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# Hours Worked and Permanent Technology Shocks in Open Economies

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## Abstract

We use Structural Vector Autoregressions to study the impact of technology improvements on hours worked in the major seven countries. While previous studies estimate the response of labor input to permanent shocks to country-level labor productivity, we consider the response of labor input to aggregate-level labor productivity. Since labor productivities do cointegrate in the G7, the estimated responses should look very similar. They do not: for each country but Germany, the responses estimated using G7 labor productivity sizeably exceed those estimated using country-level labor productivity. These results also hold in larger SVAR models.

**Keywords:** Technology shocks, Hours Worked, Vector Autoregressions, Open Economies.

*JEL* classification: C32, E32, F41.

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# Introduction

This paper uses Structural Vector Autoregressions (SVAR) to assess the short run effects of technology shocks on hours worked in the major seven countries. It provides a contribution to the lively debate about the effect of productivity improvements on labor input in an open economy setup.

The challenging task in measuring the effects on inputs (including labor) of technology shocks is to measure technology itself. The conceptual object with which macroeconomists describe technology is the aggregate production function, the empirical counterpart of which is not observable. Under constant returns to scale, permanent labor-augmenting improvements in technology can however be identified. Because Harrod-neutral permanent technology shocks do not eventually affect the optimal mix of inputs, the long-run movements in average labor productivity, which are observable, reveal those of technology. Galí [1999], Galí and Rabanal [2004] and Francis and Ramey [2005] endorse this identifying scheme to measure the effects of permanent shocks to productivity with a Structural Vectorial Auto-Regressive (SVAR) model, using a long-run restriction *à la* Blanchard and Quah [1989]. These studies conclude that such technology shocks drive labor input down during several quarters in most industrialized countries. This finding contradicts standard flexible-price models, but favours sticky-price models in which output is demand-determined in the short-run.<sup>1</sup>

In this paper, we argue that the international transmission of shocks first prevents the SVAR used in the existing literature to accurately identify permanent shocks to technology, but, second, provides alternative identifying restrictions.

Our first claim is that evaluations carried over using SVAR on country-level data are not informative. Using annual growth rates of labor productivity and per capita hours worked for the period 1972–2004, we show that the sign of the measured short-run response of hours worked to permanent technology shocks depends on the aggregation level. Precisely, the following three observations are inconsistent with each other: *i*) SVAR evaluations carried out with single-country data suggest that hours worked do not increase in any of the seven G7 countries.<sup>2</sup> *ii*) an evaluation with G7 aggregate data (*i.e.* total G7 hours worked and average productivity of labor) reveals a sizeable increase in G7 hours worked. *iii*) labor productivities of the major seven country cointegrate, meaning that the permanent technology shock is

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<sup>1</sup>Accepting this interpretation, Collard and Dellas [2007] and Francis and Ramey [2005], among others, specify flexible-price models able to reproduce a fall in hours following a technology shock.

<sup>2</sup>Our results are similar to those obtained by Galí [2005].

common to the G7 countries.<sup>3</sup> Since hours worked do not increase in any G7 country after a common permanent shock, it should therefore not do so at the G7 level. If the SVAR properly uncovered the responses to a permanent productivity shocks, we would obtain the same results with country-level and aggregate-level data. We label the discrepancy between the response of hours worked evaluated at the country and G7 level an *aggregation puzzle*. We interpret this puzzle as a consequence of identification errors at the country level which disappear once data are aggregated.

Our results are related to those in Chari, Kehoe and McGrattan [2008], Erceg, Guerrieri and Gust [2005] and Dupaigne, Fève and Matheron [2007]. These papers show through closed-economy structural models that preference and fiscal shocks disturb the identification of permanent technology shocks. Their common intuition is that, under decreasing returns to labor input, every shock with long-lasting detrimental effects on labor input stimulates average labor productivity, even in the medium-run. Such shocks contaminate the estimated response of labor input to permanent productivity shocks. Quantitatively, such distortions appear to be large enough to reverse the sign of the employment response for DGPs mimicking different statistics of US data. We extend these analysis to a multi-country setup.

In an international context, foreign non-permanent shocks also induce the contamination of permanent technology shocks. To see this, let us consider a simple two-country model *à la* Baxter and Crucini [1993] with a world permanent shock and country-specific stationary shocks.<sup>4</sup> A shock that temporarily increases the productivity of the domestic country shifts down the labor input in the foreign country, because the positive wealth effect (due to asset portfolio diversification) leads households to reduce their labor supply. The drop in hours worked raises productivity in those countries as long as capital is not fully reallocated to the most productive economy. Hence, the average productivity of labor in any country does not only reflect its own shocks, but also those of its neighbors. SVARs models cannot therefore accurately identify permanent technology shocks from country-level data because of the international transmission of shocks.

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<sup>3</sup>A large number of papers, including Stock and Watson [2005], Canova, Ciccarelli and Ortega [2007] and Kose, Otrok and Whiteman [2008], establish the large contribution of world shocks to aggregate fluctuations. Moreover, Rabanal, Rubio-Ramírez and Tuesta [2008] have shown that Total Factor Productivity (TFP) cointegrates among major industrialized countries and thus favored the relevance of a world permanent technology shocks.

<sup>4</sup>In Dupaigne and Fève [2009], we estimate and simulate a two-country DSGE model with a permanent world technology shock and stationary country-specific technology and preference shocks. We obtain that country-level SVAR models lead to biased estimation of the true permanent technology shock. We also show that an aggregate measure of labor productivity reduces the bias when it is used instead of domestic ones in SVARs with long run restriction. See also Collard and Dellas [2007] for an open economy setup about the effect of permanent technology shocks on employment.

In a second step, we consider a novel specification of the SVAR model which accounts for open economy mechanisms. We replace country-level labor productivity (the variable supporting the identifying restriction) by a variable which is as little contaminated as possible by persistent shocks. The measure of productivity we use is the average G7 labor productivity, which aggregates each domestic labor productivity of the seven countries. Aggregation potentially offsets the country-level stationary shocks which contaminate country-level data. Indeed, when we use the G7 labor productivity instead of country-level labor productivities, almost no discrepancy between the responses of hours evaluated at the country and G7 level remains. Our findings also hold in larger SVAR models.<sup>5</sup>

The paper is organized as follows. Section 1 presents the identification of permanent technology shocks using SVARs. In section 2, we discuss the short-run effects of these shocks on hours worked using country level data. Section 3 reports the empirical findings when we mix aggregate and country-level data. Section 4 documents the robustness of our empirical findings and the last section concludes.

## 1 Identification of permanent technology shocks

To identify technology shocks and their effects, Galí [1999] estimates a canonical vectorial autoregressive (VAR) model over the growth rates of labor productivity,  $\Delta x_t$ , and labor input,  $\Delta h_t$  (omitting the constant term without loss of generality):

$$\begin{bmatrix} \Delta x_t \\ \Delta h_t \end{bmatrix} = \mathbf{A}_1 \begin{bmatrix} \Delta x_{t-1} \\ \Delta h_{t-1} \end{bmatrix} + \dots + \mathbf{A}_p \begin{bmatrix} \Delta x_{t-p} \\ \Delta h_{t-p} \end{bmatrix} + u_t. \quad (1)$$

The error term  $u_t$  in this expression is not serially correlated and has a variance-covariance matrix  $\Omega$ .

When this VAR is invertible, the growth rates of labor productivity and labor input can be expressed as a moving average (the order of which is possibly infinite) of the innovations  $u$ :

$$\begin{bmatrix} \Delta x_t \\ \Delta h_t \end{bmatrix} = u_t + \mathbf{B}_1 u_{t-1} + \mathbf{B}_2 u_{t-2} + \dots$$

In this setup,  $\mathbf{B}_k$  measures the  $k^{\text{th}}$  period response of the endogenous variables to a unit disturbance. However, neither the disturbance  $u$  nor these responses  $\mathbf{B}_k$  can receive any structural interpretation at this point, because this vectorial moving average (VMA) representation is definitively not unique. In fact, any process

$$\mathbf{C}_0 v_t + \mathbf{C}_1 v_{t-1} + \mathbf{C}_2 v_{t-2} + \dots, \text{ with } Ev_t v_t' = \Psi.$$

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<sup>5</sup>At the quarterly frequency, only employment data are available on this sample. Our results hold on quarterly employment data (see Dupaigne and Fève [2009]).

yields the same vector of observables  $[\Delta x'_t, \Delta h'_t]$  as soon as

$$\begin{cases} \mathbf{C}_0 v_t &= u_t, \\ \mathbf{C}_j \mathbf{C}_0^{-1} &= \mathbf{B}_j, \\ \mathbf{C}_0 \Psi \mathbf{C}'_0 &= \Omega. \end{cases}$$

In a two–variables VAR, these conditions give three constraints while  $\mathbf{C}_0$  has four elements. Structural VARs use economic theory to impose the restrictions required to compute  $\mathbf{C}_0$  and to recover the structural shocks from the disturbance  $u$ .

The theoretical restriction used by Galí [1999] and Francis and Ramey [2005] is that improvements in technology raise the average productivity of labor, and that labor productivity is in the long–run only driven by such technology shocks. These properties arise in a large number of macroeconomic models, even though not in all of them.<sup>6</sup> The use of average labor productivity as a proxy for technology imposes long–run identification: in the short and medium run, the stock of physical capital also affects the average productivity of labor given technology; but shocks with permanent effects on labor productivity, *i.e.* after capital (and any potential other input) has adjusted, are technological in nature.

Using the lag operator  $L$ , the growth rates of labor productivity and labor input are written as distributed lags of two orthogonal shocks,  $\{\epsilon_t^z\}$  and  $\{\epsilon_t^m\}$  of identity variance–covariance matrix:

$$\begin{bmatrix} \Delta x_t \\ \Delta h_t \end{bmatrix} = \begin{bmatrix} C_{11}(L) & C_{12}(L) \\ C_{21}(L) & C_{22}(L) \end{bmatrix} \begin{bmatrix} \epsilon_t^z \\ \epsilon_t^m \end{bmatrix}. \quad (2)$$

The identifying restriction  $C_{12}(1) = 0$  implies that the second shock,  $\{\epsilon_t^m\}$ , does not have any long run impact on productivity. Hence, the first shock,  $\{\epsilon_t^z\}$ , is the only one having permanent effects on labor productivity, and can be interpreted as a permanent technology shock.

We use this methodology to evaluate the impact response of hours worked to the permanent technology shock in the major seven countries (United States, Canada, Japan, United Kingdom, Germany, France and Italy). As emphasized by Galí [2005], the choice between the different measures of labor input available may have some consequences on the identification of permanent technology shocks. We use hours worked rather than employment to ensure that (potential) permanent shocks to hours per worker do not have long–run effects on our measure of labor productivity. In the OECD countries, hours per worker are only available at annual frequency for relatively long homogenous time series. We use annual data on labor productivity and hours worked for the period 1972–2004 from the OECD National Accounts and Labor Force Statistics.

Hours worked are defined as the product of civilian employment and hours per employee. They

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<sup>6</sup>Endogenous growth models are obvious examples of setups in which non–technology shocks (here, any shock) have long–run effects on labor productivity. Alternatively, Uhlig [2004] emphasizes permanent changes in the capital tax rate or changing attitude towards the workplace.

are subsequently converted per capita using a measure of population over the age of 16. Labor productivity is defined as the ratio of real output per capita to hours worked.

The specification of hours worked (levels *vs* first-differences) in the VAR models is an important and controversial empirical issue (see Galí [1999], [2005] and Christiano, Eichenbaum and Vigfusson [2004]). The results of ADF unit root tests are reported in Table 1 (in appendix). They suggest that log hours are difference stationary and that the VAR model (1) underlying the VMA representation (2) is stationary. The number of lags is set to two, according to usual information criteria.

## 2 Empirical results from country level data

Model (1) is estimated for each of the major seven countries. Figure 1 displays the estimated impact responses of hours worked to the permanent productivity shock. For each country, it reports the empirical distribution of the population of impact responses (smoothed using a Gaussian kernel), its median and the two 5% tails. Figure 6, in appendix, complements Figure 1. It plots the impulse response function (IRF) at a five-year horizon and its centered 90% confidence interval obtained by standard bootstrap techniques, using 1000 draws from the sample residuals.

Figure 1 shows that the short-run response of hours worked in all countries is negligible negative. For all countries but Japan, the response of hours is persistently negative; and significantly so in five countries out of seven (Canada, UK, Germany, France and Italy). These first empirical results are obtained from each of the major seven countries separately. The OECD Statistics Directorate reports hours worked and output data for the entire G7.<sup>7</sup> We redo the previous exercise using these aggregate data instead of country-level data and we compute the IRFs of hours worked. The last panel of Figure 1 displays the distribution of impact responses of hours worked to a permanent technology shock in the G7 aggregate. At this level of aggregation, the response of hours worked is now positive (and persistently so, as shown in the last panel of Figure 6).

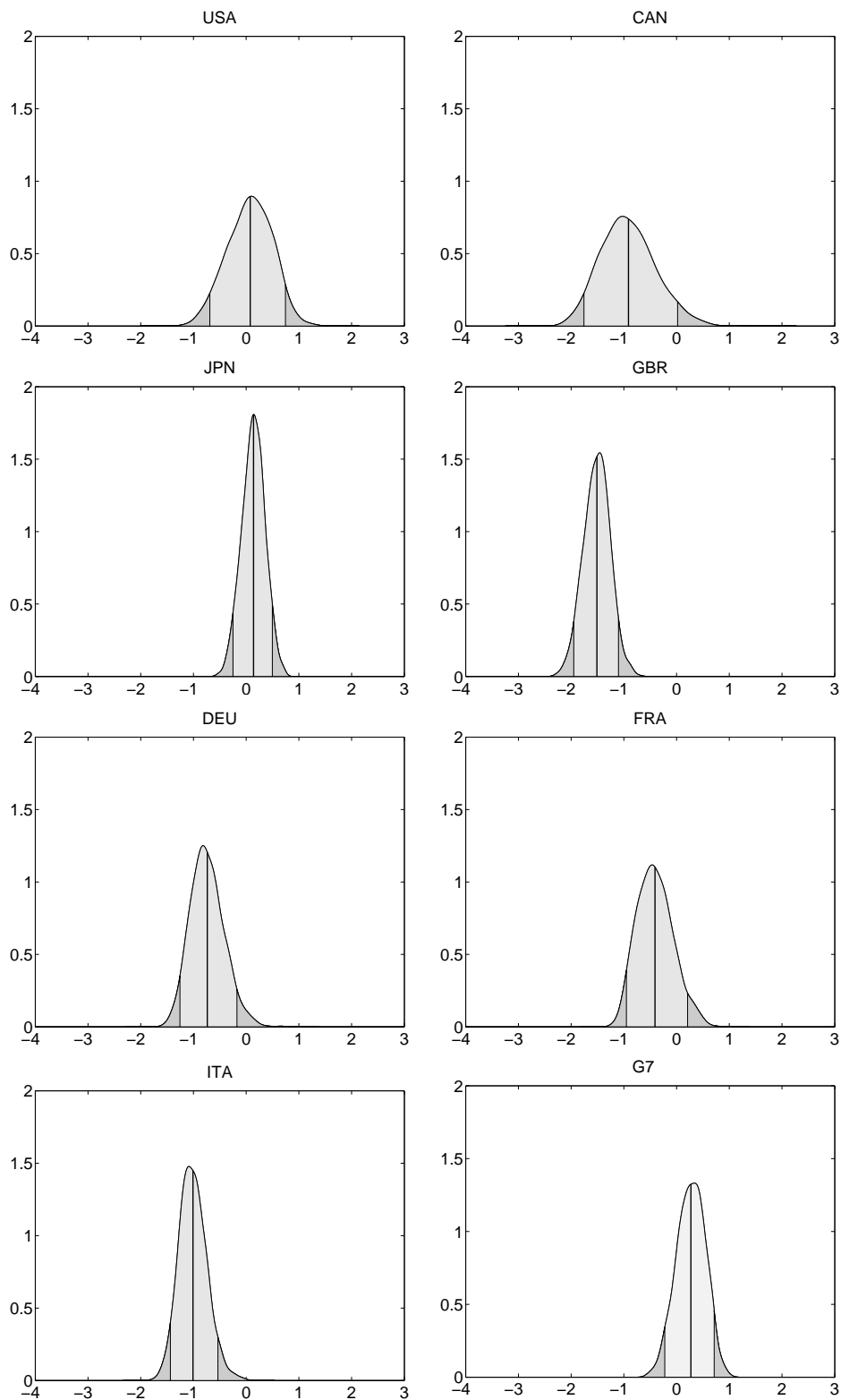
The discrepancy between estimates at the country level and at the aggregate level is exemplified by the implied response of hours for the G7 as a population-weighted sum of country-level point estimates.<sup>8</sup> This computed impact response is displayed (by squares) in the left panel of

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<sup>7</sup>Hours worked and population numbers are simply the sums of country-level data. To compute aggregate GDP, national accounts data are converted to US dollars using 1995 GDP purchasing power parities (PPPs) for constant price data and current PPPs for data in current prices.

<sup>8</sup>Country-level point estimates are weighted according to the share of each country in total population because we consider *per capita* productivity and hours worked.

Figure 1: Impact response of hours worked to a country-level permanent productivity shock

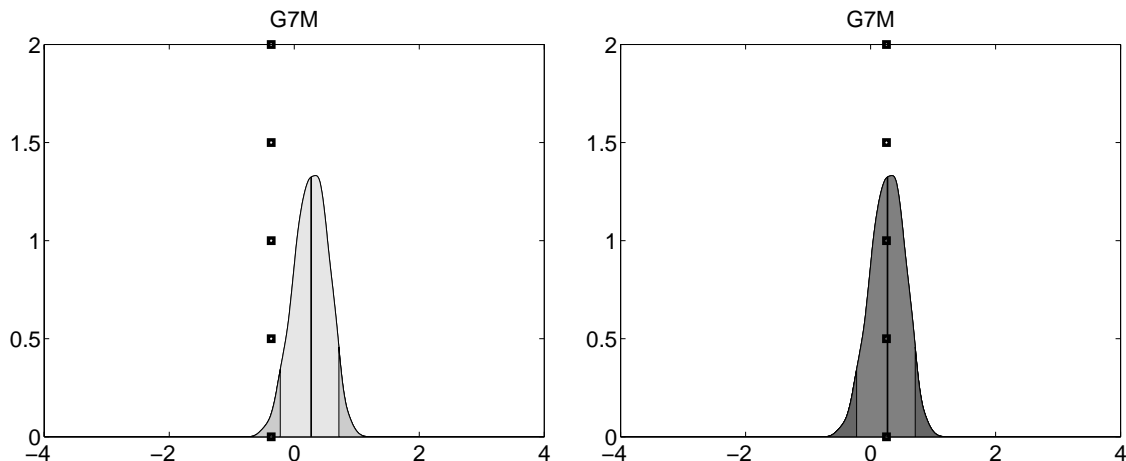


Note: These figures display the smoothed distribution of impact responses obtained by standard bootstrap techniques, using 1000 draws from the sample residuals.



Figure 2 together with the distribution estimated on aggregate data. The country-level based impact response equals -0.368, while the impact response obtained at the aggregate level is 0.254. Hence, the impact response at the aggregate level differs sharply from the country-level responses. Over time, left panel of Figure 7 shows that the weighted sum of point estimates remains negative and outside the confidence interval.

Figure 2: Impact response of G7 hours implied by country-level experiments



Note: This figure displays the impact response of G7 hours worked to technology improvement, as estimated in a VAR  $(\Delta x^{G7}, \Delta n^{G7})$ . The smoothed distribution of impact responses obtained by standard bootstrap techniques, using 1000 draws from the sample residuals. On the left panel, squares symbolize the weighted sum of hours worked response based on country-level VAR  $(\Delta x^i, \Delta n^i)$ . On the right panel, squares symbolize the weighted sum of hours worked response based on VAR  $(\Delta x^{G7}, \Delta n^i)$ .

Is a large discrepancy between these two quantitative evaluations of the aggregate effect of a technology improvement really puzzling? If the seven major countries were hit by country-specific permanent shocks which does not cointegrate, the answer is no. To see why, consider a world composed of two countries, A and B. Assume that labor productivity in A rises by 1%, triggering a 0.5% reduction in labor input. At the same time, country B experiences a 1% drop in labor productivity and a 1% increase in labor input. As soon as A is larger than B, world average labor productivity increases. If A is very large relative to B (precisely, over two-thirds of world population), world labor input falls. Below this threshold, world average labor input increases. In the latter situation, the conditional correlation between world average labor input and productivity is positive even though this conditional correlation is negative in both countries. At the opposite, if there exists a permanent and common technology shock for the major seven countries, the discrepancy is a puzzle. The common shock hypothesis can be easily tested with actual data, since it implies that labor productivities of the major seven

countries do cointegrate.

We perform cointegration tests over the seven country–level labor productivities using Johansen’s method. We estimate a Vector Error Correction Model with two lagged differences of the explanatory variables and one error correction (lagged once) term. In this procedure, variables are first demeaned.<sup>9</sup> This specification implies that all upward trending in the data has to be attributed to stochastic trends. A unique stochastic trend would receive the natural interpretation of a world permanent shock. Johansen’s test statistics are reported in Table 2 (in appendix). We find that none of the test statistics leads to reject six long–run relationships among the seven labor productivities. These tests favor the existence of a common stochastic trend.<sup>10</sup> The unique common trend in country–level labor productivities can be interpreted as a permanent world technology shock. Our findings are in accordance with Rabanal et al. [2008]. They find that a proxy of TFP cointegrates one to one among major industrialized countries.<sup>11</sup>

### 3 Results from mixing aggregate and country data

Given the previous quantitative findings, we propose in this paper another SVAR specification to assess the effect of a world technology shock. We replace each country–level labor productivity by the aggregation of country–level labor productivities to offset country–specific persistent shocks and eliminate these sources of contamination. Although imperfect in the very short–run, the observed labor productivity of the G7 zone, denoted  $x_t^{G7}$ , is a promising and available candidate in the VAR model (1). The variable  $\Delta x_t$  in equation (1) is now replaced by  $\Delta x_t^{G7}$ .

Figure 3 reports the empirical distributions of the impact response of hours (while the dynamic responses appear in Figure 8, in appendix). For each country, it displays two smoothed distributions of impact responses. The light grey one refers to VAR  $(\Delta x^i, \Delta n^i)$ , as in Figure 1. The medium grey one refers to VAR  $(\Delta x^{G7}, \Delta n^i)$ .

Figure 3 shows that the distributions of impact responses move on the right for each country but Japan. These new estimations differ significantly from those obtained with country–level data for Canada, UK, France and Italy. Contrary to the results at the country level, these estimates suggest two groups of countries regarding the impact of technology improvements on

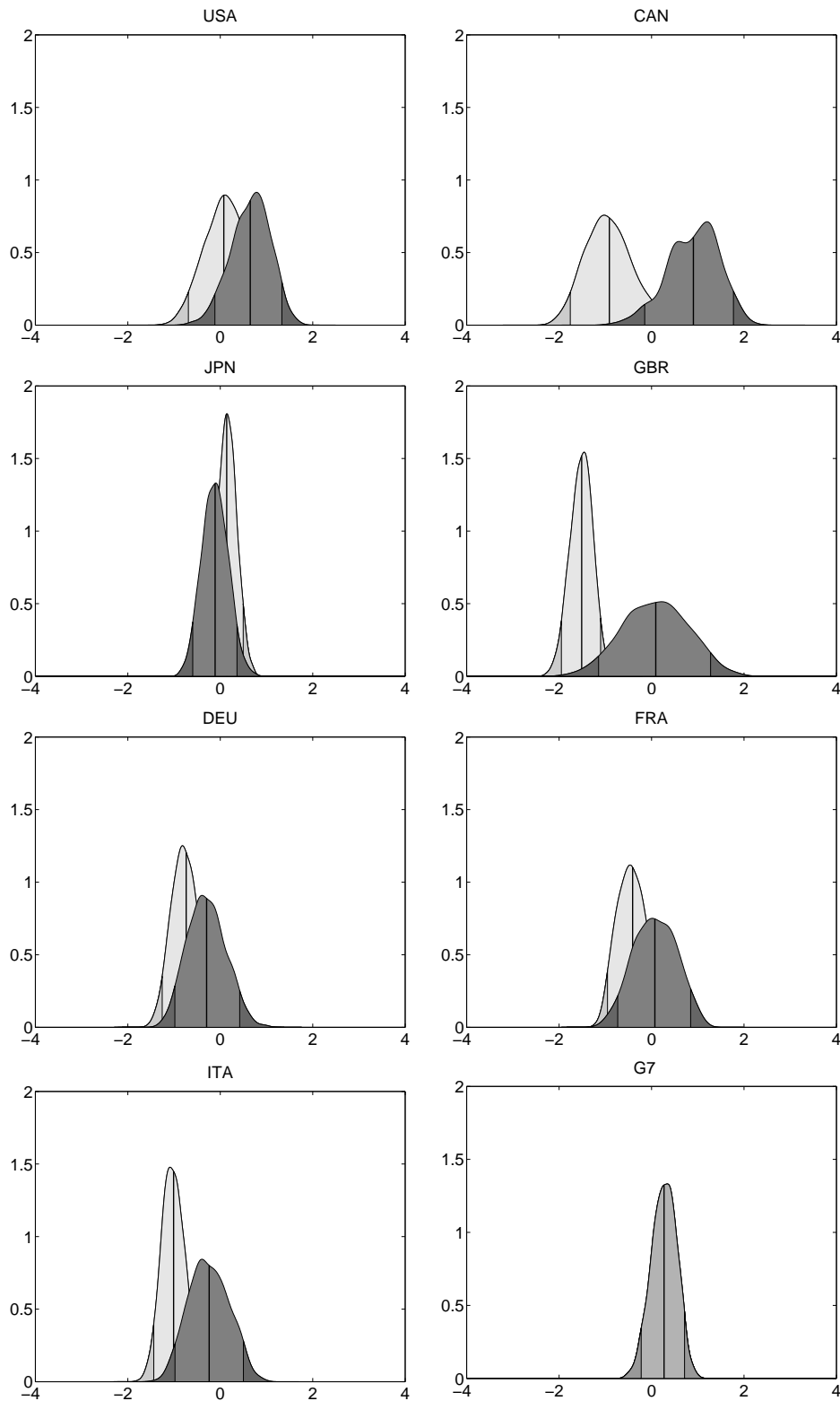
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<sup>9</sup>We also perform cointegration tests without any prefiltering of the data and find very similar results. With the latter procedure, we include an intercept in the cointegration equation but none in the VAR.

<sup>10</sup>The country–level labor productivities used in these cointegration tests are expressed in units of local currency at constant price (basically, in units of local good). Hence, they might not be comparable from one country to the other in the short–run. To investigate this issue, we redo the cointegration tests using purchasing power parity (PPP) adjusted labor productivities. The results are identical. Throughout the rest of the paper, we have checked the sensitivity of our results to PPP–adjustment. They remain unchanged.

<sup>11</sup>Due to data availability, their international TFP measures are obtained from the labor input only.

Figure 3: Impact response of hours worked to an aggregate-level permanent productivity shock



Note: These figures display two smoothed distributions of impact responses obtained by standard bootstrap techniques, using 1000 draws from the sample residuals: the light grey one refers to VAR  $(\Delta x^i, \Delta n^i)$ , as in Figure 1; the medium grey one refers to VAR  $(\Delta x^{G7}, \Delta n^i)$ .

hours worked. Continental European countries exhibit tiny adjustments in labor input, while US, Canada and UK display positive (and persistent, as can be seen in Figure 8) responses of hours worked.

To assess the estimates of IRFs based on aggregate-level productivity, we compute the implied response for the G7 as a population-weighted sum of country-level point estimates. This computed impact response is displayed by squares in the right panel of Figure 2 together with the distribution of impact responses estimated on aggregate data. The two estimates are indistinguishable, and remain so at longer horizons (see the right panel of Figure 7).

The use of aggregate-level labor productivity and country-level hours worked therefore solves the aggregation anomaly. Our interpretation is that country-level productivities are highly contaminated measures of aggregate technology in the short run. Therefore, SVAR models that use country-level labor productivity data deliver biased estimates of the response of hours to technology shocks. On the contrary, aggregate-level labor productivity in SVAR models can eliminate the distortions due to country-specific persistent shocks. This view counters the usual intuition that useful information is lost through aggregation.

## 4 Larger SVAR models

We now assess the robustness of the empirical findings of Section 3 by considering larger SVAR models.

First, we augment the specification with an additional variable, the difference between the country-level labor productivity and the G7 aggregate labor productivity. Johansen's test statistics (in Table 2) suggest that a single stochastic trend hits permanently the seven country-level labor productivities. As in the previous section, we use in (1) the G7 labor productivity to measure this shock. The difference  $x_t^i - x_t^{G7}$  ( $i = 1, \dots, 7$ ) can thus help to capture highly persistent, if not permanent, components in country-level labor productivities. The results of this experiment are reported in Figure 4 (again, the dynamic responses appear in Figure 9, in appendix). For each country, it displays two smoothed distributions of impact responses: the light grey one refers to VAR  $(\Delta x^i, \Delta n^i)$ , as in Figure 1; the medium grey one refers to VAR  $(\Delta x^{G7}, \Delta n^i, x^i - x^{G7})$ . Once again, the distribution of impact response shifts right for all countries but Japan. Indeed, the response of hours in US, Japan and UK in the three-variables VAR are very similar to those obtained with the two-variables VAR while the discrepancy between the results of the two VAR models in Canada, Germany, France and Italy suggest that these countries have a persistent country-specific component in labor productivity. Figure 9

displays the impulse response functions at longer horizons.

Second, we include in the SVAR the seven country-level labor inputs. The specification  $(\Delta x_t^{G7}, \Delta n_t^1, \dots, \Delta n_t^7)$  can potentially account for the international transmission of shocks in a multi-country setup.<sup>12</sup> The estimated impact responses are displayed in Figure 5 and the estimated dynamic responses in Figure 10, in appendix.

The results established in the two-variables VAR are preserved in this eight-variables VAR: the short-run response of hours worked to global permanent technology improvements by and large exceeds the response estimated using country-level data..

## 5 Concluding remarks

This paper belongs to the large literature evaluating the empirical effects of technology shocks on labor input using VAR models. The aim of this literature is to establish a robust stylized fact which would discriminate between competing business cycle models.

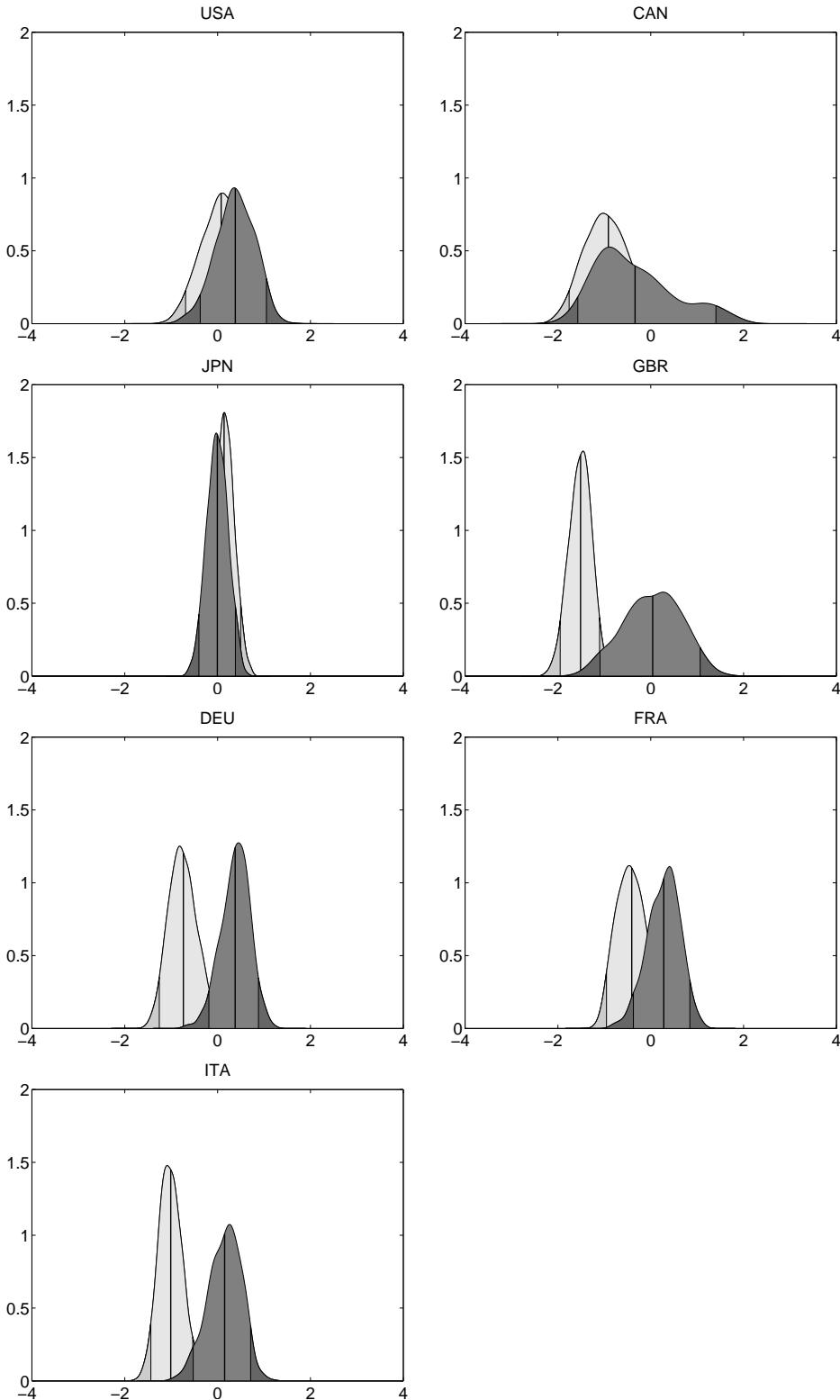
When SVAR models are estimated with country-level data, we obtain that hours worked persistently decrease in most of countries, whereas they persistently increase with aggregate-level data. We suggest to replace the country-level productivity by a cross-country aggregate. Using aggregate-level data, the response of the labor input shift up in most of countries as compared to our initial estimates. The use of an aggregate measure of the labor productivity solves the conflicting results obtained from country-level data.

The analysis undertaken in this paper emphasizes the international transmission of shocks. We believe that the empirical quest for the forces driving the business cycle should take into account such external shocks on top of domestic factors.

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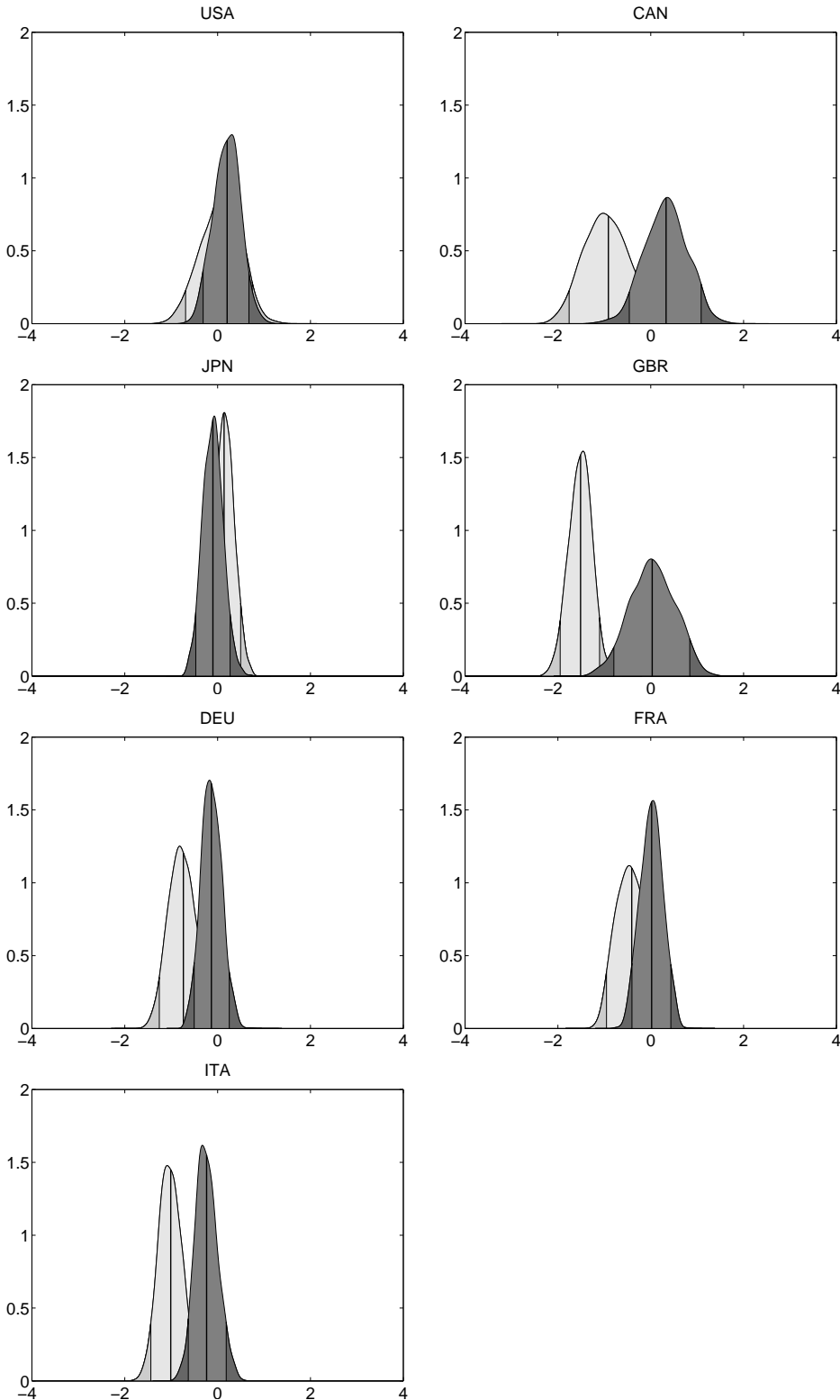
<sup>12</sup>Given the size of our sample, we cannot estimate the 31 parameters of a two lag VAR including both productivity differentials and labor inputs for all countries.

Figure 4: Impact response of hours worked to an aggregate-level permanent productivity shock in larger VARs – Productivity differentials



Note: These figures display two smoothed distributions of impact responses obtained by standard bootstrap techniques, using 1000 draws from the sample residuals: the light grey one refers to VAR  $(\Delta x^i, \Delta n^i)$ , as in Figure 1; the medium grey one refers to VAR  $(\Delta x^{G7}, \Delta n^i, x^i - x^{G7})$ .

Figure 5: Impact response of hours worked to an aggregate-level permanent productivity shock in larger VARs – Seven countries' labor inputs



Note: These figures display two smoothed distributions of impact responses obtained by standard bootstrap techniques, using 1000 draws from the sample residuals: the light grey one refers to VAR  $(\Delta x^{G7}, \Delta n^i)$ , as in Figure 3; the medium grey one refers to VAR  $(\Delta x^{G7}, \Delta n^i, \Delta n^{-i})$ .

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## Appendix

Table 1: ADF unit root tests on hours worked

country	hours worked	critical values		
		1%	5%	10%
United States	-1.181	-3.640	-2.946	-2.616
Canada	-1.008	-3.640	-2.946	-2.616
Japan	0.126	-3.640	-2.946	-2.616
United-Kingdom	-1.605	-3.640	-2.946	-2.616
Germany	-1.461	-3.640	-2.946	-2.616
France	-1.845	-3.640	-2.946	-2.616
Italy	-1.348	-3.640	-2.946	-2.616
G7	-1.479	-3.640	-2.946	-2.616

Note: ADF  $t$ -statistics for the null hypothesis of a unit root in the log-level of each time series, based on an ADF test with 2 lags and an intercept. Sample period 1972–2004.

Table 2: Johansen cointegration tests of labor productivity

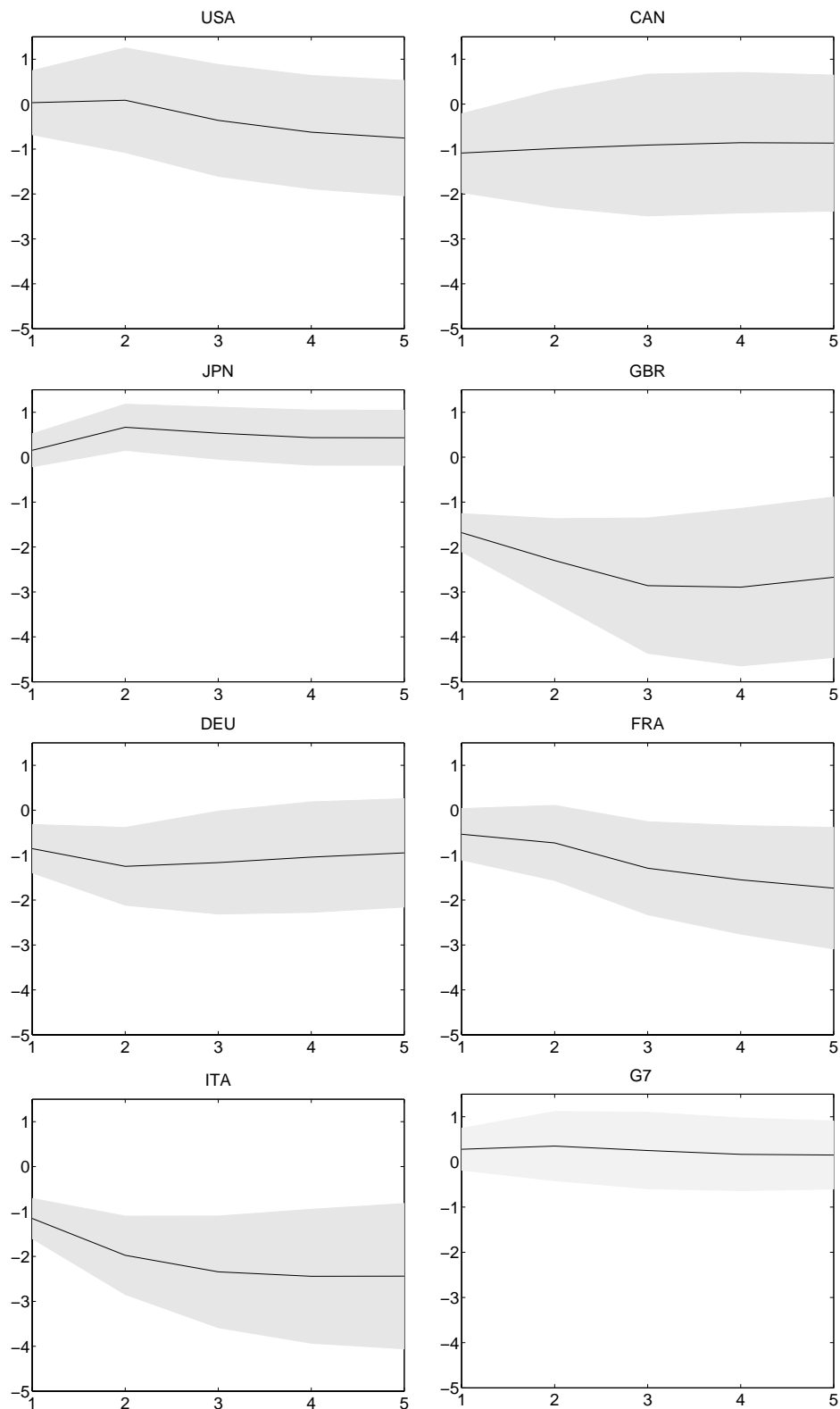
$H_0$	trace stat.	critical values		
		1%	5%	10%
$r \leq 0$	320.327	120.367	125.619	135.982
$r \leq 1$	180.787	91.109	95.754	104.964
$r \leq 2$	114.366	65.820	69.819	77.820
$r \leq 3$	66.717	44.493	47.855	54.682
$r \leq 4$	34.999	27.067	29.796	35.463
$r \leq 5$	15.485	13.429	15.494	19.935
$r \leq 6$	0.005	2.705	3.841	6.635

$H_0$	eigenvalue stat.	critical values		
		1%	5%	10%
$r \leq 0$	139.540	43.295	46.230	52.307
$r \leq 1$	66.421	37.279	40.076	45.866
$r \leq 2$	47.649	31.238	33.878	39.369
$r \leq 3$	31.718	25.124	27.586	32.717
$r \leq 4$	19.514	18.893	21.131	25.865
$r \leq 5$	15.480	12.297	14.264	18.520
$r \leq 6$	0.005	2.705	3.841	6.635

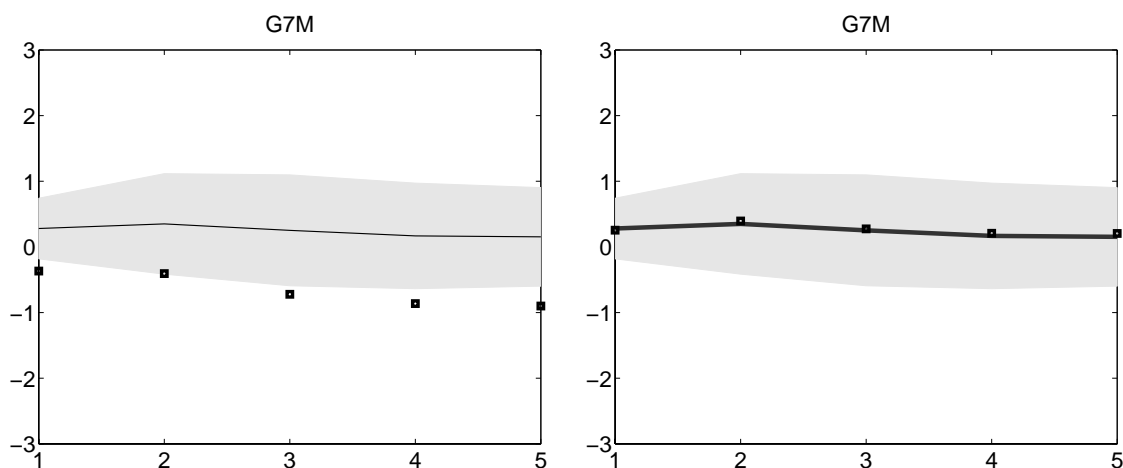
Note: Johansen cointegration tests with 2 lags on demeaned variables. Sample period 1972–2004.

Figure 6: IRFs of hours worked to a country-level permanent productivity shock



Note: These figures display the impulse response function of hours worked to a permanent productivity shock in a VAR  $(\Delta x^i, \Delta n^i)$  and its 90% confidence interval.

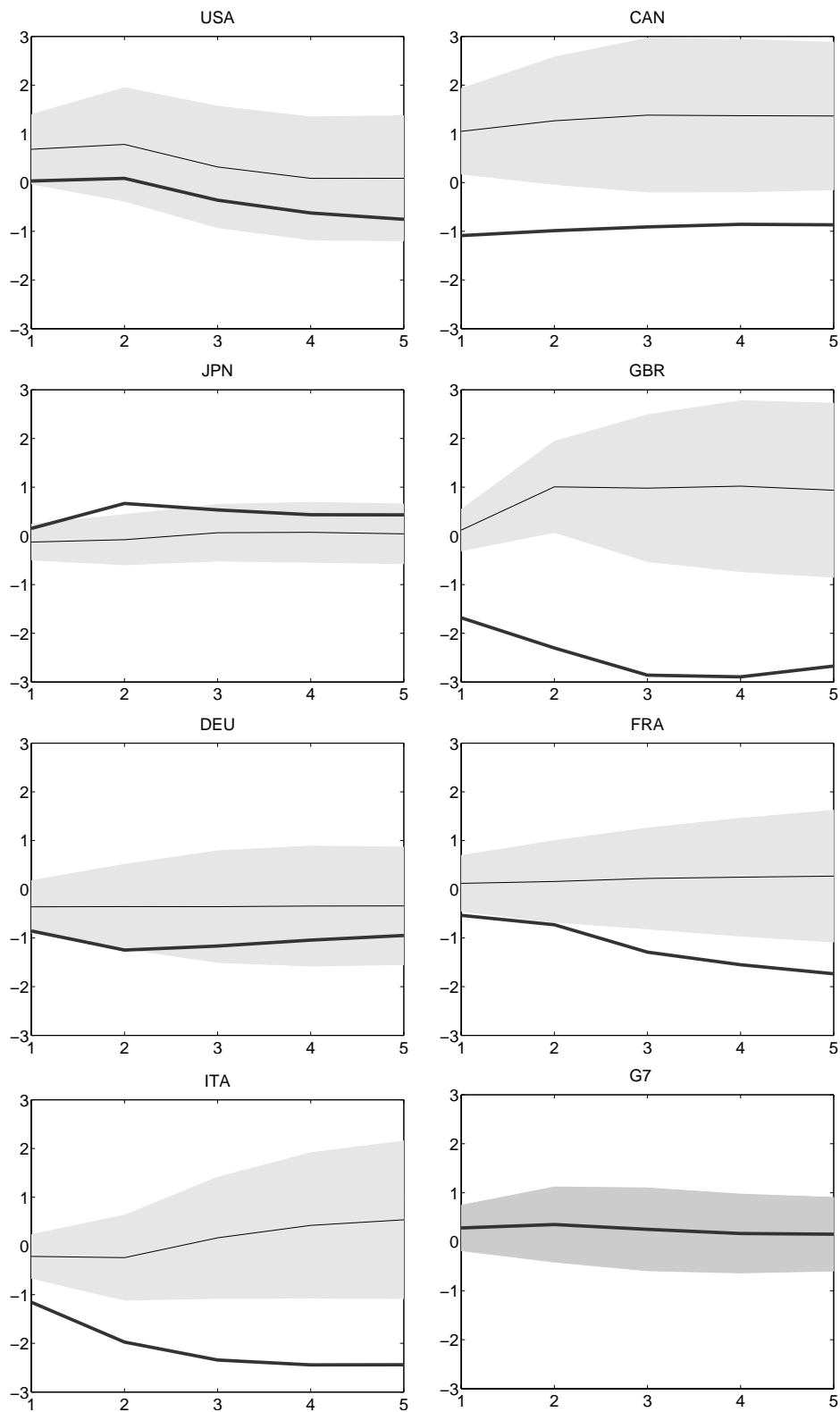
Figure 7: IRFs of G7 hours implied by aggregate-level experiments



Note:

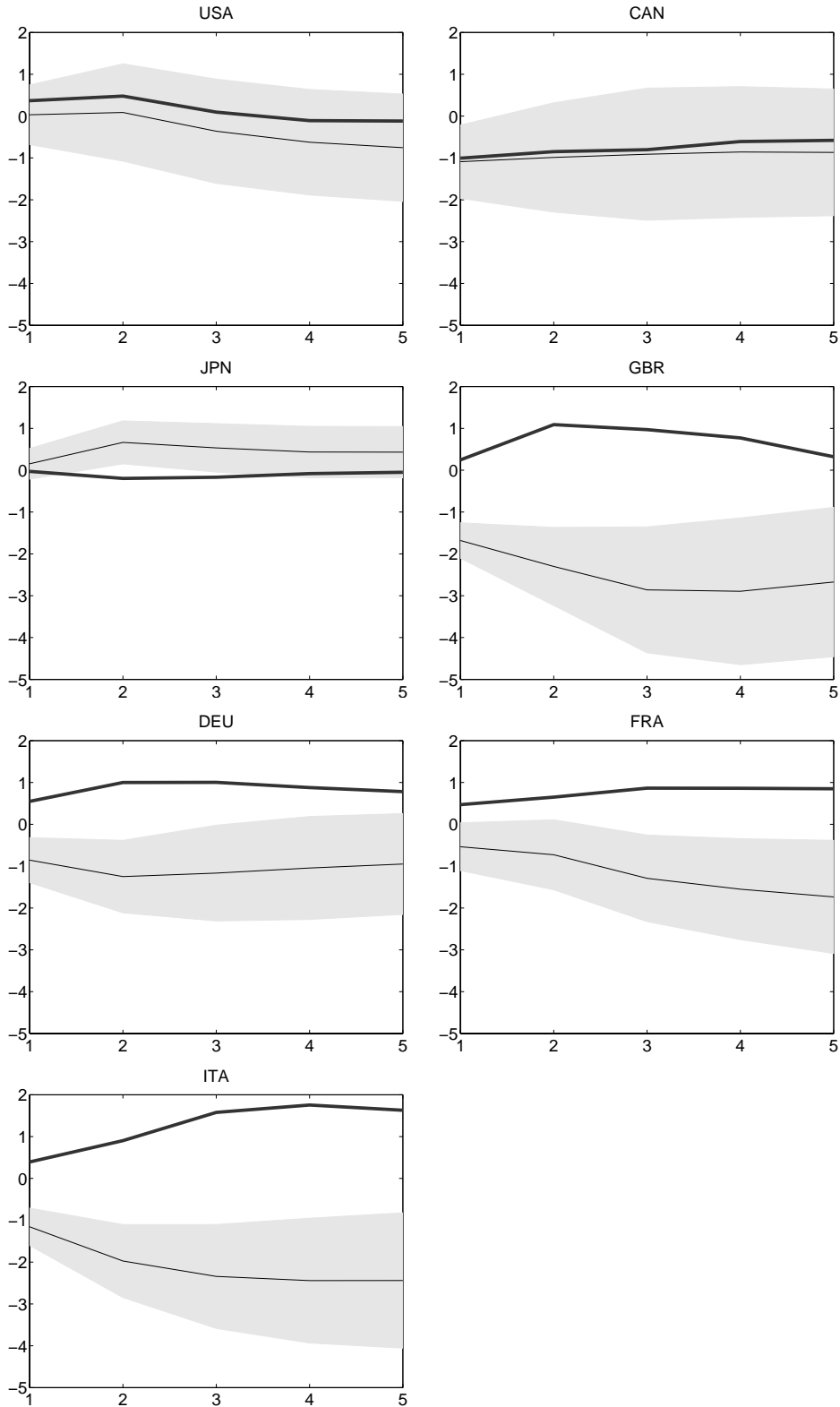
This figure displays the impulse response function of hours worked to a permanent productivity shock in a VAR  $(\Delta x^{G7}, \Delta n^{G7})$  and its 90% confidence interval. On the left panel, squares symbolize the weighted sum of hours worked response based on country-level VAR  $(\Delta x^i, \Delta n^i)$ . On the right panel, squares symbolize the weighted sum of hours worked response based on VAR  $(\Delta x^{G7}, \Delta n^i)$ .

Figure 8: IRFs of hours worked to an aggregate-level permanent productivity shock



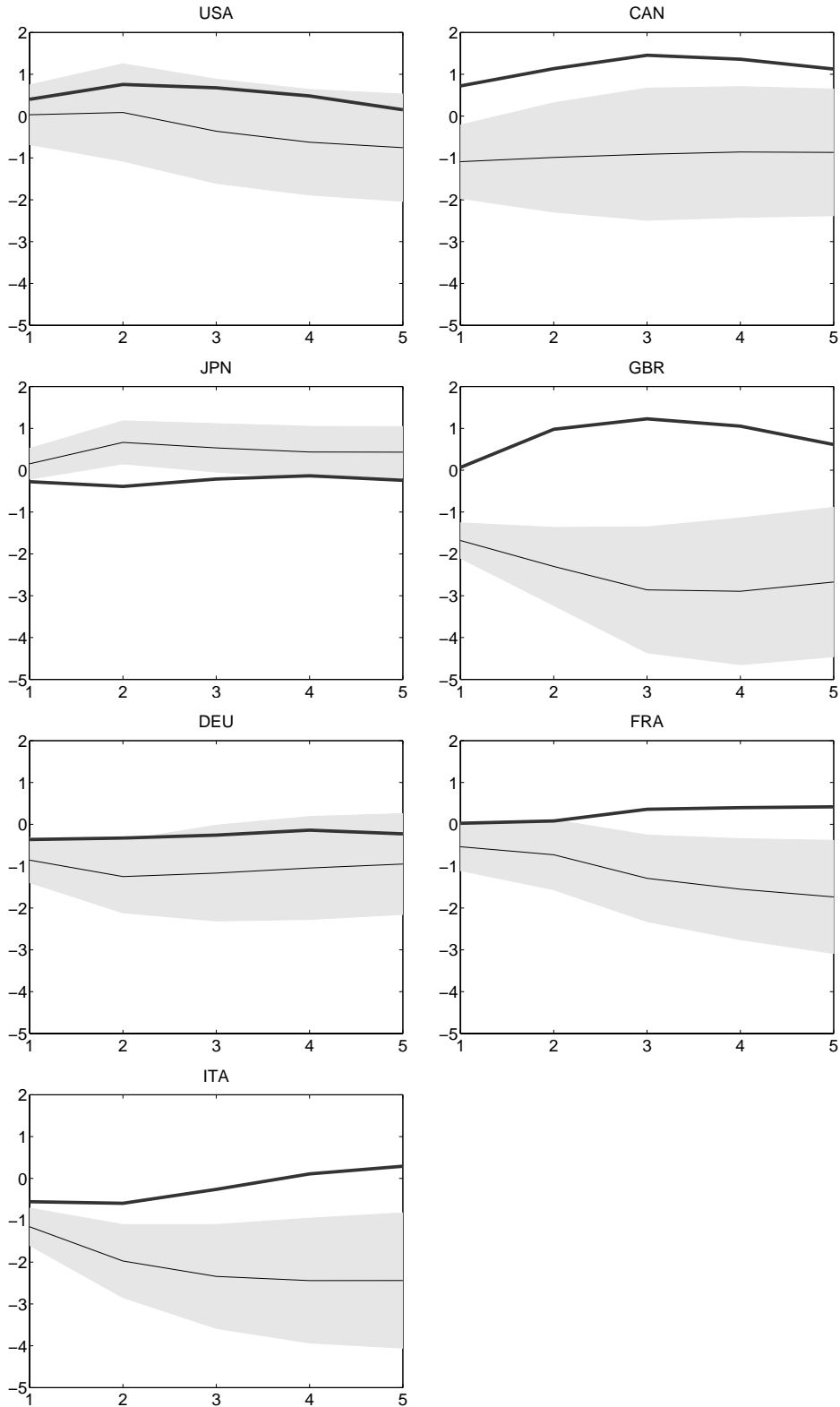
Note: These figures display the impulse response function of hours worked to a permanent productivity shock in a VAR  $(\Delta x^{G7}, \Delta n^i)$  and its 90% confidence interval, as well as the point estimate impulse response of Figure 6.

Figure 9: IRFs of hours worked to an aggregate-level permanent productivity shock in larger VARs – Productivity differentials



Note: These figures display the impulse response function of hours worked to a permanent productivity shock in a VAR  $(\Delta x^{G7}, \Delta n^i, x^i - x^{G7})$  (thick grey line), as well as the point estimate impulse response of Figure 8 and its 90% confidence interval.

Figure 10: IRFs of hours worked to an aggregate-level permanent productivity shock in larger VARs – Seven countries' labor inputs



Note: These figures display the impulse response function of hours worked to a permanent productivity shock in a VAR  $(\Delta x^{G7}, \Delta n^i, \Delta n^{-i})$  (thick grey line), as well as the point estimate impulse response of Figure 8 and its 90% confidence interval.