon_{B,t} = \varepsilon^0_{B,t} + \varepsilon^1_{B,t-1} + \varepsilon^2_{B,t-2} + \varepsilon^3_{B,t-3} + \varepsilon^4_{B,t-4} \tag{26}$$

Those shocks are assumed to be i.i.d., gaussian, with mean zero and variance $\sigma^2$.

Figure 10 displays the response of the economy to a news shock in country $A$ four periods ahead (shock $\varepsilon^4_{A,t-4}$). The model does create NBC and IBC during the interim period and after the shock, except for hours who decrease in country $A$ when the shock to TFP $A$ is implemented.

#### 3.1.3 Simulation and VAR Estimation

Here we simulate $x$ times the model over 200 periods, and report the average (over 1000 replications) estimated IRF to a news shock to country $A$, this shock being identified according to the method presented in section 1. We set the variance of the ten innovations such that the HP-filtered variance of output is 1.70% ($\sigma = .67\%$).

The estimated IRF are qualitatively similar to the one we obtained in the data.

# Conclusion

[TO BE WRITTEN]

Figure 10: Pigou Model, Response to a Technological News in Country A

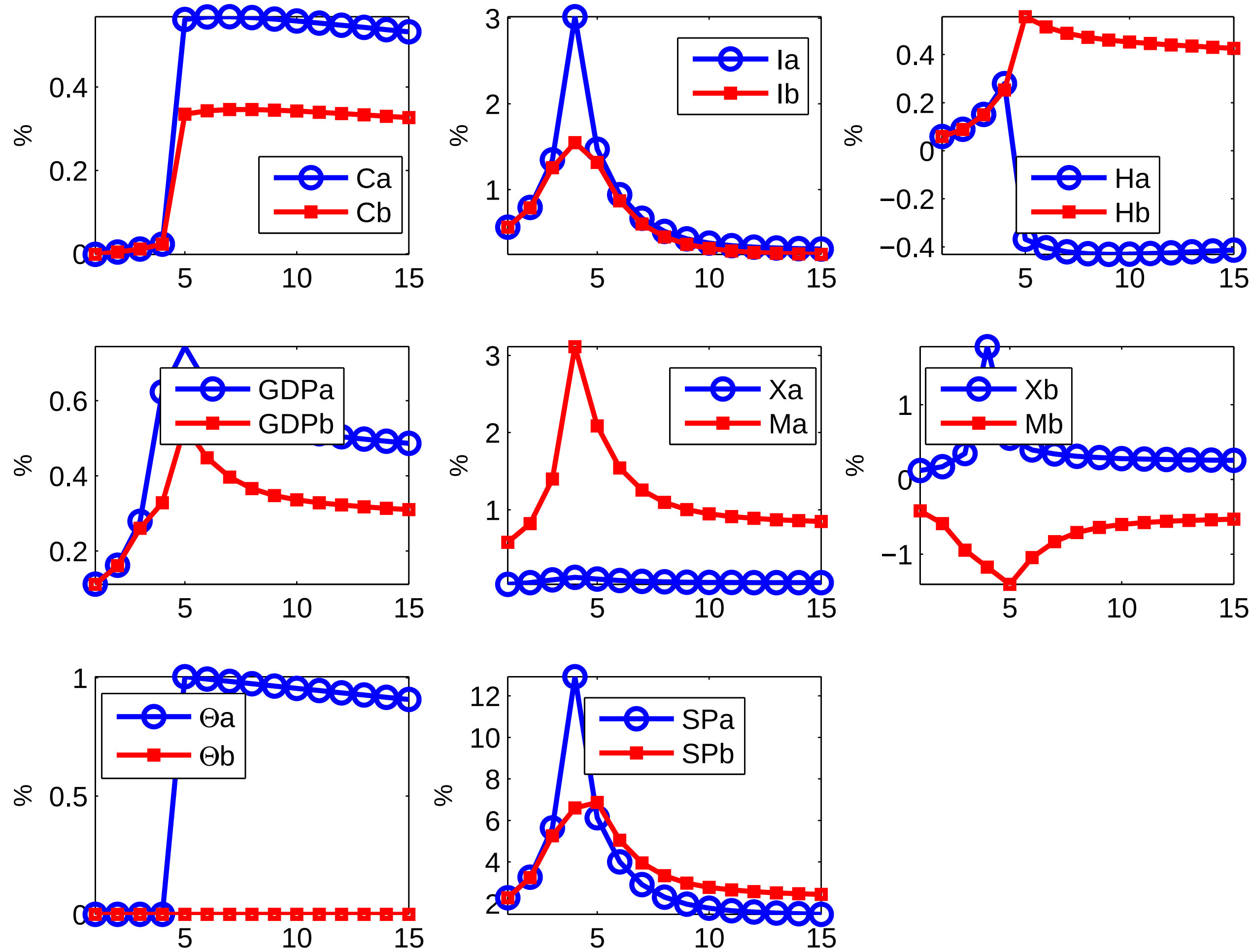



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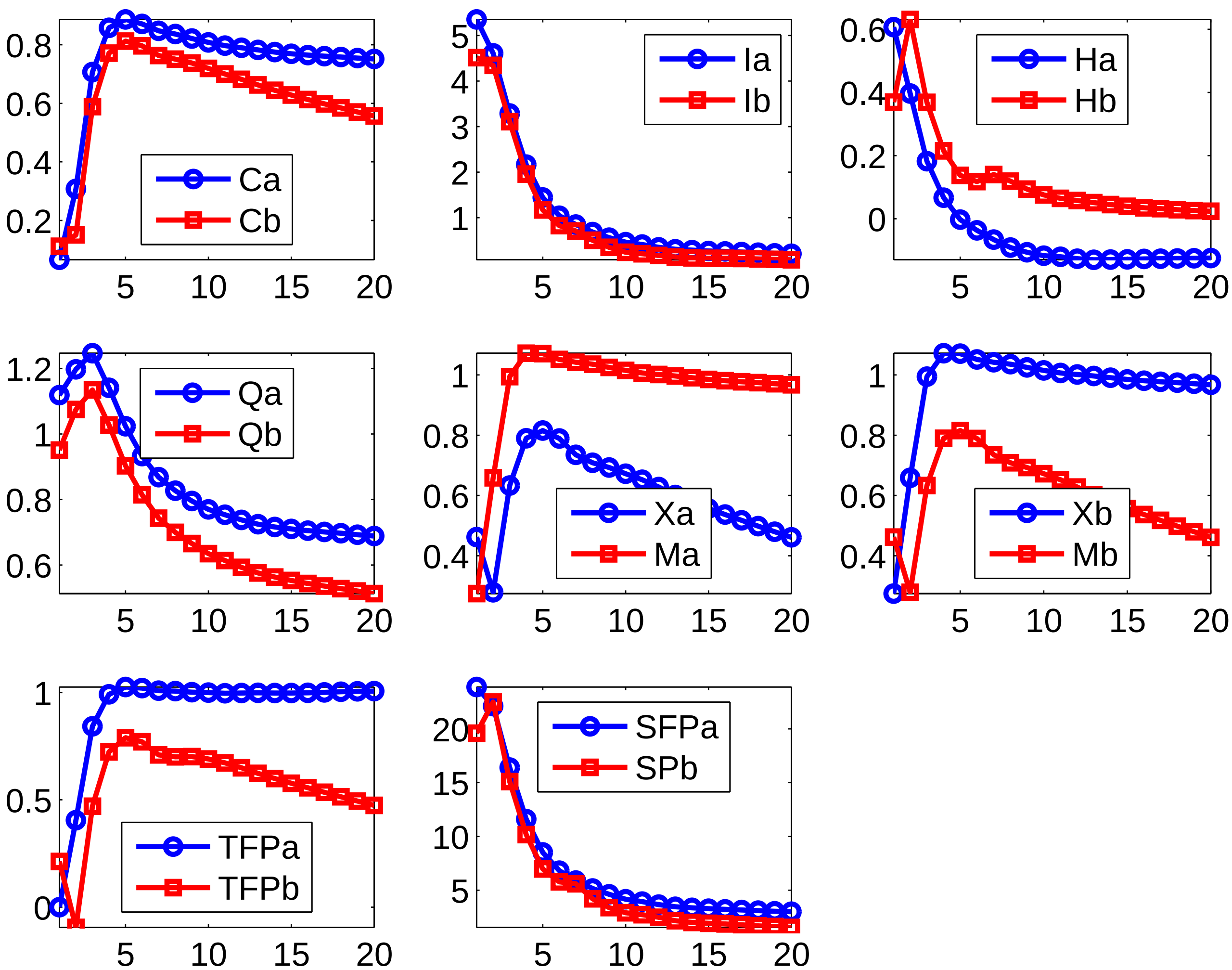
Figure 11: Response to a Country $A$ Identified News Shock

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# A Data appendix

## A.1 TFP and Stock Market Capitalization

We use existing data from the previous study of Beaudry and Portier [2006] and Haertel and Lucke [2007].

## A.2 Macroeconomic Aggregates

Nominal GDP, private consumption, investment (gross fixed capital formation), exports and imports of goods and service – as well as their deflators – are from OECD's Quarterly National Accounts dataset. We use Civilian Employment data from OECD's Labor Force Statistics. Finally, all variables are expressed per capita using the population aged 15 to 64.

The following computations were performed:

**Austria**

The dataset with benchmark year 2000 is available from 1988Q1 on. From 1964Q1 to 1987Q4, Quarterly National Accounts were retropolated from data in base 1983, after X-11 seasonal adjustment.

**France**

The dataset with benchmark year 2000 is available from 1978Q1 on. From 1970Q1 to 1977Q4, Quarterly National Accounts were retropolated from data in base 1980.

**Germany**

German macroeconomic aggregates refer to West Germany (BRD) from 1970Q1 to 1990Q4, and to unified Germany from 1991Q1 onwards. The benchmark year for West German deflator is 1991, while that for unified German deflator is 2000.

**Italy**

The dataset with benchmark year 2000 is available from 1980Q1 (or 1980Q4) on. From 1970Q1 to 1979Q4 (or 1980Q3), Quarterly National Accounts were retropolated from data in base 1995.

# B Responses of French, British and Italian Aggregates to a German News Shock

# C Specification Tests

## C.1 Lag selection

Figure 12: Response of French Aggregates to a News on German TFP

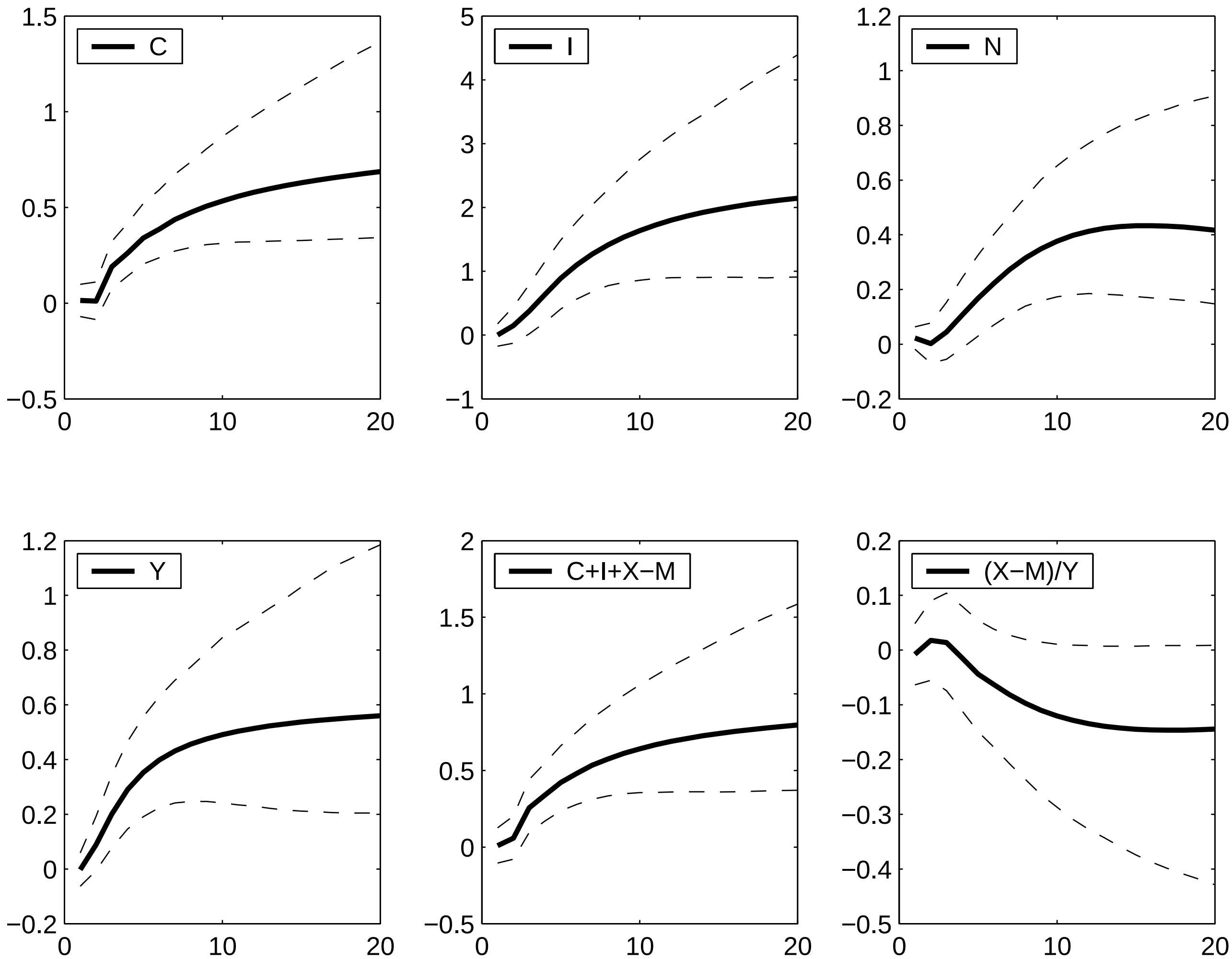


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Figure 13: Response of Italian Aggregates to a News on German TFP

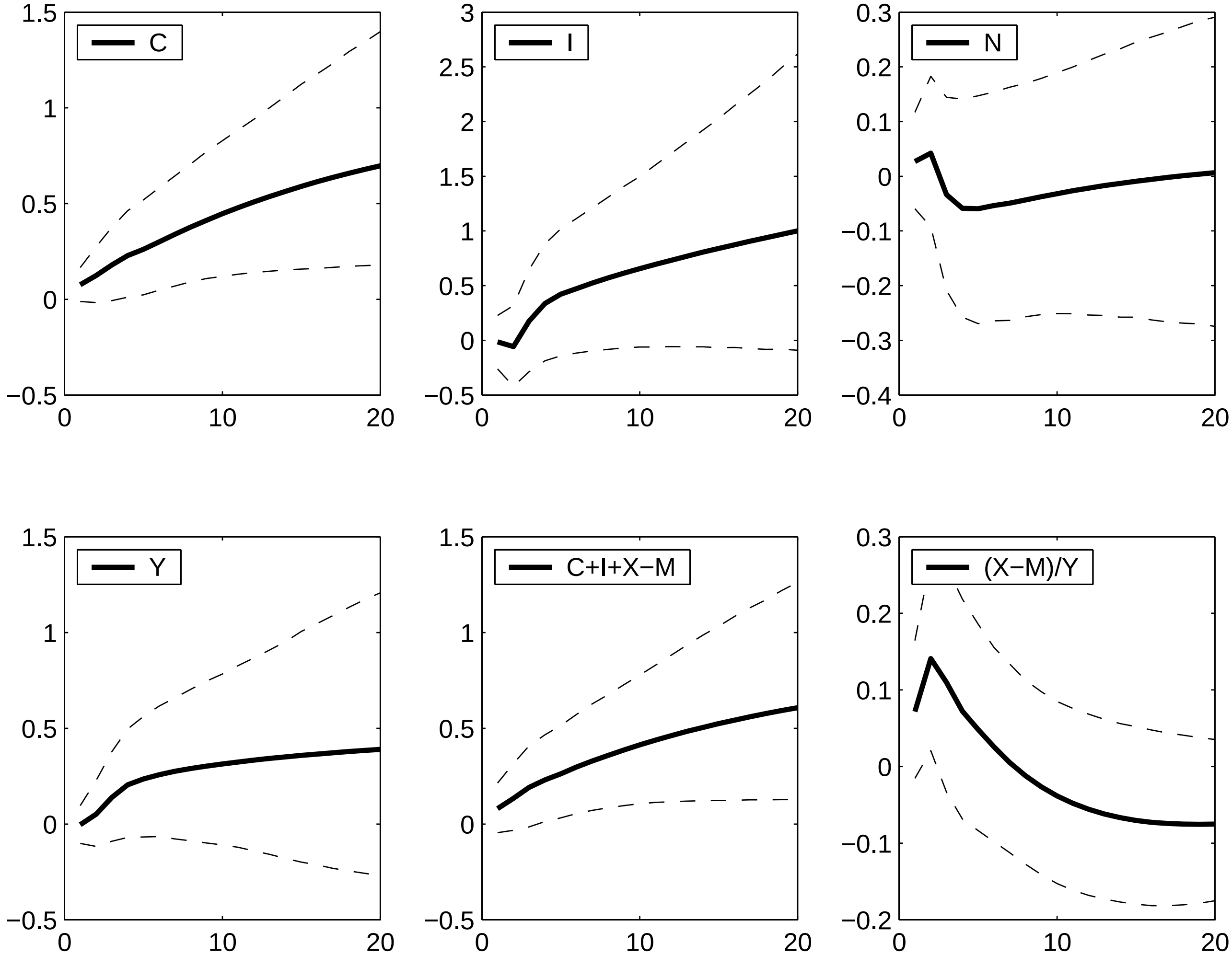


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Figure 14: Response of British Aggregates to a News on German TFP

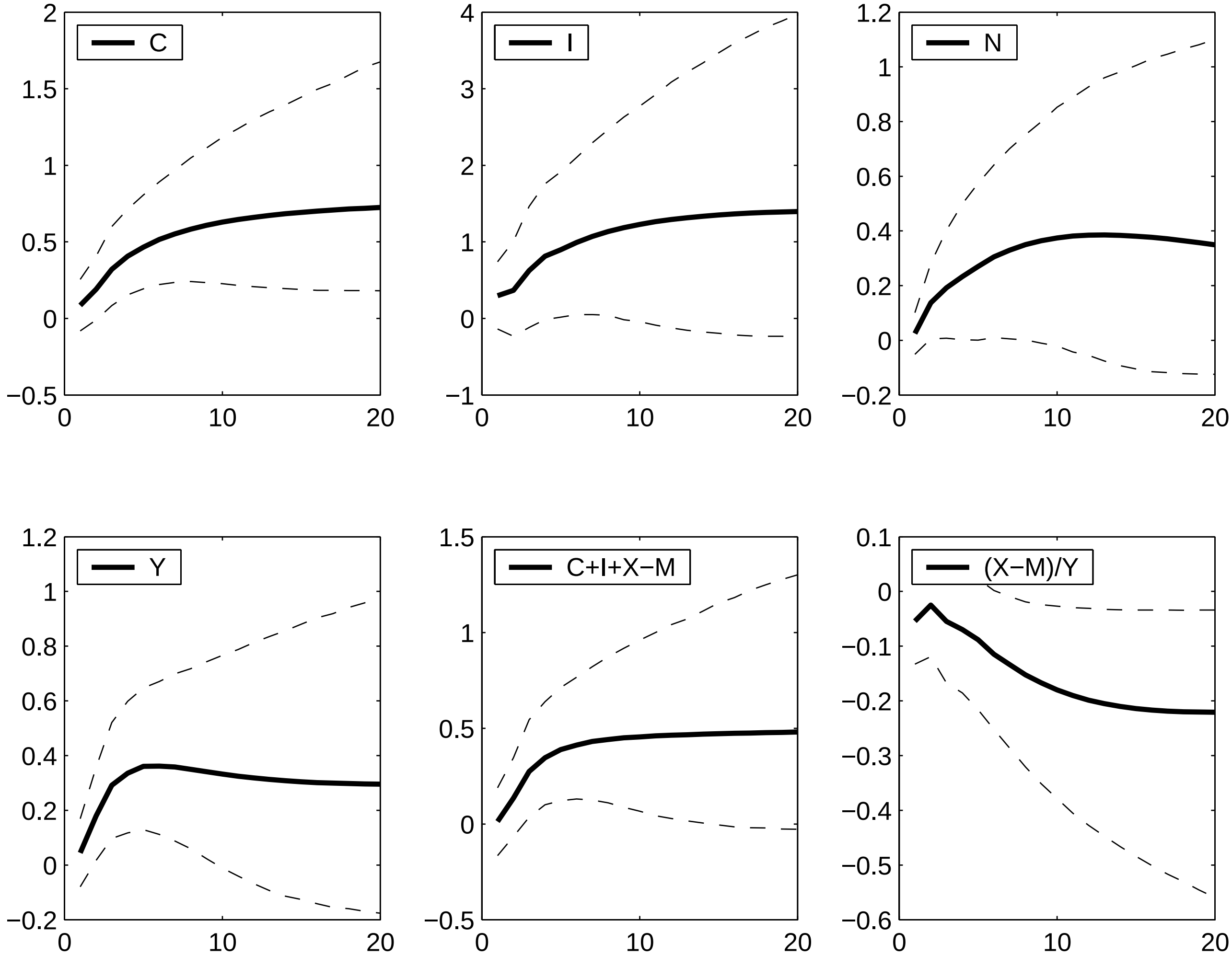


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Table 2: Likelihood ratio tests: USA

8 lags vs 7

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 8.5474 | 15.0146 | 8.5885 | 8.7334 | 14.0734 | 13.6952 | 14.9253 |
| P–value | 0.71319 | 0.96419 | 0.71643 | 0.72763 | 0.95011 | 0.94312 | 0.96303 |

7 lags vs 6

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 12.0338 | 9.6264 | 11.3427 | 13.2764 | 10.3903 | 14.4147 | 18.0398 |
| P–value | 0.90055 | 0.78925 | 0.87565 | 0.93435 | 0.83249 | 0.95572 | 0.98821 |

6 lags vs 5

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 5.7286 | 10.0245 | 2.6826 | 4.5211 | 3.5118 | 2.1245 | 5.0356 |
| P–value | 0.42823 | 0.81281 | 0.08727 | 0.28182 | 0.16603 | 0.04737 | 0.34438 |

5 lags vs 4

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 8.3021 | 16.142 | 15.2615 | 23.5336 | 10.8624 | 12.1478 | 12.109 |
| P–value | 0.69329 | 0.97615 | 0.96721 | 0.99862 | 0.85527 | 0.9042 | 0.90297 |

4 lags vs 3

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 24.7234 | 8.84 | 21.2122 | 21.9068 | 17.0869 | 12.0456 | 14.5258 |
| P–value | 0.99915 | 0.73565 | 0.99653 | 0.99736 | 0.98316 | 0.90093 | 0.95742 |

3 lags vs 2

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 17.6162 | 23.0886 | 12.6372 | 14.3227 | 25.208 | 19.5195 | 18.8919 |
| P–value | 0.98617 | 0.99835 | 0.91854 | 0.95427 | 0.9993 | 0.99329 | 0.99147 |

2 lags vs 1

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 16.9296 | 32.2351 | 47.1627 | 10.8436 | 17.984 | 50.6131 | 12.8623 |
| P–value | 0.98214 | 0.99996 | 1 | 0.85441 | 0.98796 | 1 | 0.92447 |

Table 3: Likelihood ratio tests: Canada

8 lags vs 7

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 8.8891 | 12.2925 | 11.5576 | 8.5796 | 7.0376 | 9.5535 | 8.6808 |
| P–value | 0.73929 | 0.90866 | 0.88392 | 0.71573 | 0.57503 | 0.78468 | 0.72361 |

7 lags vs 6

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 8.0201 | 12.0466 | 21.5154 | 13.9785 | 11.7958 | 15.5844 | 11.1595 |
| P–value | 0.66917 | 0.90096 | 0.99692 | 0.94843 | 0.89252 | 0.9708 | 0.86819 |

6 lags vs 5

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 12.0388 | 10.318 | 17.0043 | 5.086 | 10.6972 | 7.6878 | 9.5969 |
| P–value | 0.90071 | 0.82874 | 0.98263 | 0.35053 | 0.84762 | 0.63907 | 0.78741 |

5 lags vs 4

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 6.3024 | 10.1374 | 13.6124 | 13.696 | 9.5594 | 7.7833 | 13.0433 |
| P–value | 0.49508 | 0.81908 | 0.94148 | 0.94314 | 0.78506 | 0.64791 | 0.92894 |

4 lags vs 3

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 17.7985 | 9.8393 | 10.7203 | 15.94 | 14.8258 | 17.9145 | 18.8657 |
| P–value | 0.98709 | 0.80214 | 0.84871 | 0.97433 | 0.9617 | 0.98764 | 0.99138 |

3 lags vs 2

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 13.0461 | 9.0206 | 6.869 | 6.9005 | 6.8677 | 8.6066 | 6.1423 |
| P–value | 0.92901 | 0.74882 | 0.55735 | 0.56069 | 0.55721 | 0.71785 | 0.47677 |

2 lags vs 1

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 8.0433 | 21.4463 | 57.3324 | 5.2533 | 6.1312 | 25.1914 | 11.1486 |
| P–value | 0.67121 | 0.99684 | 1 | 0.37092 | 0.47548 | 0.9993 | 0.86773 |

Table 4: Likelihood ratio tests: Germany

8 lags vs 7

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 11.8404 | 15.3391 | 8.9847 | 11.6631 | 12.8086 | 11.8635 | 10.1297 |
| P–value | 0.89407 | 0.96811 | 0.74624 | 0.8878 | 0.92309 | 0.89486 | 0.81866 |

7 lags vs 6

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 3.9669 | 3.5016 | 4.7219 | 5.6902 | 4.8738 | 4.2277 | 3.5014 |
| P–value | 0.21641 | 0.16495 | 0.30614 | 0.42364 | 0.32464 | 0.2468 | 0.16493 |

6 lags vs 5

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 4.7173 | 4.3157 | 2.5973 | 3.4269 | 4.3062 | 3.2396 | 3.0307 |
| P–value | 0.30558 | 0.25722 | 0.080404 | 0.15709 | 0.25609 | 0.13802 | 0.11785 |

5 lags vs 4

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 0.23869 | 5.8078 | 3.6735 | 7.6747 | 3.0995 | 1.0138 | 4.9403 |
| P–value | 4.6023e-005 | 0.43763 | 0.18348 | 0.63785 | 0.12435 | 0.0053974 | 0.33275 |

4 lags vs 3

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 14.0117 | 13.8576 | 17.7322 | 16.7225 | 14.6647 | 15.6226 | 15.6444 |
| P–value | 0.94903 | 0.94623 | 0.98676 | 0.98072 | 0.95945 | 0.9712 | 0.97143 |

3 lags vs 2

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 3.764 | 7.465 | 6.0353 | 3.8544 | 7.4533 | 5.8245 | 3.8513 |
| P–value | 0.19348 | 0.61788 | 0.46437 | 0.20362 | 0.61674 | 0.43961 | 0.20326 |

2 lags vs 1

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 22.4699 | 15.7654 | 13.2594 | 14.1527 | 21.7987 | 23.9257 | 21.3879 |
| P–value | 0.99789 | 0.97265 | 0.93396 | 0.95147 | 0.99725 | 0.99883 | 0.99676 |

Table 5: Likelihood ratio tests: Austria

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8 lags vs 7 | | | | | | | |
| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
| stat | 9.3323 | 12.0713 | 11.0632 | 11.6413 | 11.4834 | 12.119 | 12.4931 |
| P–value | 0.77033 | 0.90176 | 0.86411 | 0.88701 | 0.88112 | 0.90329 | 0.91453 |
| 7 lags vs 6 | | | | | | | |
| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
| stat | 6.2079 | 7.6037 | 6.332 | 5.7691 | 5.71 | 21.8898 | 20.9247 |
| P–value | 0.48431 | 0.63117 | 0.49843 | 0.43305 | 0.42601 | 0.99735 | 0.99612 |
| 6 lags vs 5 | | | | | | | |
| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
| stat | 3.1666 | 3.6375 | 4.5987 | 11.1277 | 6.6118 | 3.1106 | 4.1154 |
| P–value | 0.13082 | 0.17954 | 0.291191 | 0.86685 | 0.52962 | 0.12541 | 0.2336 |
| 5 lags vs 4 | | | | | | | |
| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
| stat | 11.1247 | 7.7968 | 12.3595 | 6.2892 | 16.7054 | 14.398 | 18.6419 |
| P–value | 0.86673 | 0.64915 | 0.91066 | 0.49359 | 0.9806 | 0.95546 | 0.99061 |
| 4 lags vs 3 | | | | | | | |
| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
| stat | 336.3719 | 341.6659 | 335.5568 | 338.301 | 335.5894 | 342.2159 | 340.5745 |
| P–value | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 lags vs 2 | | | | | | | |
| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
| stat | 159.5907 | 161.3544 | 173.4376 | 155.954 | 160.1247 | 165.3326 | 154.6764 |
| P–value | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 lags vs 1 | | | | | | | |
| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
| stat | 56.4616 | 43.4968 | 77.1545 | 45.927 | 51.1864 | 36.6638 | 42.2941 |
| P–value | 1 | 1 | 1 | 1 | 1 | 0.99999 | 1 |

Table 6: Likelihood ratio tests: France

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8 lags vs 7 | | | | | | | |
| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
| stat | 8.7031 | 3.1667 | 7.9437 | 4.2572 | 5.4731 | 6.7992 | 10.4925 |
| P–value | 0.72532 | 0.13084 | 0.66242 | 0.25028 | 0.39757 | 0.54992 | 0.83766 |
| 7 lags vs 6 | | | | | | | |
| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
| stat | 15.0786 | 9.1756 | 6.9438 | 8.5206 | 6.1713 | 10.4344 | 7.8598 |
| P–value | 0.96499 | 0.7597 | 0.56524 | 0.71107 | 0.4801 | 0.83473 | 0.65488 |
| 6 lags vs 5 | | | | | | | |
| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
| stat | 8.9157 | 15.5924 | 4.9405 | 8.6082 | 7.8918 | 7.6724 | 7.522 |
| P–value | 0.74124 | 0.97089 | 0.33278 | 0.71798 | 0.65777 | 0.63764 | 0.62338 |
| 5 lags vs 4 | | | | | | | |
| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
| stat | 8.1446 | 8.549 | 4.6358 | 3.4615 | 3.8826 | 4.2436 | 2.5224 |
| P–value | 0.67998 | 0.71332 | 0.29569 | 0.16071 | 0.2068 | 0.24867 | 0.074603 |
| 4 lags vs 3 | | | | | | | |
| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
| stat | 9.6662 | 6.8084 | 3.8457 | 8.1015 | 7.0208 | 3.1491 | 5.7627 |
| P–value | 0.79171 | 0.5509 | 0.20263 | 0.67628 | 0.57329 | 0.12912 | 0.43228 |
| 3 lags vs 2 | | | | | | | |
| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
| stat | 7.6561 | 8.3055 | 18.8273 | 5.6263 | 5.7843 | 16.896 | 12.1477 |
| P–value | 0.63611 | 0.69357 | 0.99125 | 0.416 | 0.43485 | 0.98192 | 0.90419 |
| 2 lags vs 1 | | | | | | | |
| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
| stat | 28.482 | 26.4979 | 44.0114 | 16.6724 | 21.0141 | 21.6489 | 15.5898 |
| P–value | 0.99982 | 0.99959 | 1 | 0.98036 | 0.99625 | 0.99708 | 0.97086 |

Table 7: Likelihood ratio tests: United Kingdom

8 lags vs 7

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 6.3161 | 8.7819 | 4.2762 | 2.9904 | 4.4907 | 17.0101 | 11.7925 |
| P–value | 0.49664 | 0.73131 | 0.25253 | 0.11411 | 0.27816 | 0.98267 | 0.89241 |

7 lags vs 6

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 10.9724 | 8.0201 | 5.8365 | 7.449 | 6.3316 | 7.2248 | 6.4166 |
| P–value | 0.86017 | 0.66917 | 0.44104 | 0.61632 | 0.49839 | 0.59415 | 0.50797 |

6 lags vs 5

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 30.2135 | 9.509 | 5.2976 | 5.4005 | 17.4726 | 29.164 | 21.6014 |
| P–value | 0.99991 | 0.78185 | 0.37631 | 0.38879 | 0.98541 | 0.99986 | 0.99703 |

5 lags vs 4

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 35.1462 | 13.6701 | 3.3263 | 10.3559 | 35.5067 | 30.9886 | 19.1051 |
| P–value | 0.99999 | 0.94263 | 0.14674 | 0.83072 | 0.99999 | 0.99994 | 0.99214 |

4 lags vs 3

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 17.4377 | 8.8731 | 9.3461 | 21.7745 | 20.0395 | 14.5859 | 10.8825 |
| P–value | 0.98522 | 0.7381 | 0.77125 | 0.99722 | 0.99451 | 0.95831 | 0.85617 |

3 lags vs 2

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 2.2649 | 6.6832 | 3.85923 | 8.4993 | 1.7874 | 15.4202 | 4.0383 |
| P–value | 0.056264 | 0.5374 | 0.20412 | 0.70937 | 0.029337 | 0.96903 | 0.22464 |

2 lags vs 1

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 16.908 | 13.5142 | 46.9483 | 27.0211 | 26.5392 | 14.8017 | 17.8863 |
| P–value | 0.982 | 0.93947 | 1 | 0.99967 | 0.9996 | 0.96137 | 0.98751 |

Table 8: Likelihood ratio tests: Italy

8 lags vs 7

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 14.2316 | 12.1233 | 15.6094 | 15.6681 | 13.5013 | 8.8622 | 13.1812 |
| P–value | 0.95279 | 0.90342 | 0.97107 | 0.97167 | 0.9392 | 0.7373 | 0.93218 |

7 lags vs 6

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 7.3941 | 5.9136 | 17.4184 | 10.0674 | 4.7271 | 5.8707 | 9.517 |
| P–value | 0.61097 | 0.45013 | 0.98511 | 0.81521 | 0.30678 | 0.44507 | 0.78236 |

6 lags vs 5

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 3.7017 | 6.1479 | 21.5147 | 4.1742 | 5.6321 | 7.3261 | 9.0415 |
| P–value | 0.18658 | 0.47741 | 0.996929 | 0.2405 | 0.4167 | 0.60427 | 0.75031 |

5 lags vs 4

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 5.1021 | 5.2934 | 1.7456 | -0.38949 | -1.1297 | 5.3761 | 5.5523 |
| P–value | 0.3525 | 0.37579 | 0.02743 | NA | NA | 0.38583 | 0.40712 |

4 lags vs 3

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 14.3519 | 13.2452 | 31.6656 | 12.8714 | 13.3924 | 16.1936 | 17.8659 |
| P–value | 0.95473 | 0.93364 | 0.99995 | 0.9247 | 0.9369 | 0.97659 | 0.98741 |

3 lags vs 2

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 8.0981 | 1.8867 | 4.079 | 4.713 | 3.7022 | 6.1262 | 5.7432 |
| P–value | 0.67598 | 0.034153 | 0.22937 | 0.30505 | 0.18663 | 0.47491 | 0.42996 |

2 lags vs 1

| variable | C | I | N | (X-M)/Y | C+I+X-M | Y | Y/N |
|---|---|---|---|---|---|---|---|
| stat | 21.7299 | 11.5219 | 13.0745 | 8.907 | 9.8639 | 32.6904 | 18.7441 |
| P–value | 0.99717 | 0.88258 | 0.92969 | 0.7406 | 0.80358 | 0.99997 | 0.99097 |