A New Measure of Hours Per Capita
with Implications for the Technology-Hours Debate

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Abstract

The standard way to measure hours per capita is to divide private hours by the noninstitutional population aged 16 and over. This measure displays significant low frequency movements. In this paper, we develop a more sophisticated measure of the population available for work in the private sector. This adjustment of total hours eliminates virtually all low frequency movements in hours per capita over the past 100 years. Another advantage of this measure is its robustness in certain applications. In particular, when the new measure of hours per capita is used to determine the effect of technology shocks on hours using long-run restrictions, both the levels and difference specifications give the same answer: hours decline in the short-run in response to a positive technology shock.

I. Introduction

Measures of hours per capita are an important part of many studies. For example, almost all real business cycle analysis compares predictions from the model to the behavior of hours per capita in the data. The trends in hours per capita relative to consumption per capita have led some to conclude that labor market distortions have grown significantly over the last century (e.g. Mulligan (2002)). Recent work on the effects of technology shocks on hours has revealed that different assumptions concerning the stationarity of hours per capita leads to dramatically different results (e.g. Christiano, Eichenbaum and Vigfusson (2003)). Virtually all researchers in these areas measure hours per capita as total hours worked in the private sector divided by the civilian noninstitutional population aged 16 and over.

In this paper, we argue that the standard measure of hours per capita is significantly affected by low frequency demographic and institutional trends. We offer a new measure that uses more sophisticated adjustments of the population available for work in the private sector. This new measure overturns some key results that were obtained using the standard measure. In particular, positive technology shocks (identified through long-run restrictions) lead to a decrease in hours whether one assumes that hours per capita are stationary or non-stationary.

II. Theoretical Considerations

This section briefly reviews the theoretical rationale for dividing data quantities, such as hours, by some measure of total time endowment in order to match the data with a standard DGE model. To this end, consider an economy with the following production function and utility function:

$$Y_t = (A_t N_t)^{\alpha} K_t^{1-\alpha} \qquad \text{Production Function}$$

$$U(C_t, N_t) = \ln(C_t) + \phi \ln(\bar{L}_t - N_t) \qquad \text{Utility}$$

Y is output, A is the level of technology, N is hours worked, K is the capital stock, C is consumption, and $\bar{L}$ is the time endowment of the representative agent.

Consider embedding these equations into a simple model with labor and capital taxation.[1] Let τ_n be the tax rate on labor income. A key steady-state condition involving hours is the marginal rate of substitution condition:

$$\frac{\bar{L} - N}{N} = \frac{\phi}{\alpha(1-\tau_n)} \frac{C}{Y} \qquad \text{Marginal Rate of Substitution}$$

This condition states that as long as the tax rate on labor income and the parameters of the production function and utility function are constant, the ratio of leisure to hours worked will be proportional to the consumption-output ratio.

Any changes in the working-age population in the data must be manifested in $\bar{L}$ in the model. Thus, adjusting for the working-age population in the data is similar to dividing all quantities by $\bar{L}$ in the model. For example, the marginal rate of substitution condition above can be rewritten as:

[1] See Francis and Ramey (2003) for details of this model.

$$\frac{1-N/\bar{L}}{N/\bar{L}}=\frac{\phi}{\alpha(1-\tau_n)}\frac{C/\bar{L}}{Y/\bar{L}}$$

These quantities correspond to those usually studied, such as per capita hours, per capita consumption and per capita output.

The question then is: what is the appropriate measure of $\bar{L}$? The next section will discuss the standard measure and suggest a better measure.

III. A New Measure of Hours Per Capital: Annual Historical Data

A. Comparison to the Standard Measure

How should an economy's potential working hours be measured? The standard measure is the civilian non-institutional population aged 16 and over. The motivation is as follows. Children are omitted because their potential to work is severely limited by labor laws, particularly in the post-WWII period. Inmates of institutions are omitted because their status prohibits market work. Persons in the armed forces are omitted because they are not available for private sector work.

As discussed by Francis and Ramey (2003, 2004), hours per capita constructed with this measure has significant trends and other low frequency movements. Figure 1A shows the log of private hours per capita from 1900 using a series that is similar to the standard measure used in post-WWII data. The numerator is total hours worked in the private business sector.[2] The denominator is the civilian non-institutional population aged 16 and over, i.e.,[3]

Civilian non-institutional population

= (total population) – (population aged 0-15)

– (institutional population aged 16 and over) – (armed forces).

According to this measure, hours per capita in the private sector fell almost 40 percent from 1900 to 2000. Mulligan (2002) uses a similar measure and concludes that government induced distortions are a major source of the decline in hours. Moreover, even in the post-WWII period this measure shows substantial low frequency movements, exhibiting a U-shape with a trough in the 1970s. Whether this measure of hours per capita is stationary or has a unit root has been the subject of intense recent debate, particularly since the estimated effects of technology shocks on hours reverses signs depending on the specification (e.g. Christiano, Eichenbaum and Vigfusson (2003), Francis and Ramey (2003)).

There are a number of reasons that hours per capita could display such a trend in a representative agent model. As Mulligan argues, an increase in labor income tax rates and other labor market distortions can lead to permanently lower hours per capita. Another possibility is that the wealth and substitution effects of a permanent increase in wages do not cancel, as implied by the utility function specified in the previous section. If the wealth effect outweighs the substitution effect, then hours could have fallen over the last 100 years in response to the increase in real wages.

[2] The data appendix gives details of the construction of all data used.

Or, the problem might be measurement. Francis and Ramey (2004) make some additional adjustments to population and find that a revised hours per capita measure shows far fewer low frequency movements. Figure 1B shows an alternative measure of hours per capita, which is an extension of the measure introduced by Francis and Ramey (2004). The graph gives a dramatically different picture of the behavior of hours per capita during the last century. In contrast to the standard measure, which shows hours per capita 40 percent lower in 2000 than in 1900, our measure shows that hours per capita were *essentially the same* in 2000 as they were in 1900. Moreover, many of the intervening low frequency movements, such as the U-shape of hours in the post-WWII period, have disappeared.

The next section describes in detail how the new measure is constructed.

B. Adjustments to the Population Available for Work

The hours per capita series shown in Figures 1A-1B have identical numerators, but different denominators. We now describe and motivate the adjustments made to the working-age population in order to produce the series shown in Figure 1B. The goal is to accurately measure the potential hours available for work in the private sector.

Government Workers

The standard measure of available working population typically subtracts the armed forces, but not those employed in the civilian government. This omission is not problematic if one studies total hours worked, including the government. Most RBC studies, however, use private hours or nonfarm private hours. One reason for this choice is the absence of quarterly

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[3] This measure is slightly different from the one used in Francis and Ramey (2004) because it subtracts the institutional population and armed forces. The graphs look very similar, though.

frequency data on total hours worked.[4] Another reason is that the RBC model assumes that workers and capital are hired based on market incentives, assumptions that may not hold for the government sector.

For the most part, people employed in government are not available for private sector work. Moreover, the fraction of the population employed in government displays significant trends. The lower line in Figure 2a shows the number of individuals employed in government as a fraction of the population. (Disregard the higher line for now). Other than the large spikes of the two world wars and the smaller spikes of the Korean and Vietnam wars, the most noticeable movement is the upward trend in government employees as a fraction of the population. It is clear that the failure to account for this movement will bias the estimates of hours per capita down in the second half of the century. Thus, it is important to adjust for the number of people employed in government.

One can think of the economy as having two sectors, the private sector and the government sector. If the government workers are doing tasks that private workers would have done, total hours worked per capita should not change. If there is imperfect substitutability of government tasks for private tasks, an increase in government workers should raise total hours per capita because of the negative wealth effect. In the extreme case that the output of government workers has no consumption value for individuals, an increase in the number of government workers should have the same effects as an increase in government consumption. Yet if no adjustments are made to the measure of private hours per capita, an *increase* in government employment can lead to a measured *decline* in private hours per capita. The question is how to adjust the denominator in the hours per capita measure.

[4] The BLS quarterly hours index does not include government workers.

Standard per capita measures subtract the armed forces to create the civilian population. Should we do the same with civilian government workers? No. As we now show, this adjustment is not enough to maintain the stationarity of the private hours per capita measure.[5]

Consider first an example. An economy of 100 households that each has two individuals, one who supplies one hour of labor to the market and one who stays at home. The population is 200 and hours (and employment) is 100. Initially, there are only private sector jobs, so private hours per capita are 0.5. Now suppose that 20 jobs that were classified as private sector jobs suddenly become government jobs (such as airport security workers or school teachers). With no adjustment, private hours per capita falls to (100-20)/200 = 0.4. If we subtract government workers from population totals in the denominator, private hours per capita is (100-20)/(200-20) = 0.444. Yet total hours per capita (including the government jobs) is still 0.5. To fully adjust for this shift in employment, we would need to subtract *the reciprocal of the labor force participation rate* multiplied by the number of government employees from total population. That is, we would need to calculate (100-20)/(200-(1/0.5)·20) = 0.5.

More generally, total hours worked relative to the population available to work is given by:

$$\text{Total hours per capita} = \frac{H_g N_g + H_p N_p}{\bar{L}},$$

where H is the average hours worked per person in a sector, N is the number of workers, $\bar{L}$ is the total time endowment, and the subscripts g and p refer to the government and private sectors,

[5] In Francis and Ramey (2004), we adopted this method because of the analogy with the standard measures. We have since realized additional adjustment is needed.

respectively. The question is whether we can construct a measure of hours per capita with only private hours in the numerator that has the same trends as the total hours measure. In particular, we want it to be the case that if there are no permanent shifts in total hours per capita there will be no permanent shifts in private hours per capita. The key is to subtract some proportion of the number of employees in government from the denominator to adjust for changes in government employment. To be specific, one should find the value of θ that makes the following two ratios equal:

$$\frac{H_g N_g + H_p N_p}{\bar{L}} = \frac{H_p N_p}{\bar{L} - \theta \cdot N_g}$$

That value of θ is:

$$\theta = \frac{\bar{L}}{N_g + \frac{H_p}{H_g} N_p}$$

If average hours per worker are roughly equal across the two sectors, then θ is equal to the reciprocal of the employment-population ratio. In fact, average hours are lower in the government sector, but this adjustment is easily made by using full-time equivalent workers in government.

One problem with using the employment-population ratio, though, is that it would make private hours per capita have the same cyclical variability of total hours per capita. It is well known that government hours are much less cyclical. Because we want to preserve the cyclical properties of private hours per capita, we use the labor force participation rate rather than the employment-population ratio, since the former has very small cyclical fluctuations. Thus, we adjust the denominator in our private hours per capita measure by subtracting the full-time equivalent number of individuals engaged in production in government (including military) multiplied by the reciprocal of the labor force participation rate for individuals aged 25-64.[6] We use the labor force participation rate for this age group because of issues we address below. As Figure 2A shows, the scaled number follows similar patterns to the raw number, but lies above it.

Younger population and school enrollment

The standard adjustment subtracts the population between ages 0 to 15 because labor laws in the post-WWII period severely limit the employment of children under 16.[7] This adjustment ignores another trend that interacts with demographic trends in age. In particular, because of increased government expenditures and government subsidies, as well as the increasing returns to education during some sub-periods, the years of schooling has increased substantially over the last 100 years. Ideally, one would build these incentives into the theoretical model. Since most models do not, it is important to adjust for these low frequency movements. Hours spent in school are not spent in the market and are not leisure. Thus, the hours spent in school should be subtracted from the time endowment. While some people enrolled in school also hold jobs, it is a reasonable approximation to simply subtract the number of people enrolled in school from the population in order to measure the population available for work. Since children between birth and four years do not typically go to school (and since preschool is not in our school enrollment figures) we also subtract the population between birth

[6] Average hours worked in government are less than average hours worked in the private sector. The use of full-time equivalent government workers corrects for the differences in hours.
[7] Before WWII, the population 14 and over are often included in the working-age population.

and four years. Thus, the second adjustment subtracts children between birth and age 4 and total school enrollment, including college.

Figures 2b and 2c show the fraction of the population between ages 0 and 4 and the fraction of the population enrolled in school respectively. There is an overall downward trend in the fraction of the population between ages 0 and 4, with the noticeable exception of the baby boom during the 1950s. Figure 2c shows booms in school enrollment in the 1920s and the 1960s and 1970s. Although the fraction of the population under 16 years of age in 2002 was lower than the fraction in 1900 (22 percent versus 36 percent), the fraction of the total population enrolled in school was slightly higher in the late 20th century than in the early 20th century.

Older population

The standard measures of hours per capita assume that anyone still alive and not institutionalized can potentially supply labor to the market. There is a good argument for adjusting for the older population, particularly the population aged 65 and above.[8] For much of the 20th century, health issues, mandatory retirement laws, and the advent of social security have limited the labor supply of individuals aged 65 and over.

Figure 2d shows the fraction of the population that is 65 and over. This ratio rises from four percent in 1900 to over twelve percent in 2000. Not only has the fraction of the population in this age group increased, but its labor force participation has decreased. Figure 2e shows the labor force participation rate of the population 65 and older relative to the population 25 to 64.

[8] When Prescott (2004) compares hours worked by Americans versus Europeans, he divides by the population between the ages of 16 and 64.

This ratio has fallen dramatically, from over 60 percent to under 14 percent.[9] The combination of these two sources has had a noticeable effect on the population available for work.

Why did the labor force participation rate of individuals aged 65 and over fall so much? Clearly, changes in the generosity of Social Security and Medicare benefits have been a major factor since the 1930s.[10] Another factor that may play a role is mandatory retirement. Before the late 1970s, many firms imposed mandatory retirement at age 65. The 1978 Amendments to the Age Discrimination in Employment Act raised the permissible mandatory retirement age from 65 to 70. Further amendments prohibited any mandatory retirement after the late 1980s.

During the era of mandatory retirement, individuals that were self-employed were exempt from mandatory retirement. In 1950, agriculture accounted for almost half of all self-employed workers. Further, in 1950, 25 percent of employed workers aged 65 and over were employed in agriculture. Thus, the dramatic decline in agriculture over the last century may have eliminated many of the employment opportunities for older workers. Since the prohibition of mandatory retirement in the late 1980s, there has been a small increase in labor force participation rates of older workers, but nowhere near to where they had been.

To adjust for the different effective time endowment of older workers caused by institutions and sectoral shifts, we adjust for the differential rate of labor force participation rates of the population aged 65 and older. In particular, letting LFPR stand for "labor force participation rate," we subtract the following quantity from the total population:

$$(\text{noninstitutional population } 65\,\&\,\text{over}) \cdot \left(1\text{-}\frac{\text{LFPR } 65\,\&\,\text{over}}{\text{LFPR } 25\text{-}64}\right)$$

[9] The graph looks smooth before 1948 because of interpolation. The labor force by age group was available only in 1900, 1920, 1930, and 1940. Beginning in 1948, the labor force by age group was reported on a regular basis.
[10] For example, see Chart 6 of McGrattan and Rogerson (2004) for the period 1940 to 2000.

If the labor force participation rate of those 65 and over were equal to the rate of those between aged 25 and 64, no individuals in the older age group would be subtracted from the available working-age population.[11]

Institutionalized Population

The final adjustment we make is also used in the standard adjustments. Inmates of institutions cannot be part of the work force, and are therefore subtracted from total population. The two most important components of inmates of institutions are residents of homes for the aged and inmates of correctional facilities. The fraction of the population incarcerated has risen significantly since the 1980s so it is important to account for this factor.

Data on the number of people institutionalized of all ages is available beginning in 1950 and for individuals 65 years and older is available starting with the 1940 census. We extrapolate to the earlier years by assuming that the institutionalization rates were constant by age group. See the data appendix for details.

Our revised hours per capita measure thus divides total private hours by the following measure of the population available for work in the private sector:

Population available for work = (Total Population) – (Population Aged 0 – 4)

– (School Enrollment) - (Institutional Population)

– ([1- LFPR65+/LFPR25_64] · Noninstitutional Population aged 65 and over)

– ([1/LFPR25_64] · Full Time Government Employment)

[11] The labor force participation rates are defined relative to the noninstitutional population.

Figure 3 shows the effect of each adjustment to the standard measure. All three adjustments are important for eliminating the trend in hours per capita. In 1950s and 1960s, the most important adjustment is government employment, perhaps because of the large number of teachers who were hired to teach the baby boom. By the end of the sample, the adjustment for population 65 and older is the most important, with the government and schooling adjustments having a slightly smaller effect. All three adjustments together result in the revised hours per capita series which lies significantly above the standard series by 2002.

C. Implications of the Revised Measure of Hours Per Capita in Historical Data

The adjusted series paints a very different picture from the standard series concerning the behavior of hours per capita in the last century. The standard measure suggests that the population available for work works less now than it did 100 years ago. The revised measure suggests that there has been no long-run trends in hours worked per capita properly measured. This is not to say that there have not been substantial shifts in work across groups. McGrattan and Rogerson (2004) summary of hours changes in the 1950 – 2000 period shows substantial shifts in hours across certain groups, such as from males to females.

This revised measure has implications for a variety of studies that have used population aged 16 and over for their only per capita adjustment. For example, Mulligan (2002) calculates labor distortions by comparing measures of the marginal rate of substitution (MRS) relative to the marginal product of labor (MPL). He finds that the estimated wedges increased more over the last century than the measured marginal labor tax rates. His finding depends very much on his measure of hours per capita, which shows a significant downward trend (see his Figure 1).[12]

[12] Mulligan does include government hours in his measure of hours, so his measure does not suffer from the effects of shifts to greater government employment share.

Similarly, Hall's (1997) estimates of shifts to the MRS condition depend on his measure of hours per capita. He measures hours per capita as private hours divided by the adult population. As a result, he estimates low frequency movements in the MRS in the post-WWII period that display the U-shape of hours per capita that is apparent in our Figure 1A, but not in Figure 1B.

In the next section, we will show that substituting our new measure of hours per capita for the standard one also has implications for the technology-hours debate.

IV. The Revised Measure of Hours Per Capita and the Technology-Hours Debate

A. Quarterly Hours Per Capita in the Post-WWII Period

We now consider our revised measure of hours per capita in quarterly post-WWII data. The total population, the population aged 0 to 4, the number enrolled in school, and the number of full-time equivalent government workers are all available only on an annual basis. The number in institutions is available only on a decennial basis. Thus, these series must be interpolated to obtain quarterly numbers. Interpolation is not a concern, though, because the available population measure should be free of cyclical components anyway. In fact, to ensure that our adjustments are free of any cyclical components, we use the HP filtered trends of the variables that may have cyclical components: the number enrolled in school and the labor force participation rate variables.

Figure 4a shows private hours per capita using the noninstitutional civilian aged 16 and over in the denominator and Figure 4b shows private hours per capita using our measure of available population in the denominator. The standard measure of hours per capita displays a U-shape from 1948 to 2002. Although hours per capita started rising in the mid-1980s, the peak in

1999 was still below the levels in the 1950s. Our revised measure has no U-shape. It does show a slight upward trend over the post-WWII period. Both measures display very similar cyclical deviations from the low frequency trend movements.

B. Background on the Technology-Hours Debate

Several recent papers have presented evidence that technology shocks do not affect hours in the way predicted by the RBC model. Although they use different methods, Galí (1999), Shea (1998) and Basu, Fernald, and Kimball (1999 (revised 2004)) all find that positive technology shocks lead to measured declines in labor input. Galí identifies technology shocks using long-run restrictions in a structural VAR; Shea uses data on patents and R&D; and Basu, Fernald, and Kimball identify technology shocks by estimating Hall-style regressions with proxies for effort and utilization. Francis and Ramey (2003) test the robustness of Galí's results by imposing additional long-run restrictions and subjecting the models to tests of over-identifying restrictions and Granger-causality tests. They too find a robust negative relationship between hours and technology shocks.

On the other hand, Christiano, Eichenbaum and Vigfusson (CEV) (2003) find the opposite result in a Galí-type set-up. The opposing result comes from one source: they treat the level of hours per capita as stationary and thus do not impose the second difference restriction imposed by others. In response, Galí and Rabanal (2004) explore the effect of twelve different specifications of labor input with labor input defined as: (1) total hours; (2) hours per capita; (3) total employment; (4) employment rate and with the data in levels, first-differences and detrended. In eleven of the twelve cases, they find that positive technology shocks lead to a decline in hours. It is only in the case that is the focus of the CEV analysis – hours per capita – that leads to the opposite result.

Fernald (2004) provides a possible explanation of the CEV result. He shows that average productivity growth follows a similar U-shape pattern to the U-shape pattern in hours per capita measured the standard way. Once he allows for structural breaks in productivity growth, he also finds a negative relationship even in the levels specification.

Additionally, CEV argue that standard unit root tests, which cannot reject a unit root for hours per capita measured in the conventional way, are misleading. They use tests with higher power (at least theoretically) and conclude that hours per capita are stationary over a shortened sampled from 1959. They also use encompassing tests to support their specification of the model.

C. The Effects of Technology Shocks Using the New Measure of Hours Per Capita

We now investigate how the use of the new measure of hours per capita changes the previous results on the effect of technology on hours. In Francis and Ramey (2004), we found that with demographic adjustments to hours per capita both first-difference and levels specifications gave the same result in annual data in the post-WWII period.[13] We now investigate the results for our improved measure in quarterly data.

The first thing to note is that our improved measure shows more evidence of stationarity. Table 1 shows standard ADF tests for both the standard measure and our new measure. While one cannot reject a unit root against either the stationary alternative or the deterministic trend

[13] The same was not true for the pre-WWII data. The effects of technology shocks on hours differed according to whether hours were assumed to be stationary or had a unit root.

alternative in the case of the standard measure of hours per capita, one can reject a unit root in favor of either alternative for our revised measure.

We then re-estimate the structural VAR used by Galí, Francis and Ramey, and Christiano, Eichenbaum and Vigfusson using the new measure of hours. In the baseline bivariate case, we estimate the following system:

$$\begin{bmatrix} \Delta x_t \\ n_t \end{bmatrix} = \begin{bmatrix} C^{11}(L) & C^{12}(L) \\ C^{21}(L) & C^{22}(L) \end{bmatrix} \begin{bmatrix} \varepsilon_t^z \\ \varepsilon_t^m \end{bmatrix}$$

x_t denotes the log of labor productivity, n_t denotes the log of hours per capita, ε^z denotes the technology shock, and ε^m denotes the non-technology shock. C(L) is a polynomial in the lag operator. We maintain the usual assumption that ε^z and ε^m are orthogonal. Our assumption identifying the technology shock implies that $C^{12}(1) = 0$, which restricts the unit root in productivity to originate solely in the technology shock.

This system applies to the case in which hours are assumed to be stationary. We also estimate a system in which hours are assumed to have a unit root:

$$\begin{bmatrix} \Delta x_t \\ \Delta n_t \end{bmatrix} = \begin{bmatrix} C^{11}(L) & C^{12}(L) \\ C^{21}(L) & C^{22}(L) \end{bmatrix} \begin{bmatrix} \varepsilon_t^z \\ \varepsilon_t^m \end{bmatrix}$$

We impose the same restriction, that $C^{12}(1) = 0$, to identify the technology shock. In the baseline case, we use four lags and limit our attention to a bivariate system. The data are quarterly and extend from 1948 to 2002.

Recall the previous summary of the literature. Using standard measures of hours per capita, the specification with stationary hours implies that hours increase significantly in response to a technology shock. In contrast, the specification with a unit root in hours implies that hours fall significantly in response to a technology shock.

Figure 5 shows the results when the new measure of hours per capita is used. The model is bivariate in the logs of labor productivity and hours, but we also show the implied effects for the log of output, since it is equal to the sum of the other two variables. The first column shows the results from the system estimated under the assumption that hours per capita are stationary and the second column shows the results from the system estimated under the assumption that hours per capita have a unit root. Both of these specifications imply that hours decrease in the short-run in response to a positive technology shock. Moreover, the levels specification suggests that even output decreases slightly on impact, though the estimate is not significant.

Thus, in contrast to the case with the standard measure, the negative effect of technology shocks on the new hours measure is robust across specifications with differing assumptions about whether hours are stationary or not. These results also shed light on the debate concerning the results with the standard measure. CEV claim that over-differencing of hours per capita leads to different estimated effects of technology shocks on hours. This is not true with the new measure. Even the standard ADF tests reject a unit root, assuming a unit root in hours does not change the qualitative nature of the impulse response functions. Furthermore, these results support Fernald's argument that the coincidental U-shape in both productivity growth and the standard measure of hours per capita is driving CEV's finding of a positive response of hours. When Fernald removes the U-shape in productivity growth, but leaves the U-shape in the standard measure of hours per capita, he finds a negative effect of technology shocks on hours.

Conversely, when we eliminate the U-shape in hours per capita by using an improved measure, but do not allow for structural breaks in labor productivity, we also obtain the same negative response.

D. Robustness Checks

How robust are the results? CEV initially argued that omitted variables were the source of the Galí finding. To check the robustness, we estimate the larger system used by CEV. This system adds four variables: the federal funds rate, the rate of inflation (measured using the GDP deflator), the log of the ratio of nominal consumption to nominal GDP (where consumption is measured as the expenditures on nondurables and services plus government expenditures), and the log of the ratio of nominal investment expenditures to nominal GDP (where investment is measured as expenditures on consumer durables and gross private investment). The C(L) matrix of this system is now a block 6 x 6 matrix in the lag operator. If labor productivity is the first variable in the system, we identify the technology shock by imposing the restriction that $C^{1j}(1) = 0$ for $j = 2, 3, 4, 5, 6$. Because the federal funds rate is only available beginning in 1954, the model is estimated over a shorter sample.

Figure 6 shows the results using the new measure of hours per capita in levels. A positive technology shocks raises productivity permanently. In contrast to CEV's results, the impulse response functions show a significant decline in hours per capita in the short-run. Moreover, both output and investment fall temporarily as well, though the falls are not significant. In response to the shock, the federal funds rate and the inflation rate fall. Thus, the negative effect of the technology shock on hours survives in the bigger system. The results are again similar with hours entered in first differences.

We also checked robustness in two more ways. First, we estimated the bivariate system in which we allowed hours per capita to have a linear trend. We thought it was important to consider this possibility because of the slight upward trend shown in Figure 4B. The results (not shown) look similar to those for the first-difference specification. Hours fall for a couple of quarters before becoming positive. The initial negative impact effect is estimated to be –0.22, and is statistically significant. (The impact effects were –0.43 for the levels specification and -0.30 for the difference specification.)

Cooley and Dwyer (1998) point out that the results from structural VARs may be sensitive to auxiliary assumptions with respect to lag length. Our baseline models all include four lags. To determine whether our results were due to too few lags, we re-estimated the bivariate system in levels and included 50 lags. The impulse responses were qualitatively similar to those from the system with only 4 lags. In particular, hours declined in response to a technology shock, with an impact effect estimated to be –0.37. Hours remained negative for two years, but then became positive. The impulse response function for output was always above zero.

Thus, when our new measure of hours per capita is used, hours always respond negatively to technology shocks. This is true for levels, first-differences, and trend specifications. It is true for specifications with more variables in the system. It is also true when we add 50 lags to the specification.

V. Conclusion

This paper has introduced modifications to the standard adjustments made to produce hours per capita series that match those from theoretical model. The new adjustments allow for the impact of institutional and demographic changes on the population available for work in the private sector. The adjustments include netting out those enrolled in school and those employed in government jobs. The adjustments also include allowances for the differential employment possibilities for those aged 65 and over.

The new measure of hours per capita gives a very different picture of the behavior of hours per capita during the last 100 years. Whereas the standard measure implies hours per capita have fallen almost 40 percent, the new measure shows that hours per capita in 2000 were about equal to hours per capita in 1900.

The new measure also gives new results on the effects of technology on hours. In contrast to results using the standard measure, the new measure produces a uniformly negative effect of technology on hours, no matter the assumption concerning the stationarity of hours.

Data Appendix

I. Annual Historical Data, 1900-2002

The denominator of the standard measure of hours per capita is defined as:

(Total Population) – (Population Aged 0 to 15) – (Institutionalized Population Aged 16+)

– (Armed Forces)

The denominator of the new measure of hours per capita is defined as:

(Total Population) – (Population Aged 0 – 4) - (School Enrollment) - (Institutional Population)

– ([1- LFPR65+/LFPR25_64] · Noninstitutional Population 65 and over)

– ([1/LFPR25_64] · Full Time Government Employment)

Hours in Private Business:

Data Sources: 1900-1946: John Kendrick, *Productivity Trends in the United States*, 1961, Table A-X. 1947-2002: BLS Productivity data from www.bls.gov.

Series Creation: 1900-1946 data were multiplied by the ratio of the BLS data in 1947 to the historical data in 1947.

Population:

Data Sources: 1900- 2002 data, including age breakdown, is from the U.S. Census, *Mini Historical Statistics,* Table HS-3 and *Economic Report of the President, 2003*, Table B-34.

Series Creation: Only the resident population was available before 1939. To obtain a better estimate of the total population, we added the number of armed forces overseas during WWI.

School Enrollment:

The school enrollment numbers were obtained by combining information from the *Digest of Education Statistics*, *2002*, *Historical Statistics* Table H-442, and Claudia Goldin "A Brief History of Education in the U.S." August 1999, NBER working paper H0119. The

Digest of Education Statistics contained total enrollment figures annually from 1964 – 2002, and every 10 years before that. We used Goldin's numbers and the *Historical Statistics* enrollment numbers for K-12 to interpolate the total enrollment numbers.

Armed forces

Data are from *Mini Historical Statistics*, Table HS-51.

Government Employment

1900 -1929 data are from Kendrick *Productivity Trends in the United States*, 1961, Table A-VI. Data from 1929-2002 are from BEA NIPA Tables 6.8A-D. The data were spliced using overlap data at 1929. Employment is full-time equivalent workers.

Labor Force

The labor force by age group is available for the years 1900, 1920, 1930,1940, and annually from 1948. We calculated the labor force participation rate as the labor force divided by the non-institutional population. Before 1948, we linearly interpolated the numbers between decades.

Institutional Population

Data on inmates of institutions for people aged 65 and older are available annually from 1940, and for aged 0 to 64, from 1950. We calculated the institutionalization rate for the two age groups, interpolated between years and extending before 1940. Technically we should only subtract the institutional population aged 5 and above since we subtract the total population aged 0 to 4, but the data were not available. The overlap is a very small number since the institutionalization rate of the 0-4 age group is very low.

II. Post-WWII Quarterly Data

Quarterly data on hours in private business, labor force participation rates, labor force, and the civilian noninstitutional populational population are available from the BLS. Data on total population, population by age groups, institutionalization rates, school enrollment, and government employment were interpolated to quarterly figures. The cyclical elements were removed from labor force participation rates and school enrollment using a standard HP filter.

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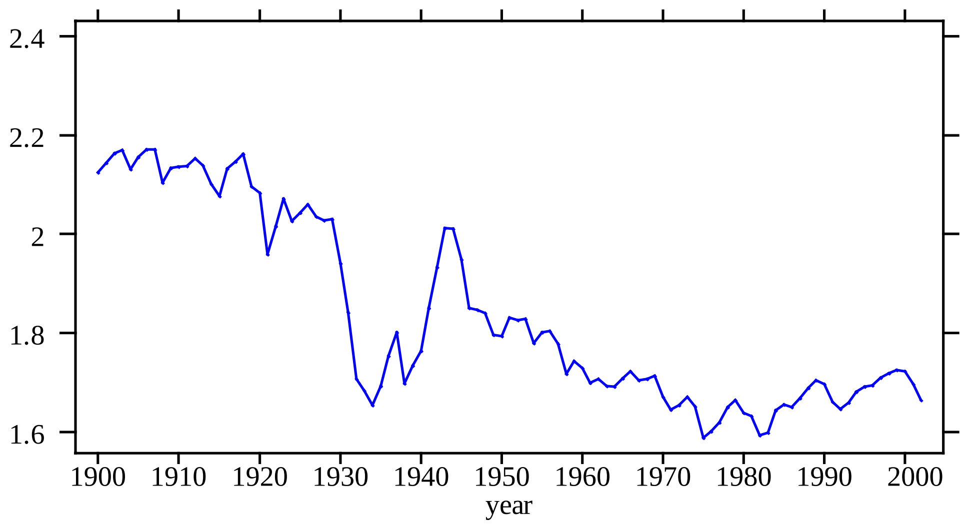
Table 1. Augmented Dickey-Fuller Tests: Quarterly Data 1948-2002
P-values

Variable	**Against H_a: stationarity**	**Against H_a: linear deterministic trend**
Standard hours per capita measure	0.129	0.316
New measure of hours per capita	0.040	0.007

Figure 1: Private Hours Per Capita

A. Based on Civilian Noninstitutional Population Aged 16 and Over



B. Based on Demographically Adjusted Population

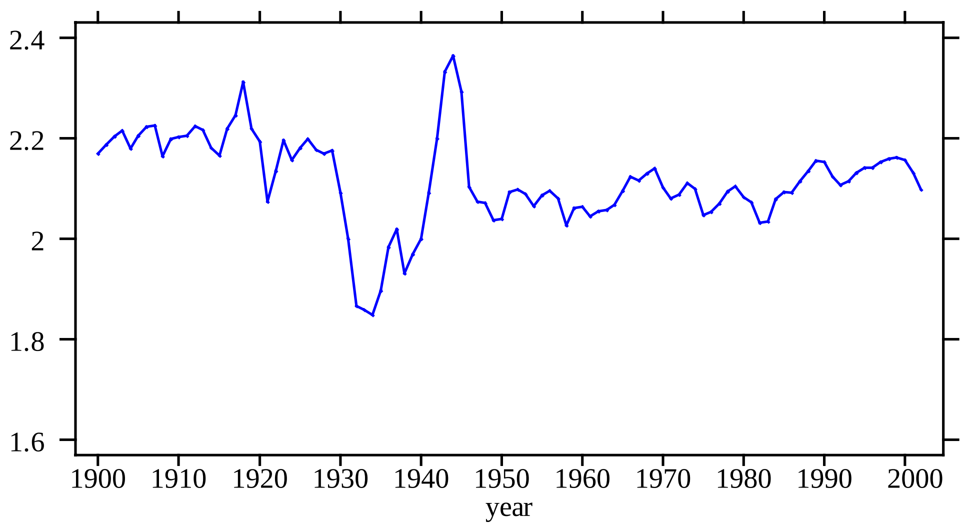


Figure 2. Demographic Groups as a Fraction of Total Population

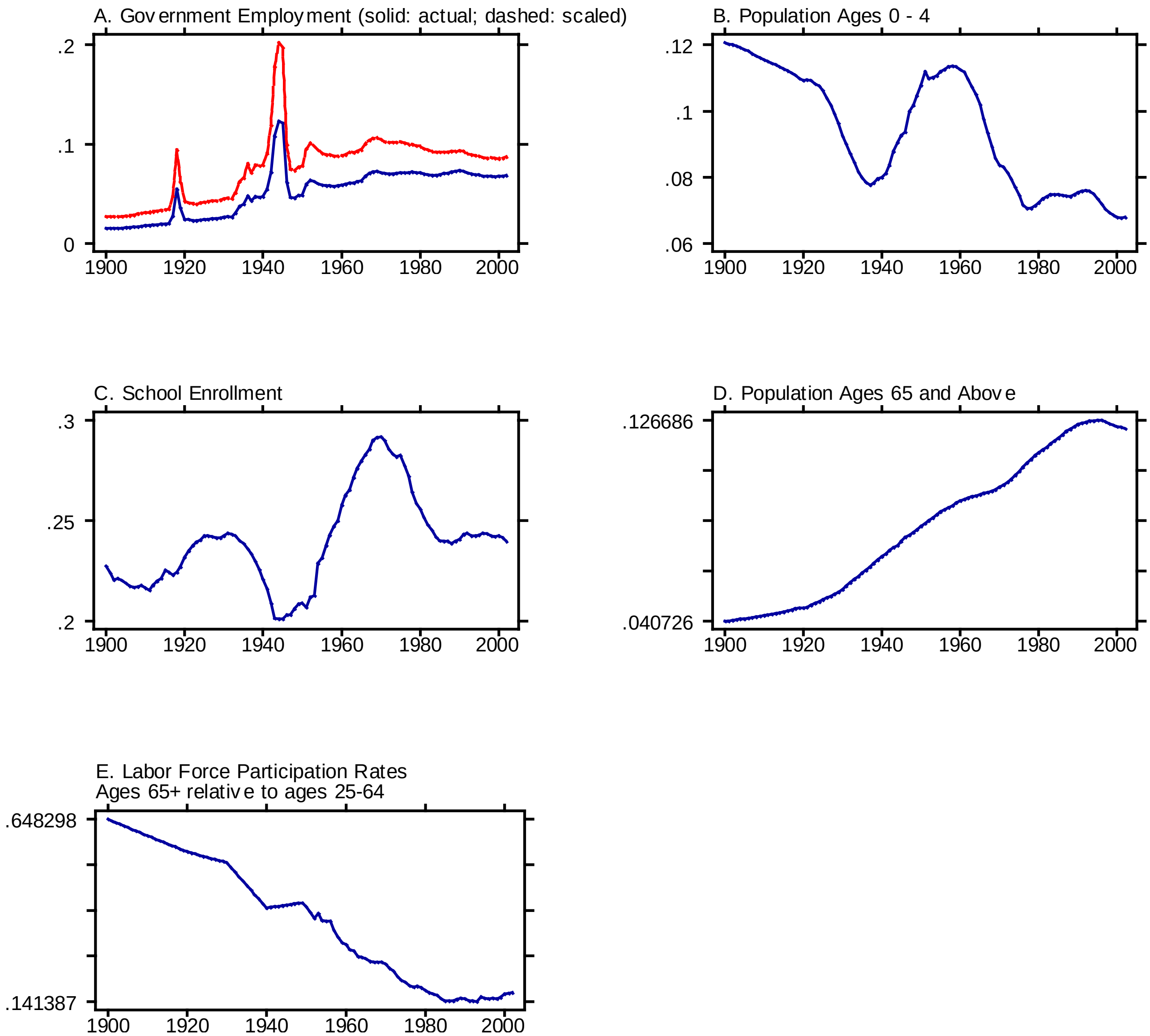


Figure 3. Effects of the Demographic Adjustments

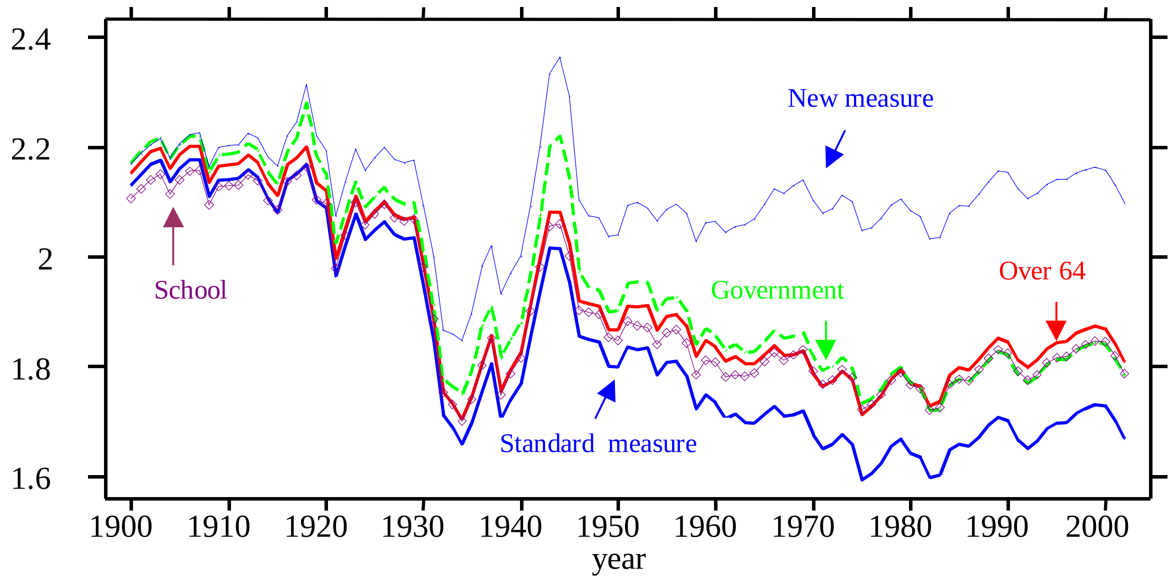
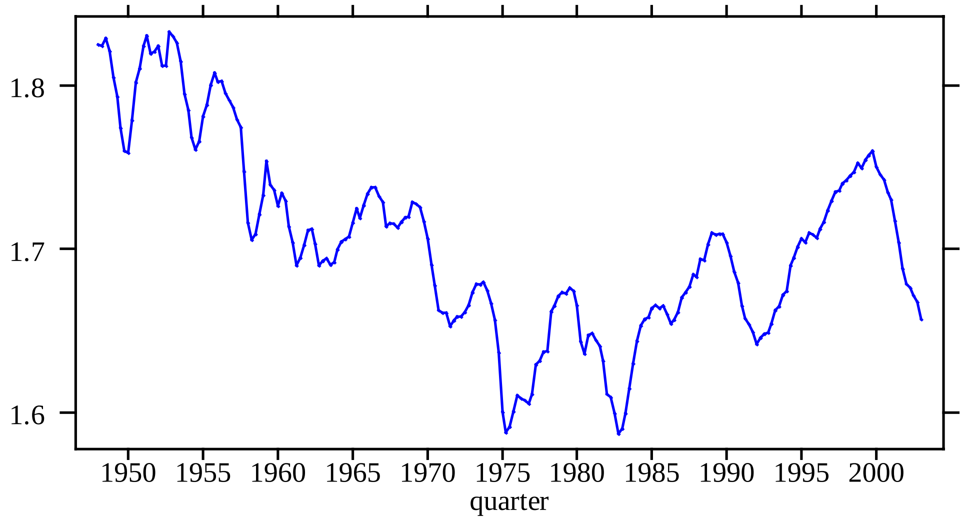


Figure 4. Private Hours Per Capita in Post-WWII Quarterly Data

A. Based on Civilian Noninstitutional Population Aged 16 and Over



B. Based on Demographically Adjusted Population

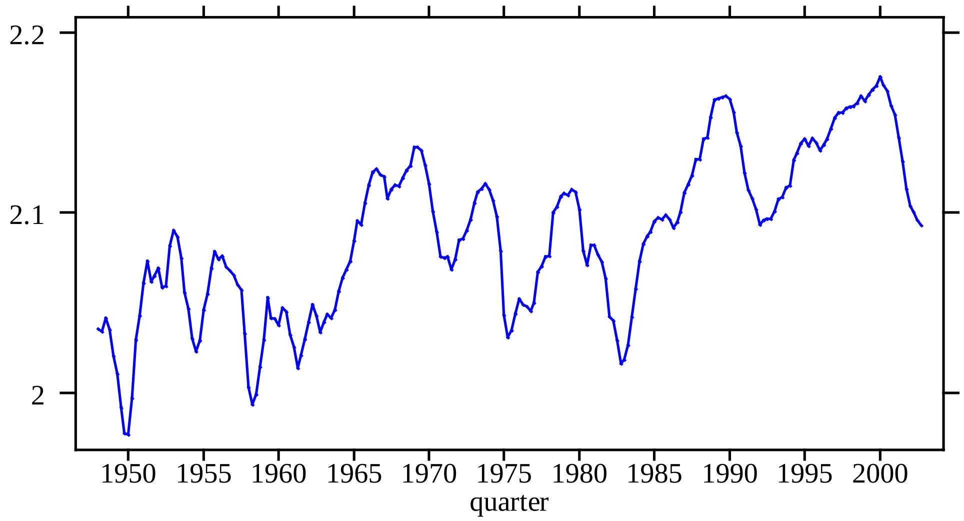


Figure 5. Impulse Responses to a Technology Shock: Quarterly 1948-2002
(Bivariate System with 95% standard error bands)

Stationary Hours

Non-Stationary Hours

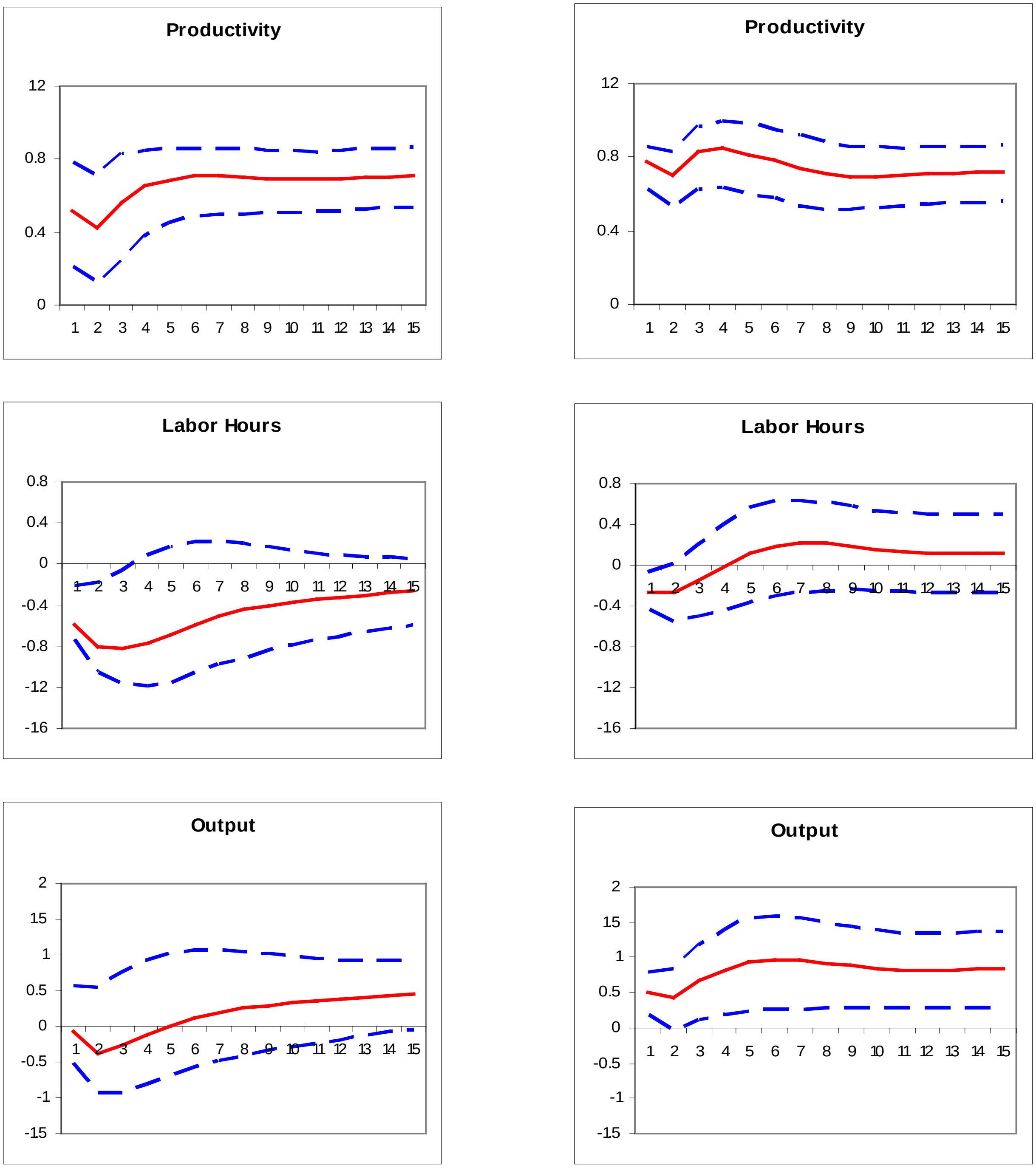


Figure 6. Impulse Responses to a Technology Shock: Quarterly 1954-2002
(Six-Variable VAR with 95% standard error bands, Hours in Levels)