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The New Economy and an Old Problem: Net versus Gross Output

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Abstract

Fifty years ago most economists would have agreed that the appropriate measure of a country's output would be its net domestic product, or output net of the consumption of capital. However, currently the most widely reported and used concept of output that is gross domestic product (GDP). It can be shown that the "new economy" can potentially result in new biases in GDP estimates of output growth. Hence, it is perhaps timely to consider again the problem of how to measure net output. This paper demonstrates how potentially sensitive estimates of GDP growth are to issues arising from the new economy, and how the use of net output can mitigate this problem.

Key words: Net output, gross domestic product, user cost, depreciation, new economy
JEL classification: O47

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1 Introduction

We make a case for placing more emphasis on the calculation and use of net output as a measure of economic activity, especially in light of changes in investment composition and quality changes due to the "new economy." We present different models for calculating net investment, and illustrate their implications for output growth with applications to Canadian data, 1965–1999.

Over at least the last fifty years, the practice of reporting Gross Domestic Product (GDP) and using this to infer the economic performance of a country has been standard across industrialized countries. For example, Spant (2003) notes that the OECD *Economic Outlook* for December 2002 mentions GDP 531 times. However, economists (and accountants) have long thought that the correct measure of output for many purposes is net output, as this takes into account the consumption of capital, or the decline in the efficiency of the available capital stock. Most industrialized countries calculate estimates of net domestic product (NDP), yet the same OECD publication does not make a single reference to NDP.

However, concepts of net output have been of continuing academic interest. For example, Denison consistently used net output in his studies of economic growth (e.g., Dension, 1985). In addition, Hulten (1992, 2005) showed that net output is appropriate for welfare analysis, Asheim and Weitzman (2001) showed that increases in real net national product over time are accurate indicators of true dynamic welfare improvements, and Pezzy (2003) considered the relationship between technical progress measured with gross versus net outputs. Much of this recent interest has been motivated by issues in "green accounting" arising from concern about the depletion of environmental resources; see e.g. Asheim (2000). Landefeld and Fraumeni (2001) highlight the significance of NDP as a measure of sustainable growth. More generally, Spant (2003) argues that because of the growth in the share of rapidly depreciating high technology capital in industrialized countries, a focus on GDP as opposed to NDP has lead to an overstatement of "the real rate of economic growth; productivity increases; the potential for increasing wages without inflationary risks to the labour market; gross business profits, thus increasing the risk of stock market bubbles; and differences in growth rates between countries (e.g. between the United States and Europe)."

Related to this last point, it has been argued that quality adjustment through the use of hedonic regression techniques for calculating investment deflators may be driving up the estimates of gross investment and hence GDP (e.g., Nordhaus, 2000). Some effort has been put into quantifying the size of possible distortions in cross-country comparisons arising from this source (Schreyer, 2001, 2002; Coleccia and Schreyer, 2001; Landefeld and Grimm, 2000; Scheuer, 2001).

It is clear that the extent to which the investment deflator will influence real GDP will depend on the share of investment in GDP, and the share of net investment in GDP will be much smaller (and possibly negative) than gross investment. By switching to a net domestic product concept of national output, the sensitivity of GDP to the choice of the investment deflator is reduced. Hence, two objectives are achieved at once. That is, the more appropriate concept of net output is used, and the controversial problem of quality-adjusting a price index becomes less important in determining a country's relative performance.

In order to calculate net investment, an appropriate depreciation charge must be calculated for each period. The problem of how to best calculate depreciation has been a long-standing one; see, e.g., Babbage (1835) and Böhm-Bawerk (1891). The best solution to this problem is unclear and this has lead to different national statistical agencies employing different methods. There is a strong case for greater focus on this thorny issue in light of the "new economy," or the economic environment that has been created by the large increase in the use of computers and information technology in the last couple of decades.

The paper is organized as follows. Section 2 reviews the controversy surrounding the use of different approaches to quality adjustment by different countries. Section 3 describes our approach to calculating net output, and highlights some problems with the current official numbers on depreciation and hence NDP. Section 4 introduces the two depreciation models that will be considered, the one-hoss-shay model and the linear-efficiency-decline model. These models are chosen as they can, in some circumstances, form lower and upper bounds, respectively, on the depreciation charges. Section 5 describes the three different methods for implementing these depreciation models. Specifically, three alternative methods for estimating expected asset inflation are introduced. Section 6 reports results for 1965–1999 from implementing these depreciation models using Canadian data on investment in machinery and equipment. Section 7 concludes. The data are described in a data appendix.

2 Hedonism versus Asceticism

New capital goods have provided statistical agencies with a problem which is perhaps even greater than the problem of calculating net investment. The rapid increase in the quality of computers (and related goods) has lead to the practice in some countries of adjusting price indexes in order to take into account quality improvements using hedonic regression techniques (Court, 1939; Griliches, 1961, 1994; Silver, 2004; Triplett, 2004). This, in turn, has lead to substantial declines in investment deflators, relative to the unadjusted price indexes (see Figure 1 in section 6 below). The lower deflators lead to higher real investment, and hence higher output levels. The more accelerated the fall in prices, the higher the rates of real GDP growth. This can, in turn, impact on productivity growth estimates (Jorgenson and Stiroh, 2000; Nordhaus, 2000; Gordon, 2000). As not all countries have adopted such methods (e.g., the U.S., Canada, Australia and New Zealand have, Germany has recently and the U.K. has not), there is the possibility that relative real GDP growth rates are being distorted.[1] In addition, not all countries make adjustments in the same way, to the same commodities groups, and they did not all start making adjustments at the same time; for a review of different methods employed in the construction of national accounts by different countries, see e.g. Bover and Izquierdo (2003).

The country which seems to make the most hedonic adjustments is the U.S. Landefeld and Grimm (2000) reported that 18% of GDP final expenditures are deflated using indexes

[1] Schreyer (2002, p. 1, footnote 1) notes that this issue has received widespread attention: "America's hedonism leaves Germany cold," *Financial Times*, 4 September 2000; "Apples and Oranges," *Lehman Brothers Global Weekly Economic Monitor*," September 2000; *Monthly Report of the Bundesbank*, August 2000; "The New Economy has arrived in Germany—but no one has noticed yet," *Deutsche Bank Global Market Research*, 8 September 2000; Wadhwani, Sushil, "Monetary Challenges in a New Economy," speech delivered to the HSBC Global Investment Seminar, October 2000.

that are calculated with hedonic methods, and this figure is now probably higher. Even with unprecedentedly steep declines for some hedonic price indexes, there is some empirical support for these indexes using matched-model indexes from high-frequency data (Aizcorbe, Corrado and Doms, 2000). Moulton (2001) notes the commitment of U.S. statistical agencies to increase the use of hedonic methods, as there is a view that much quality change is still being missed by statistical agencies. However, this view is not shared by all countries, and there has been much interest in the role of statistical agency methodology in driving the U.S.–Europe output growth and productivity gap of the late 1990s.[2]

Obviously, these problems of different national accounts methodologies will not matter for international comparisons if they do not affect the comparisons. Wyckoff (1995) examines labour productivity in the computer and software equipment sector across OECD countries, applying the hedonically adjusted U.S. price deflator for this sector to each country's nominal output figures. He finds that most of the differences in productivity in this sector between countries can be attributed to different methodologies in calculating the price deflator. Van Ark (2000) finds supporting evidence of this result for the 1990s for the European countries which still did not use hedonic price indexes.

So, for some sectors of the economy the choice of deflator will have significant effects on international comparisons. However, at the aggregate level, it is unclear whether the impact is significant. Pakko (2002, table 1, p. 4) reports that, on average, the contribution of equipment and software investment in the U.S. was 1.09% to GDP growth of 4.11% for the period 1995-2000, compared with a 0.12% contribution to 3.53% GDP growth in the 1950s. For New Zealand, which uses hedonic methods, the deflator for Plant, Manufacturing and Machinery fell by 29% over the period 1992–1999, while the GDP deflator rose 8.8% over same period. Plant, Machinery and Equipment has been growing as a percentage of real GDP: 5% in 1988, 9% in 1999. These observations indicate a large increase in the role of investment in determining GDP growth.

[2]The treatment of some high technology goods as either investment or intermediate goods has also been of concern. For example, the share of total software expenditures recorded as investment differs greatly between OECD countries, such as 4% for the UK and 70% for Spain (Ahmad et al., 2003).

However, Scheuer (2003) estimates that "the growth differential between Germany and the United States over the second half of the nineties is likely to have been just over 0.4 percentage points p.a. smaller if more harmonised methods had been used to deflate IT goods and to calculate software investment." Schreyer (2002), using a range of simulations, found similarly small impacts from the choice of deflator for international comparisons. Thus, it seems that different deflators can only explain part of the growth difference between countries, such as the 2.5% average between the U.S. and Germany for 1996–2002. However, it should be noted that such comparisons are fraught with difficulties, as results will depend on which country's deflator is chosen to apply across countries, the fact that different countries probably should have different deflators anyway, and that the choice of deflator is not the only difference in statistical techniques used across countries (e.g. there are also differences in terms of index number formula used). Therefore, the impact may be larger or smaller than current estimates but, other things equal, it is likely to be growing given the growing share of investment in high technology capital goods. This is mitigated in practice by an increasing trend for statistical agencies to embrace hedonic techniques.[3] However, even small differences can accumulate over time to be sizable.

3 Net Output

We have argued above that the choice of the price deflator can have an impact on estimates of real GDP growth, making this choice somewhat controversial. To investigate this impact empirically, we can consider two approaches. The most obvious approach is to somehow estimate nominal net investment, then vary the deflator and observe the impact on real

[3]Even Germany now uses hedonic methods. "In May 2004 the German statistics agency, the Statistisches Bundesamt, extended the use of the hedonic method to IT products of the producer, import and export price indexes and also the wholesale price index....Prior to this, hedonic quality adjustment had only been applied by the German statistics agency to subsets of the consumer price index. Since June 2002 this has included a sub-index for personal computers and since May 2003 a sub-index for used cars based on hedonic methods....In early 2004 hedonic price measurements were also used to calculate a house price index as part of a European pilot study. Work is currently in progress on hedonic consumer price indexes for the subsets "electrical household appliances" and "consumer electronics". The intention is to implement these in our regular reporting by January 2005." (Linz, Behrmann, Becker, 2004).

GDP; as noted above, this is the approach that has been used by several studies. However, it is unclear how the deflator should be varied, and such arbitrary manipulation of a variable seems somewhat contrived.[4]

Therefore, we consider different depreciation models to calculate nominal net investment in order to empirically examine the extent to which real (net) GDP differs in each case. This approach can be thought of in two ways. First, it demonstrates the fall in the share of investment in GDP under competing depreciation models, and hence the relative decline in importance of the investment deflator. Second, the resulting estimates of real net investment can be thought of as being calculated by dividing gross investment by different deflators. In each case, these implicit deflators will be larger than the usual gross-investment deflator. Also, they will not generally be a simple constant proportion of the usual deflator.

While this approach is equivalent, in empirical terms, to varying the deflator for investment, there remains a degree of arbitrariness. There is no clear consensus on which of a multitude of proposed depreciation models should be used for calculating net investment. Hence, two models of depreciation are considered, and three different ways of implementing these models. This can be thought of giving us six different implicit deflators for gross investment.

We consider an application to Canadian data to see what impact the different methods have on output growth, where we only consider depreciation for investment in machinery and equipment. However, first we consider the official gross and net output statistics reported by the OECD. Table 1 reports average gross and net output growth, along with the ratio of depreciation to GDP, for 16 countries, 1995–2000. What can be seen immediately is that GDP growth is higher than NDP growth on average, except for Finland and the U.K. While most countries had depreciation increasing relative to GDP between 1995 and 2000 (with considerable variation between countries), these two countries had a decrease in the importance of depreciation. As Spant (2003, p. 42) notes, this seems very unlikely:

[4]The deflator could just be increased or decreased by some constant proportion for each year, but this is quite uninformative as it is equivalent to multiplying real investment by a scaling factor.

"Given the dominant role of GDP and low interest in NDP, it is very possible that the current estimates of depreciation for certain countries are not based on up-to-date estimates of the service lives of capital assets and hence may not be capturing true changes in depreciation patterns. Therefore, we must be very careful in interpreting OECD estimates for NDP. The Finnish and UK cases are warning examples. Is it really possible that the relative importance of depreciation can be falling in economies undergoing enormous structural changes and where the role of long-term infrastructure investments is reduced and the growth in investment shifting to ICT assets?"

Hence, given what can be seen from the official statistics, it seems timely to consider different methods of calculating depreciation and their impact on estimates of net output growth.

4 Depreciation Models

There has been much debate over the years about which method of depreciation is most appropriate. Here we consider two models, the one-hoss-shay model and the linear-efficiency model. These models are chosen as they can be thought of as possible extremes, or "bounds" for other possible models.[5]

After introducing these two models, we then turn to the issues of how to estimate asset inflation and the real interest rate. Both issues need to be resolved in order to implement the depreciation models.

The price of a durable asset of vintage n, $n = 0, 1, \ldots$, at the beginning of time period t

[5]See Diewert (2005), who considers two additional depreciation models in an empirical application, the straight-line-depreciation model and the geometric-depreciation (declining-balance) model. Given certain assumptions on the rate of depreciation for the geometric-depreciation model, the one-hoss-shay and linear-efficiency models form the upper and lower bounds respectively on the estimates of the capital stock. For more on depreciation models see, e.g., Hulten (1990), Hulten and Wykoff (1981a)(1981b)(1996), Jorgenson (1989)(1996), and Diewert and Lawrence (2000).

can be written as follows:

$$P_n^t = f_n^t + [(1+i^t)/(1+r^t)]P_{n+1}^t, \tag{1}$$

where f_n^t is the beginning of period t rental price or "user cost" of the asset, i^t is the expected one-period asset inflation rate, and r^t is the expected one-period nominal interest rate.[6] The determination of i^t and r^t are further discussed in section 5, but note that it is assumed that i^t and r^t are the same for each vintage of capital, n.

Equation (1) represents the value of an asset of n periods of age at the start of period t as equal to the rental price that the asset can earn during the period, f_n^t, plus the value of the asset at the end of the period, $(1+i^t)P_{n+1}^t$ discounted back to the beginning of the period using $(1+r^t)$ as the discount factor. The price of an asset of vintage $n+1$ can be related to the price of an asset of vintage n using the following relationship,

$$P_{n+1}^t = (1-\delta_n^t)P_n^t. \tag{2}$$

From (2) and a knowledge of P_{n+1}^t and P_n^t, the period t depreciation rate δ_n^t for an asset of vintage n can be calculated. Using (2), equation (1) can be re-expressed as follows:

$$P_n^t = f_n^t + (1+r)^{-1}[(1+i^t)(1-\delta_n^t)]P_n^t. \tag{3}$$

This can be re-arranged to get an expression for the beginning of period t user cost of the asset, f_n^t:

$$\begin{aligned} f_n^t &= (1+r^t)^{-1}[(1+r^t)-(1+i^t)(1-\delta_n^t)]P_n^t \\ &= (1+r^t)^{-1}[r^t - i^t + (1+i^t)\delta_n^t)]P_n^t \end{aligned} \tag{4}$$

Or, equivalently, multiplying and dividing the right-hand-side of (4) by one plus the general

[6]Similar expressions have been used by, e.g., Christensen and Jorgenson (1969)(1973), Jorgenson (1989), Hulten (1990) and Diewert and Lawrence (2000).

inflation rate, ρ^t, we get

$$\begin{aligned} f_n^t &= (1+r^{*t})^{-1}[(1+r^{*t}) - (1+i^{*t})(1-\delta_n^t)]P_n^t, \\ &= (1+r^{*t})^{-1}[r^{*t} - i^{*t} + (1+i^{*t})\delta_n^t)]P_n^t \end{aligned} \tag{5}$$

where $1+r^{*t} = (1+r^t)/(1+\rho^t)$ is one plus the expected one-period real interest rate, and $1+i^{*t} = (1+i^t)/(1+\rho^t)$ is one plus the expected one-period real rate of asset inflation.

Now, we define π_n^t as the *ex ante* time series depreciation rate for an asset that is n periods old at the beginning of period t. That is, the rate of anticipated (real) price decline for an asset with price P_n^t at the start of period t and an anticipated price of $(1+i^t)P_{n+1}^t$ at the start of period $t+1$.[7] Then, π_n^t can be written as

$$\begin{aligned} \pi_n^t &= [P_n^t - (1+i^{*t})P_{n+1}^t]/P_n^t \\ &= [1-(1+i^{*t})(1-\delta_n^t)]. \end{aligned} \tag{6}$$

Substituting π_n^t into equation (5) we get

$$\begin{aligned} f_n^t &= (1+r^{*t})^{-1}[r^{*t} + \pi_n^t]P_n^t \\ &= (1+r^{*t})^{-1}r^{*t}P_n^t + (1+r^{*t})^{-1}\pi_n^t P_n^t. \end{aligned} \tag{7}$$

The first term in equation (7) times the number of units of vintage n capital in use, Q_n^t, is the beginning of period t opportunity cost of the vintage n financial capital. This is a primary input charge. The second term in (7) times Q_n^t is the beginning of period t depreciation. It is this second term which is of use in adjusting the national accounts for depreciation charges to gross investment in constructing measures of net domestic output.

In section 6 below, we use the reported national accounts data on investment as end-

[7]Note that δ_n^t from equation (2) can be described as the rate of "cross-section" depreciation, or the rate of depreciation due solely to the aging of an asset, whereas π_n^t is the rate of decline in the value of an asset over time, which can include changes in price due to factors other than aging. Note that the two concepts of depreciation coincide if the real asset inflation rate $i^{*t} = 0$. See Hill (1999, 2000) and Diewert (2004) for more on these definitions of depreciation.

of-period values. Hence, we find it convenient to work with the end-of-period user cost of capital, u_n^t, defined as follows:

$$\begin{aligned} u_n^t &\equiv (1+r^t)f_n^t \\ &= (1+\rho^t)(r^{*t}+\pi_n^t)P_n^t \qquad \text{using (7)} \\ &= (1+\rho^t)r^{*t}+(1+\rho^t)\pi_n^t P_n^t, \end{aligned} \tag{8}$$

so that $(1+\rho^t)r^{*t}Q_n^t$ is the end-of-period opportunity cost of vintage n capital, and $(1+\rho)\pi_n^t P_n^t Q_n^t$ is the end-of-period national accounts depreciation. In order to calculate period t net investment, $NETINV^t$, we need to subtract this depreciation from the value of gross investment in period t, I^t:

$$NETINV^t = I^t - \sum_{n=0}^{L-1}(1+\rho^t)\pi_n^t P_n^t Q_n^t, \tag{9}$$

where the useful life of an asset is L periods.[8] Then, to get real net investment, $RNETINV^t$, we divide $NETINV^t$ by the gross investment price deflator from the national accounts.

It is the choice of the deflator for investment which has caused much debate in recent years, as discussed in the introduction. From equation (9) we can see that the choice of deflator matters less the closer net investment is to zero. Clearly, the choice of deflator is irrelevant in the case of net investment being zero.

In the following two sections two different depreciation models are considered for the determination of the vintage prices, P_n^t, that are needed for the calculation of net investment in (9). Once these prices are determined, the rate of time series depreciation, π_n^t in (6) is also determined, and hence net investment for each period t can be calculated using (9).

[8] Note that $n = 0, 1, \ldots, L-1$ represents L periods.

4.1 One-hoss-shay model

It is possible that many assets yield a constant level of services throughout their useful lifetime of L periods, then suddenly expire.[9] The example of a light bulb is the most commonly suggested to fit this description of depreciation. Many other examples can and have been given, with the idea dating back at least to Böhm-Bawerk (1891; 342).[10]

Assuming that this depreciation scheme is the most accurate description of the efficiency of the asset over its lifetime, the beginning of period t user costs are as follows:

$$\begin{aligned} f_n^t &= f^t \qquad \text{for } n = 0, 1, \ldots, L-1; \\ &= 0 \qquad \text{for } n = L, L+1, \ldots, \end{aligned} \tag{10}$$

where is the useful lifetime of the asset is L periods long, so that the last period of its life is $L - 1$ after which point its rental price falls from a constant f^t to suddenly zero.

Using equations (10) in equation (1), defining $\gamma^t = (1 + i^t)/(1 + r^t)$, and re-arranging we get

$$\begin{aligned} P_n^t &= f^t[1 + \gamma^t + (\gamma^t)^2 + \ldots + (\gamma^t)^{L-n-1}] \quad \text{for } n = 0, 1, \ldots, L-1; \\ &= 0 \qquad \text{for } n = L, L+1, \ldots, \end{aligned} \tag{11}$$

which can be solved to yield f^t, given the price of a new asset P_0^t. Once f^t is known then the beginning of period prices for all the $n = 1, \ldots, L-1$ vintages can be determined. These then yield the depreciation rates, δ_n^t through equation (2), and hence we can calculate the time series deprecation rate, π_n^t, in equation (6).

We then have all the information necessary in order to calculate net inventory from equation (9), once we have determined the anticipated real rate of asset inflation, i^{*t} that appears in the definition of π_n^t in (6), and the anticipated rate of interest, r^t that appears

[9]The terminology "one-hoss shay" in this context seems to have eventuated from the poem "The Deacon's Masterpiece, or the Wonderful One-Hoss Shay: A logical story" by Oliver Wendell Holmes. We thank Bruce Grimm and Doug Meade for this reference.

[10]Hulten (1990; 124) gives the example of a 20 year-old chair doing the same job as a one-year old chair. However, this clearly depends on the initial quality of chair, and certainly does not apply to most 20 year-old chairs found in university offices.

through γ^t in equation (11). How to determine the rate of inflation and corresponding interest rate is left until section 5, while in the following section we first consider another model of asset depreciation that makes quite different assumptions about the efficiency of an asset over its lifetime.

4.2 Linear-efficiency-decline model

In the previous model, the asset delivered a constant stream of services up until the period before its total collapse into uselessness. This is a rather extreme view of depreciation. Hence, another model is introduced which assumes that the efficiency of an asset declines in a linear fashion, so that for an asset of useful life L, the beginning-of-period user cost, f_n^t is as follows:

$$\begin{aligned} f_n^t &= f^0[L-n]/L \qquad \text{for } n = 0, 1, \ldots, L-1; \\ &= 0 \qquad \text{for } n = L, L+1, \ldots. \end{aligned} \tag{12}$$

Hence, the user cost, or rental price of the asset of vintage n declines by a constant amount each year.

Using equations (12) in equation (1), defining $\gamma^t = (1+i^t)/(1+r^t)$, and re-arranging we get

$$\begin{aligned} P_n^t &= f_0^t[(L-n) + (L-n-1)\gamma^t + \ldots + 1(\gamma^t)^{L-1-n}] \quad \text{for } n = 0, 1, \ldots, L-1; \\ &= 0 \qquad \text{for } n = L, L+1, \ldots, \end{aligned} \tag{13}$$

which can be solved to yield f_0^t, given the price of a new asset P_0^t. Once f_0^t is known then the beginning of period prices for all the $n = 1, \ldots, L-1$ vintages can be determined. These then yield the depreciation rates, δ_n^t through equation (2), and hence we can calculate the time series deprecation rate, π_n^t, in equation (6).

We then have all the information necessary in order to calculate net inventory from equation (9) under two different depreciation models, once we have determined the anticipated rate of asset inflation, i^t, that appears in the definition of π_n^t in (6), and the anticipated rate of interest, r^t that appears through γ^t in equations (11) and (13). This issue is addressed in the following section.

5 Anticipated Asset Inflation

In order to implement the two depreciation models in section 4 we need to have estimates of expected asset inflation, i^t, and the expected interest rate, r^t. We consider three ways of getting estimates of i^t, and use corresponding estimates of r^t. The three approaches are as follows.

1. *Ex post inflation*: A simple approach is to assume that producers have perfect foresight, and hence exactly anticipate the asset-inflation rates that are realised. In this case, i^t is calculated directly from from the ex post data. Hence, we refer to this case as the "ex post inflation" case. For the expected interest rate, we follow the Australian Bureau of Statistics and assume a constant real rate of interest of 4%, or $r^{*t} = 0.04$. The nominal interest rate r^t is then calculated using $(1 + r^t) = (1 + r^{*t})(1 + \rho^t)$, where ρ^t is the period t general inflation rate from the consumer-price index (CPI).

2. *General inflation*: An equally simple approach is to assume that producers use the CPI to estimate asset inflation rates, i^t. As this case uses general consumer prices, rather than prices specific to investment, we refer to this case as the "general inflation" case. The expected interest rate is determined as in the ex post inflation case.

3. *Ex ante inflation:* The last approach assumes that producers use the trend of ex ante inflation rates to estimate asset inflation, rather than the more volatile ex post rates. That is, producers do not anticipate exactly all the variation in the asset inflation rates, but get the trend right.[11] Unfortunately, there is no unique way of determining this trend. Fortunately, standard econometric and statistical software come with various techniques for smoothing data, and these smoothed series can be taken to be the long-run trend series.[12] In section 6 we use the locally-weighted-regression method,

[11] See Epstein (1977) for possibly the first use of this approach to estimating anticipated price changes.

[12] Smoothing of this sort in order to get trend series is a common practice in macroeconomics in particular.

commonly known as the LOWESS smoother (Cleveland, 1979; Cleveland and Devlin, 1988; White, 1997).[13]

In combination with the two depreciation models of section 4, the above three approaches to estimating asset inflation yield a total of six possible ways of calculating net investment, and hence net output.

6 Results

Data for Canada are used to empirically implement the depreciation models described in section 4. Specifically, we calculate net investment in machinery and equipment, and the corresponding levels and growth rates of both real GDP and "net real GDP." We refer to net output here as "net real GDP" as we are only considering depreciation of machinery and equipment, rather than for all asset classes. The appendix has more details about the data, with real GDP, real investment in machinery and equipment, the deflator for machinery and equipment, the CPI inflation rate, the ex post inflation rate, the nominal interest rate and the respective smoothed values for 1965–1999 reported in table A1. The length of an asset's life, L, is taken to be 14 years following Madison (1993).[14]

Figure 1 plots the price index (deflator) for machinery and equipment investment from the national accounts. The almost constant decline in the index from 1983 to 1999 reflects

[13] As with most smoothing algorithms, LOWESS requires the choice of a smoothing parameter. This smoothing parameter determines the smoothness of the resulting series, with larger values implying a higher penalty for "roughness." Values consider were 0.20, 0.25, 0.30, with the cross-validation model-selection criterion used to determine the more appropriate smoothed series from the resulting three options. For smoothing the ex post asset inflation rates, the smoothing parameter of 0.20 was best, while the smoothing parameter of 0.30 was best for the interest rates.

[14] In terms of the well-known geometric depreciation model, and using the assumption in this model that $\delta_n^t = \delta = 2/(L+1)$, this corresponds to assuming a geometric depreciation rate of 13.3%. See, e.g., Diewert (2005) and Hotelling (1925) for more on this model of depreciation. Different countries make quite different assumptions about service lives (OECD, 1993). "For machinery and equipment (excluding vehicles) used in manufacturing activities, the average life ranged from 11 years for Japan to 26 years for the United Kingdom. For vehicles, the average service lives ranged from 2 years for passenger cars in Sweden to 14 years in Iceland and for road freight vehicles, the average life ranged from 3 years in Sweden to 14 years in Iceland. For buildings, the average service lives ranged from 15 years (for petroleum and gas buildings in the U.S.) to 80 years for railway buildings in Sweden." (Diewert, 2005).

the use of hedonic adjustment techniques by Statistics Canada. It is this kind of quite dramatic decline in the price index, which is a complete reversal of the trend in the series up until 1982, that has some statistical agencies, commentators and economists concerned about the effects of inappropriate deflation techniques on growth estimates. Hence, we look at how to minimize the potential impact of inappropriate deflation through the use of real net investment in place of real gross investment.

Table 2 reports summary statistics for real gross investment (or the quantity of investment) in machinery and equipment (QIME) for various periods of interest, as well as the estimates of real net investment from the six different depreciation models of section 4.[15] Under similar assumptions on anticipated inflation and interest rates, we can note that as the linear-efficiency-decline (LED) models imply a more accelerated rate of depreciation, real net investment is lower than for the one-hoss-shay (OHS) models. For example, for the ex post inflation case for 1965-1999, the real net investment from the OHS model (in constant 1992 Canadian dollars) is \$3.85 billion, while for the LED model it is \$2.98 billion. Note that \$3.85 billion is only 15% of the average gross real investment for this period, and \$2.98 billion is 11.7%. Over this period, the share of real gross investment in equipment and machinery in real GDP was around 4% (2% initally, growing to 8%). Hence, the share of net real investment in real GDP is substantially smaller, to the point where the choice of deflator becomes almost irrelevant in determining real GDP levels and growth.

From table 2 we can see that the ex post inflation models have the most volatility, the ex ante inflation models have the least volatility, and that for all six models the 1990s had the most volatile estimates of real net investment. This can be confirmed by observing figures 2 to 4 that plot each of the real net investment series, along with gross real investment (QIME). The increased volatility in each of the net investment series since the 1980s is immediately obvious (even in figure 4 which plots the smoothed, ex ante inflation models), and especially the volatility of the 1990s. In particular, there is a noticeably large fall in figures 2 and 3 in the net investment series between 1990 and 1991. This coincides with a large fall in

[15]All computations were performed using the SHAZAM computer program (White, 1997).

the price of machinery and equipment between these years, as can be seen from figure 1. The real gross investment series actually grows slightly (by 0.5%) between these years. If the deflator had not fallen as dramatically between these years, then real gross investment would have fallen, and hence it would have not contributed as much to real GDP as it did. It is observations such as these that raise concerns about adjustments to the investment deflator, and suggest the use of net investment.

Table 3 and figures 5 to 7 show summary statistics and plots, respectively, for real GDP and net real GDP under each of the six depreciation models. The levels in table 3 reflect the observations made relating to the real net investment estimates in table 2. In terms of means, the real net GDP from the ex-post-inflation LED model is 95% of real GDP. However, this percentage varies over the sample, as can be seen from figure 5, with net real GDP becoming only 91% of real gross GDP by 1999. A similar pattern can be seen from the other models in figures 5 through to 7.

Of particular interest is the impact of the large decline in the price deflator between 1990 and 1991 on real GDP estimates. Note that all the real GDP estimates fell in 1991. However, from figures 5 and 6 in particular, we observe that the large decline in the deflator prevented real GDP from falling as much as for the net real GDP models. That is, the substantial decline in the deflator was not enough to stop net real GDP from dropping sharply. In this sense, the estimates of net real GDP are less sensitive to the choice of deflator. In particular, note that the general-inflation LED model depends on the CPI for determining the asset-inflation rate, i^t, is less dependent of the large fall in deflator for machinery and equipment, and has a substantial fall in the level of net real GDP in 1991.

The corresponding real GDP growth rates are reported in table 4, with each series plotted in figures 8 through 10. From table 4, the growth in real GDP for 1966 to 1989 was almost 4%, while for the period 1990 to 1999 it was only 2.3%. This is a rather poor performance, on average, by the Canadian economy. What is of even more concern is that the net real GDP growth estimates are substantially lower, such as 1.85% in the latter period for the ex-post-inflation OHS model. From figures 8 to 10, the growth rates differ most in the 1990s, the period when there was more volatility in the deflator and adjustments were being made for quality. In particular, growth in 1991 was much lower (larger negative number) for the net real GDP series. It is also interesting to note from figures 8 and 9 that estimated net real GDP growth was much higher in 1997 than for gross real GDP growth.[16]

7 Conclusion

It has been argued that cross-country comparisons of economic growth and productivity are complicated by different countries employing different methodologies for accounting for quality change of investment goods. Even if similar methods are used, they are not typically introduced at the same time by all statistical agencies.

The use of net output as the main concept of output for growth comparisons is a solution to this comparability issue, as the role of investment is greatly reduced once depreciation is subtracted. As the advent of the "new economy" has increased the proportion of investment in rapidly depreciating goods, it is argued that the old problem of how to best calculated depreciation needs further attention. This is particularly so given that different countries produce such radically different estimates of depreciation as a proportion of gross output. Regardless of the arguments relating to the new economy and quality change, the issue of depreciation calculation in national accounts deserves more attention as net output can be regarded as an important indicator of national welfare and sustainable growth.

Using data for Canada, we showed how rapid price declines in the investment deflator for machinery and equipment have had a notable impact on conclusions about economic growth. This application is intended as a first step in a broader set of investigations into the calculation of net output, and the impact on international comparisons. Continuing work in this area will hopefully stimulate a renewed focus on net output as an appropriate measure of economic activity.

[16]The different growth rates for 1999 that can be seen in figures 8 to 10 illustrate how potentially difficult it can be to forecast economic activity.

Appendix

The data used in this paper are given in table A1. The value and quantity (constant 1992 dollars) of investment in machinery and equipment, in millions of dollars, is taken from the *Canadian Economic Observer: Historical Statistical Supplement 1999/00*, CAT. No. 11-210-XPB. Prices are then calculated by dividing quantity value by quantity. The prices are taken to be end-of-period prices, so that beginning of period prices are the end-of-period prices from the year before. See Diewert (2004) for more on the data.

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Table 1: Gross versus Net Domestic Product Growth

	Compound Average Annual Growth Rates 1995-2001		Difference: GDP growth− NDP	Real Depreciation as percentage of Real GDP		Difference: 2001-
	Real GDP	Real NDP	growth	1995	2001	1995
Australia	3.87	3.59	0.27	15.63	16.95	1.33
Austria	2.40	2.26	0.15	14.05	14.78	0.73
Belgium	2.41	2.22	0.19	14.22	15.17	0.95
Canada	3.56	3.41	0.15	13.16	13.90	0.74
Denmark	2.48	2.05	0.43	15.98	18.07	2.09
Finland	4.11	4.67	-0.56	18.17	15.48	-2.69
France	2.48	2.42	0.06	13.74	13.98	0.24
Germany	1.60	1.38	0.21	14.79	15.87	1.07
Greece	3.54	3.50	0.04	9.07	9.28	0.22
Iceland	4.60	4.09	0.52	14.69	17.18	2.49
Italy	1.92	1.80	0.12	13.10	13.69	0.59
Netherlands	3.29	3.20	0.10	15.12	15.60	0.48
Spain	3.64	3.52	0.12	13.00	13.61	0.60
Sweden	2.90	2.68	0.22	13.34	14.44	1.10
United Kingdom	2.76	2.85	-0.09	12.09	11.65	-0.45
United States	3.42	2.93	0.48	11.58	14.03	2.45
Unweighted 16-country average	3.06	2.91	0.15	13.86	14.60	0.75

Source: Spant (2003), using OECD National Accounts. Data for France, 1995-2000 only.

Table 2: Real Investment, Levels

	MEAN	ST. DEV	MINIMUM	MAXIMUM
1965-99				
QIME	25.54	18.17	6.01	75.56
OHS.RNETINV1	3.85	8.37	-25.88	25.52
LED.RNETINV1	2.98	6.38	-19.13	20.69
OHS.RNETINV2	9.87	7.71	1.91	32.89
LED.RNETINV2	3.02	6.26	-17.95	20.65
OHS.RNETINV3	4.22	4.20	-1.49	17.08
LED.RNETINV3	3.13	3.94	-3.37	14.90
1965-82				
QIME	11.76	5.18	6.01	23.59
OHS.RNETINV1	2.44	2.87	-6.98	6.21
LED.RNETINV1	2.01	1.82	-3.66	4.76
OHS.RNETINV2	4.74	2.69	1.91	11.89
LED.RNETINV2	2.03	1.72	-3.12	4.79
OHS.RNETINV3	2.59	1.26	0.04	4.70
LED.RNETINV3	2.07	1.10	-0.40	4.10
1983-99				
QIME	40.12	15.30	19.52	75.56
OHS.RNETINV1	5.35	11.64	-25.88	25.52
LED.RNETINV1	4.02	8.99	-19.13	20.69
OHS.RNETINV2	15.30	7.61	6.20	32.89
LED.RNETINV2	4.08	8.82	-17.95	20.65
OHS.RNETINV3	5.94	5.45	-1.49	17.08
LED.RNETINV3	4.25	5.39	-3.37	14.90
1965-89				
QIME	16.36	9.48	6.01	39.22
OHS.RNETINV1	2.79	3.22	-6.98	9.59
LED.RNETINV1	2.20	2.51	-3.66	7.95
OHS.RNETINV2	6.65	4.56	1.91	18.50
LED.RNETINV2	2.19	2.45	-3.12	7.78
OHS.RNETINV3	2.80	1.89	-1.49	7.11
LED.RNETINV3	2.18	1.91	-2.44	6.62
1990-1999				
QIME	48.48	13.76	36.86	75.56
OHS.RNETINV1	6.53	15.03	-25.88	25.52
LED.RNETINV1	4.95	11.45	-19.13	20.69
OHS.RNETINV2	17.92	8.27	10.30	32.89
LED.RNETINV2	5.11	11.19	-17.95	20.65
OHS.RNETINV3	7.77	6.13	-1.41	17.08
LED.RNETINV3	5.52	6.32	-3.37	14.90

Notes:
OHS: One-Hoss-Shay models
LED: Linear-Efficiency-Decline models
QIME: Quantity of Investment in Machinery and Equipment
RNETINV: Real Net Investment
1=Ex post inflation, 2=General inflation, 3=Ex ante inflation
Constant 1992 Canadian dollars, billions.
Arithmetic Means

Table 3: Real GDP, Levels

	MEAN	ST. DEV	MINIMUM	MAXIMUM
1965-99				
RGDP	561.31	171.18	281.25	880.25
OHS.NETRGDP1	539.63	156.56	277.68	803.89
LED.NETRGDP1	538.76	156.04	277.37	808.37
OHS.NETRGDP2	545.64	160.82	277.16	837.59
LED.NETRGDP2	538.80	156.08	277.38	808.89
OHS.NETRGDP3	539.99	156.65	277.00	818.21
LED.NETRGDP3	538.90	156.05	276.91	817.52
1965-82				
RGDP	421.30	90.67	281.25	551.30
OHS.NETRGDP1	411.98	85.90	277.68	528.90
LED.NETRGDP1	411.54	85.93	277.37	529.92
OHS.NETRGDP2	414.28	88.24	277.16	539.61
LED.NETRGDP2	411.56	85.96	277.38	530.04
OHS.NETRGDP3	412.12	86.06	277.00	531.68
LED.NETRGDP3	411.60	86.02	276.91	531.82
1983-99				
RGDP	709.56	90.16	549.84	880.25
OHS.NETRGDP1	674.78	80.66	529.12	803.89
LED.NETRGDP1	673.46	80.06	528.18	808.37
OHS.NETRGDP2	684.74	81.95	536.53	837.59
LED.NETRGDP2	673.52	80.12	528.07	808.89
OHS.NETRGDP3	675.38	80.05	528.83	818.21
LED.NETRGDP3	673.69	79.71	527.88	817.52
1965-89				
RGDP	479.97	125.73	281.25	703.58
OHS.NETRGDP1	466.40	117.59	277.68	673.95
LED.NETRGDP1	465.81	117.41	277.37	672.31
OHS.NETRGDP2	470.26	120.84	277.16	682.86
LED.NETRGDP2	465.80	117.39	277.38	672.14
OHS.NETRGDP3	466.41	117.41	277.00	670.70
LED.NETRGDP3	465.79	117.29	276.91	670.18
1990-1999				
RGDP	764.65	65.03	692.25	880.25
OHS.NETRGDP1	722.70	59.95	628.69	803.89
LED.NETRGDP1	721.12	59.10	635.44	808.37
OHS.NETRGDP2	734.09	59.38	665.40	837.59
LED.NETRGDP2	721.28	59.01	636.62	808.89
OHS.NETRGDP3	723.94	57.51	653.16	818.21
LED.NETRGDP3	721.69	57.78	651.19	817.52

Notes:
OHS: One-Hoss-Shay models
LED: Linear-Efficiency-Decline models
RGDP: Real GDP, 1992 constant dollars
NETRGDP: Net Real GDP
1=Ex post inflation, 2=General inflation, 3=Ex ante inflation
Constant 1992 Canadian dollars, billions.
Arithmetic Means

Table 4: Real GDP, Percentage Growth Rates

	MEAN	ST. DEV	MINIMUM	MAXIMUM
1966-99				
GRGDP	3.44	2.20	-2.94	7.19
OHS.GNETRGDP1	3.22	2.86	-6.51	6.86
LED.GNETRGDP1	3.23	2.61	-5.23	6.80
OHS.GNETRGDP2	3.33	2.28	-3.04	7.16
LED.GNETRGDP2	3.23	2.59	-5.02	6.80
OHS.GNETRGDP3	3.26	2.30	-3.09	7.04
LED.GNETRGDP3	3.26	2.32	-3.20	7.07
1966-82				
GRGDP	3.88	2.36	-2.94	7.19
OHS.GNETRGDP1	3.79	2.39	-1.66	6.65
LED.GNETRGDP1	3.77	2.37	-2.24	6.80
OHS.GNETRGDP2	3.83	2.40	-3.04	7.16
LED.GNETRGDP2	3.77	2.37	-2.29	6.80
OHS.GNETRGDP3	3.75	2.44	-3.09	7.04
LED.GNETRGDP3	3.74	2.45	-3.20	7.07
1983-99				
GRGDP	2.99	1.99	-1.87	5.67
OHS.GNETRGDP1	2.64	3.23	-6.51	6.86
LED.GNETRGDP1	2.69	2.80	-5.23	6.16
OHS.GNETRGDP2	2.83	2.11	-2.55	5.67
LED.GNETRGDP2	2.69	2.76	-5.02	6.13
OHS.GNETRGDP3	2.78	2.11	-2.45	6.06
LED.GNETRGDP3	2.78	2.15	-2.60	5.99
1966-89				
GRGDP	3.91	2.08	-2.94	7.19
OHS.GNETRGDP1	3.79	2.14	-1.66	6.65
LED.GNETRGDP1	3.78	2.13	-2.24	6.80
OHS.GNETRGDP2	3.85	2.13	-3.04	7.16
LED.GNETRGDP2	3.78	2.12	-2.29	6.80
OHS.GNETRGDP3	3.78	2.18	-3.09	7.04
LED.GNETRGDP3	3.77	2.19	-3.20	7.07
1990-1999				
GRGDP	2.29	2.12	-1.87	4.73
OHS.GNETRGDP1	1.85	3.91	-6.51	6.86
LED.GNETRGDP1	1.91	3.28	-5.23	6.16
OHS.GNETRGDP2	2.09	2.25	-2.55	4.79
LED.GNETRGDP2	1.92	3.22	-5.02	6.13
OHS.GNETRGDP3	2.03	2.20	-2.45	5.01
LED.GNETRGDP3	2.03	2.27	-2.60	5.02

Notes:
OHS: One-Hoss-Shay models
LED: Linear-Efficiency-Decline models
GRGDP: Growth in Real GDP, 1992 constant dollars
GNETRGDP: Growth in Net Real GDP
1=Ex post inflation, 2=General inflation, 3=Ex ante inflation
Arithmetic Means

Table A1: Data

Year	RGDP	QIME	PIME	IME	IME smoothed	ρ	ρ smoothed	r
1965	281.25	6.01	0.6566	0.0392	0.0217	0.0204	0.0264	0.0612
1966	299.69	7.16	0.6780	0.0326	0.0215	0.0400	0.0313	0.0816
1967	308.64	7.32	0.6734	-0.0068	0.0219	0.0337	0.0360	0.0750
1968	325.15	6.81	0.6728	-0.0009	0.0225	0.0419	0.0395	0.0835
1969	342.47	7.45	0.6908	0.0267	0.0227	0.0446	0.0386	0.0864
1970	351.43	7.60	0.7235	0.0474	0.0272	0.0342	0.0377	0.0756
1971	370.86	7.83	0.7430	0.0270	0.0381	0.0289	0.0416	0.0701
1972	390.70	8.46	0.7726	0.0399	0.0512	0.0482	0.0550	0.0901
1973	418.80	10.36	0.7937	0.0272	0.0609	0.0766	0.0756	0.1197
1974	436.15	11.67	0.8782	0.1065	0.0664	0.1068	0.0907	0.1510
1975	445.81	12.33	0.9837	0.1201	0.0696	0.1093	0.0936	0.1537
1976	470.29	12.87	1.0423	0.0595	0.0688	0.0754	0.0894	0.1184
1977	486.56	12.84	1.1052	0.0603	0.0585	0.0782	0.0850	0.1213
1978	506.41	13.89	1.1502	0.0407	0.0435	0.0900	0.0870	0.1336
1979	527.70	16.17	1.2210	0.0616	0.0326	0.0917	0.0955	0.1354
1980	535.01	19.51	1.1589	-0.0509	0.0251	0.1008	0.1042	0.1449
1981	551.31	23.59	1.1734	0.0124	0.0165	0.1240	0.1043	0.1690
1982	535.11	19.89	1.2602	0.0740	0.0082	0.1087	0.0924	0.1530
1983	549.84	19.52	1.2482	-0.0095	0.0034	0.0582	0.0721	0.1005
1984	581.04	20.83	1.2332	-0.0120	0.0001	0.0434	0.0527	0.0852
1985	612.42	23.99	1.2017	-0.0256	-0.0065	0.0402	0.0435	0.0818
1986	628.58	26.60	1.2002	-0.0012	-0.0126	0.0413	0.0417	0.0830
1987	654.36	30.70	1.1728	-0.0228	-0.0152	0.0435	0.0425	0.0853
1988	686.18	36.41	1.1507	-0.0188	-0.0197	0.0405	0.0445	0.0821
1989	703.58	39.22	1.1460	-0.0041	-0.0242	0.0495	0.0469	0.0915
1990	705.46	37.48	1.1366	-0.0082	-0.0241	0.0483	0.0464	0.0902
1991	692.25	37.68	1.0329	-0.0912	-0.0194	0.0557	0.0391	0.0980
1992	698.54	38.65	1.0000	-0.0319	-0.0158	0.0152	0.0283	0.0558
1993	714.58	36.86	1.0222	0.0222	-0.0142	0.0180	0.0173	0.0587
1994	748.35	40.35	1.0550	0.0321	-0.0097	0.0020	0.0139	0.0420
1995	769.08	44.29	1.0495	-0.0052	-0.0052	0.0216	0.0143	0.0624
1996	780.92	48.56	1.0008	-0.0465	-0.0126	0.0163	0.0155	0.0570
1997	815.01	59.98	1.0120	0.0112	-0.0218	0.0161	0.0150	0.0567
1998	842.00	65.36	1.0040	-0.0079	-0.0313	0.0093	0.0148	0.0497
1999	880.25	75.56	0.9311	-0.0726	-0.0413	0.0175	0.0143	0.0582

Notes: 1. RGDP: Real Gross Domestic Product; 2. QIME: Quantity of Investment in Machinery and Equipment (real investment); 3. PIME: Price index of Investment in Machinery and Equipment (investment deflator); 4. IME: Rate of ex post asset inflation for Machinery and Equipment (i^t); 5. IME Smoothed: Trend of IME, estimated using LOWESS; 6. ρ: general rate of inflation calculated from the Consumer Price Index; 7. ρ smoothed: Trend of ρ, estimated using LOWESS; 8. r: Nominal interest rate.

Figure 1: Deflator for Machinery and Equipment

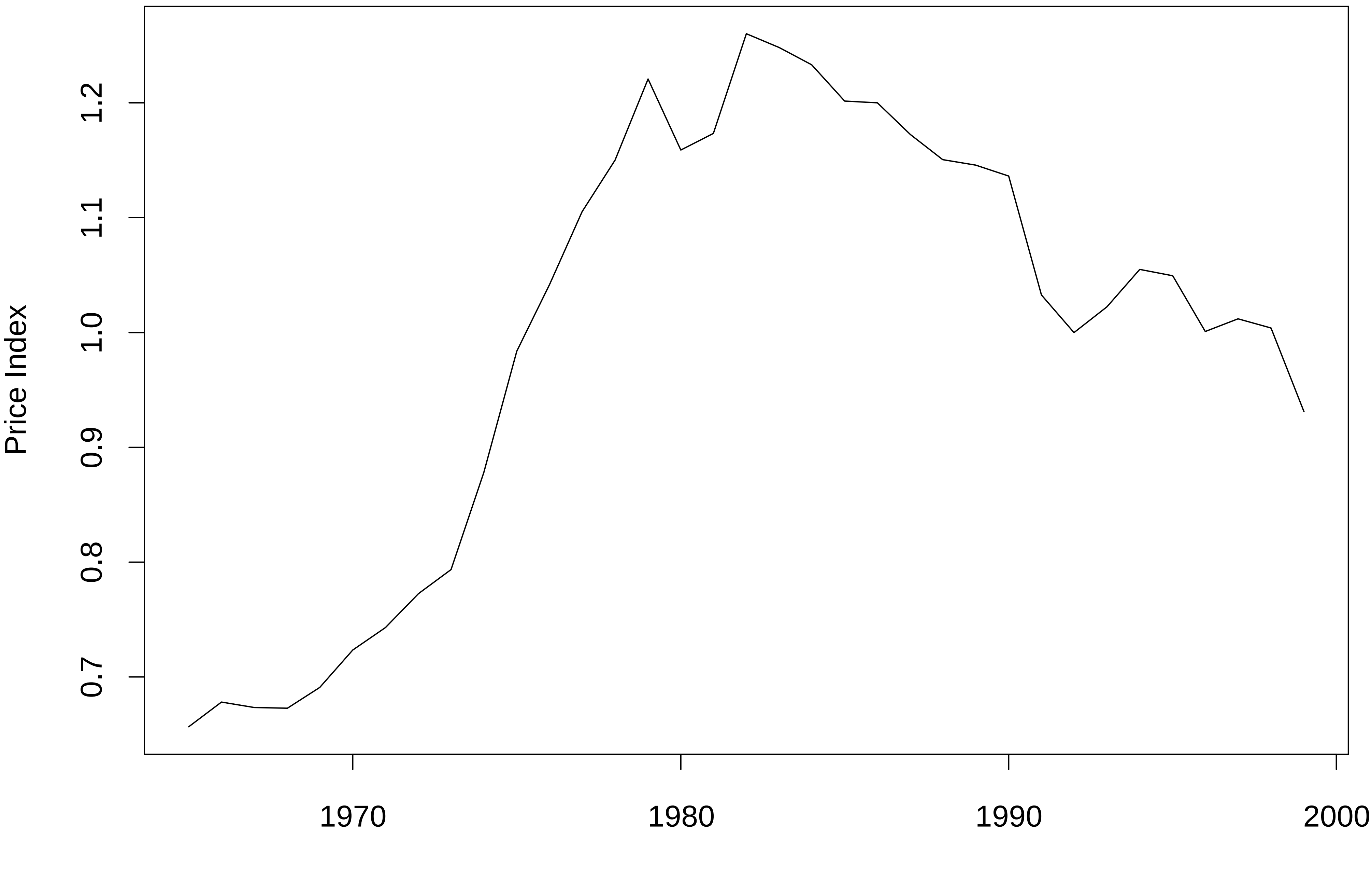

Figure 2: Real Investment, Ex Post Inflation Models

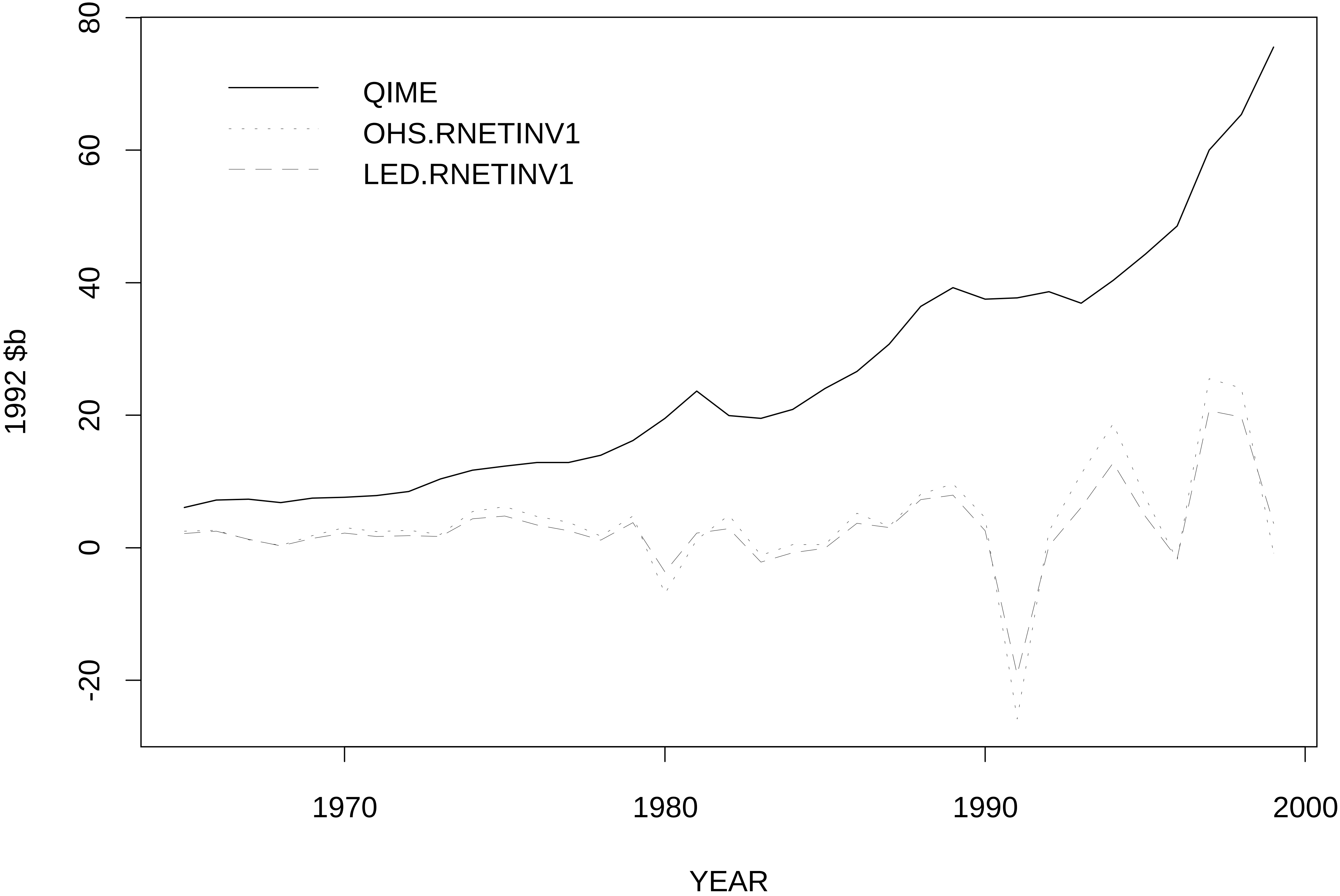

Figure 3: Real Investment, General Inflation Models

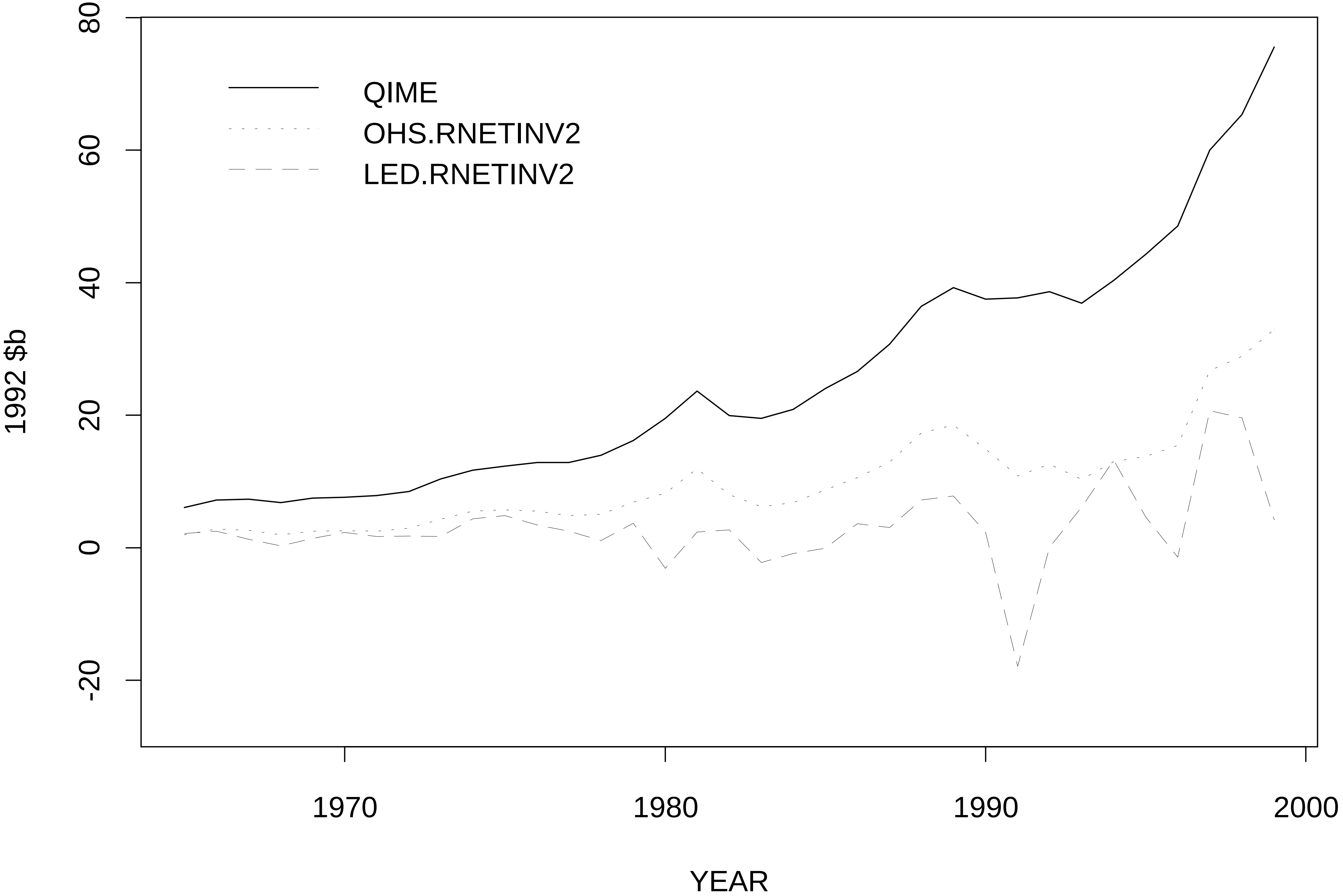

Figure 4: Real Investment, Ex Ante Inflation Models

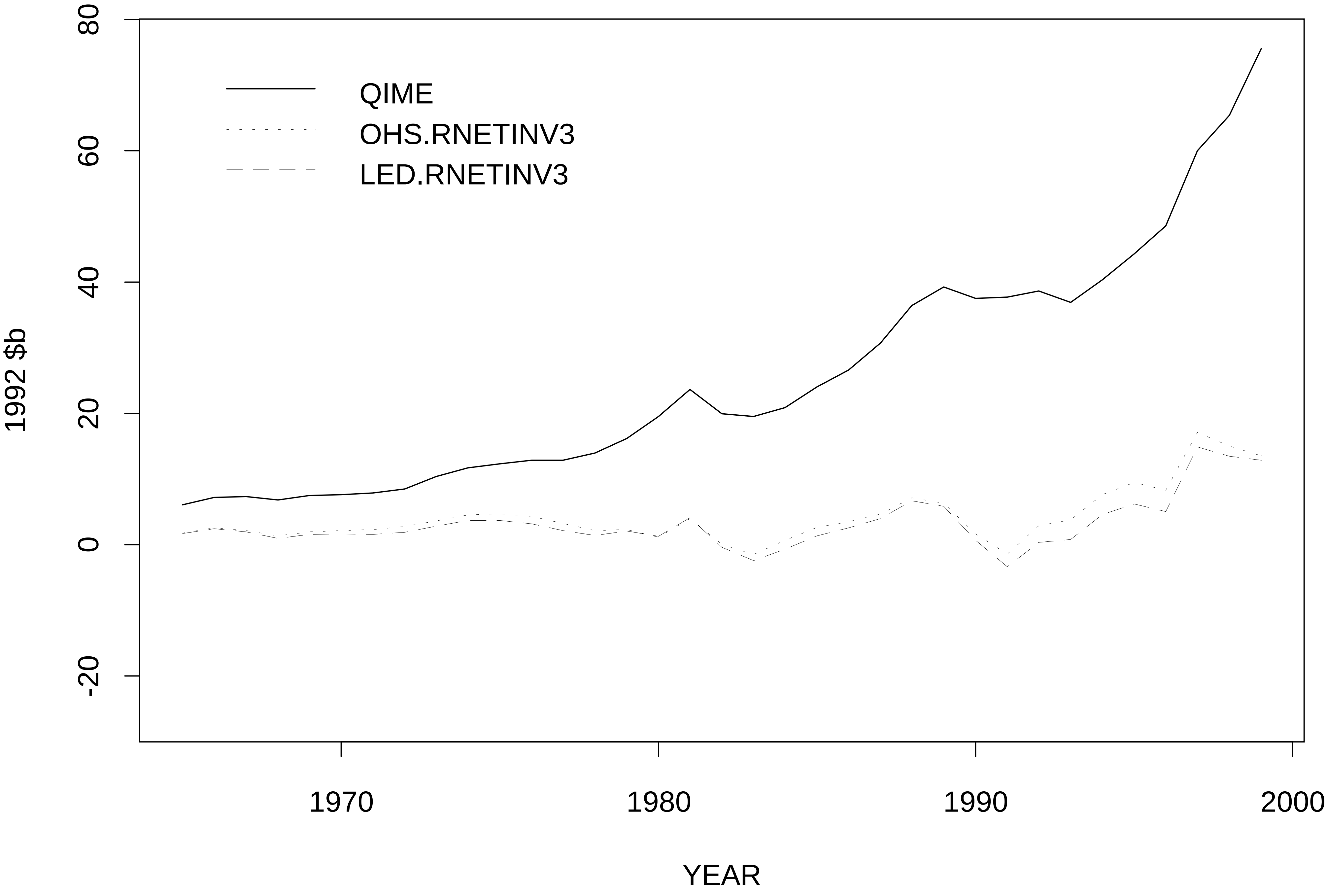

Figure 5: Real GDP, Ex Post Inflation Models

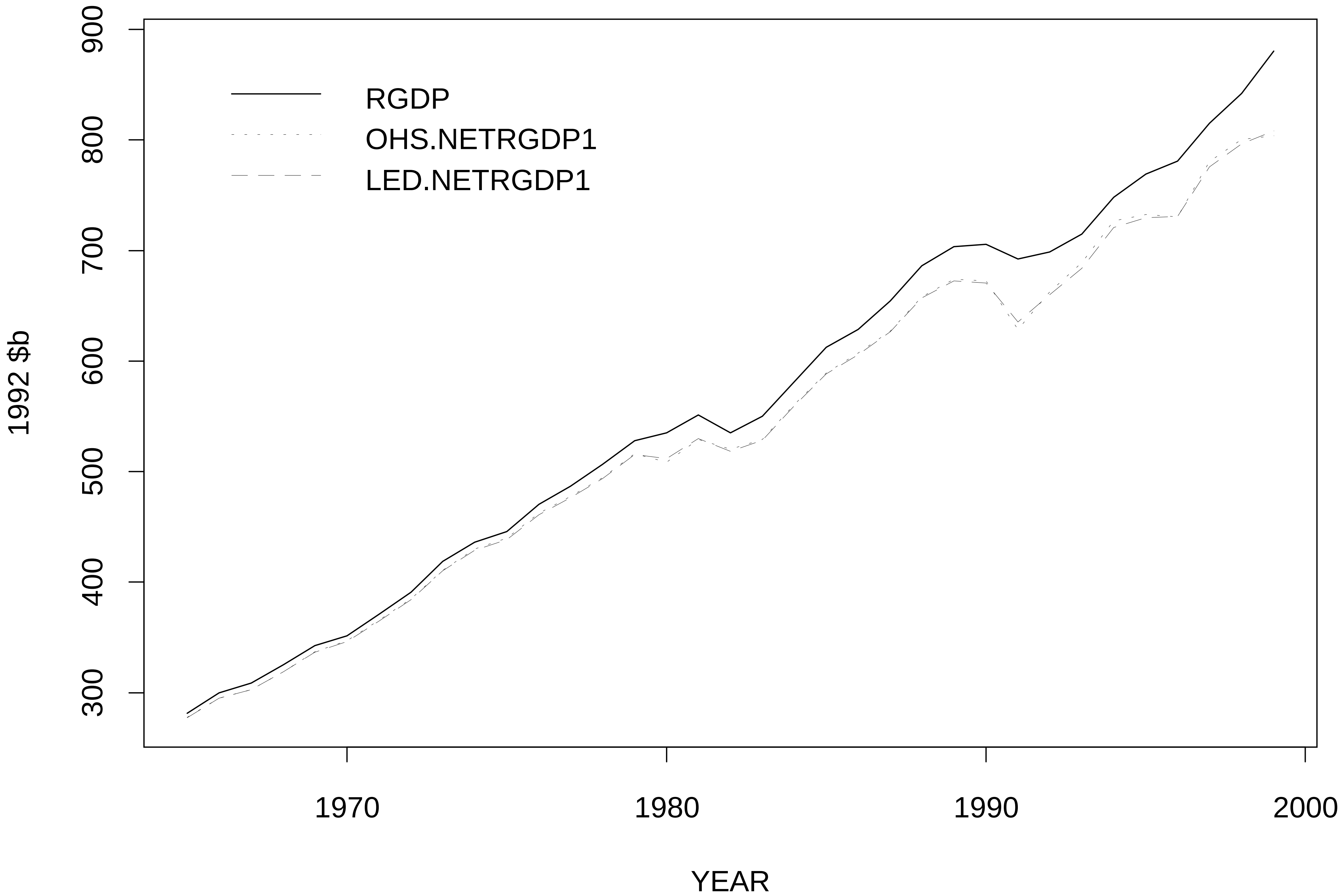

Figure 6: Real GDP, General Inflation Models

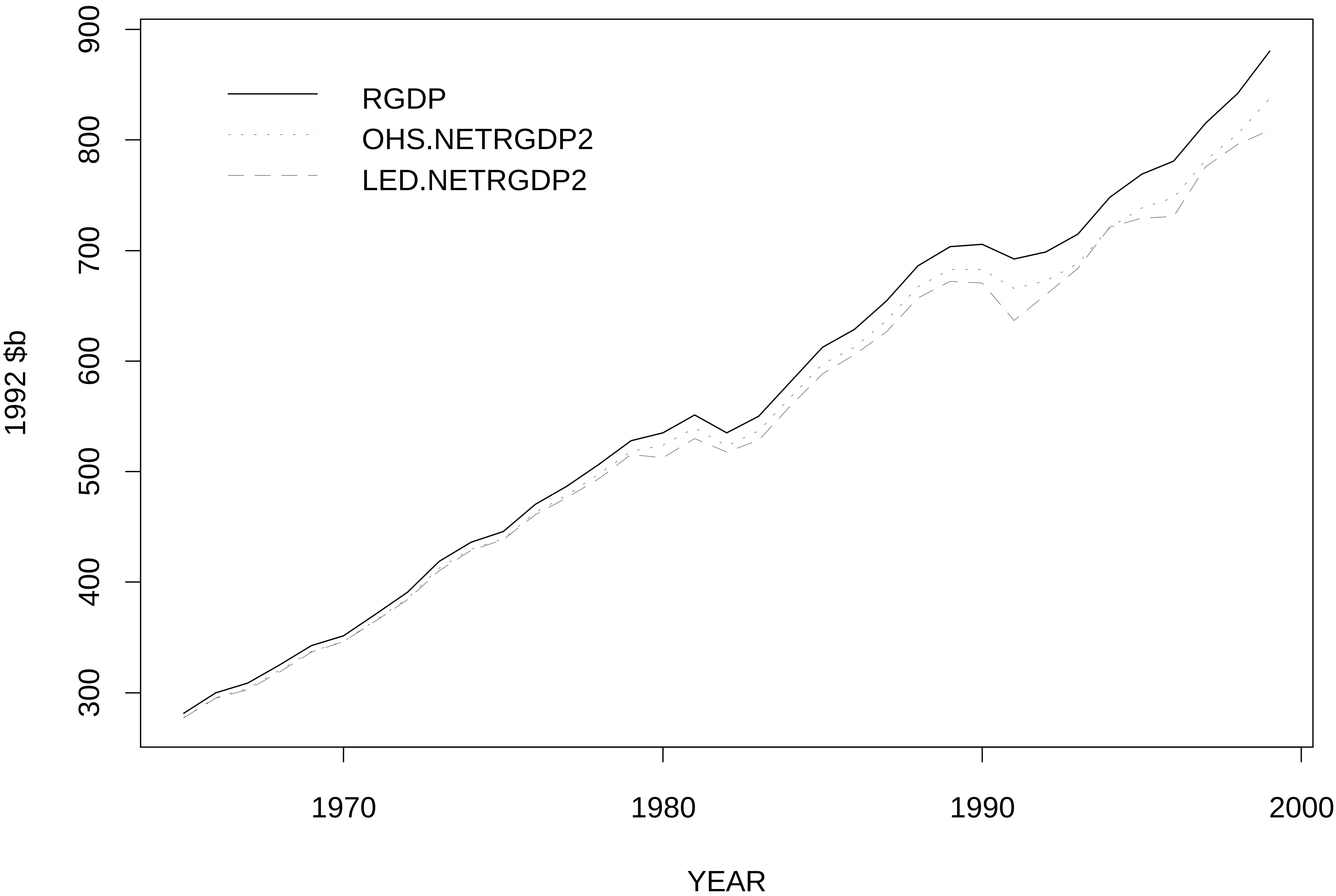

Figure 7: Real GDP, Ex Ante Inflation Models

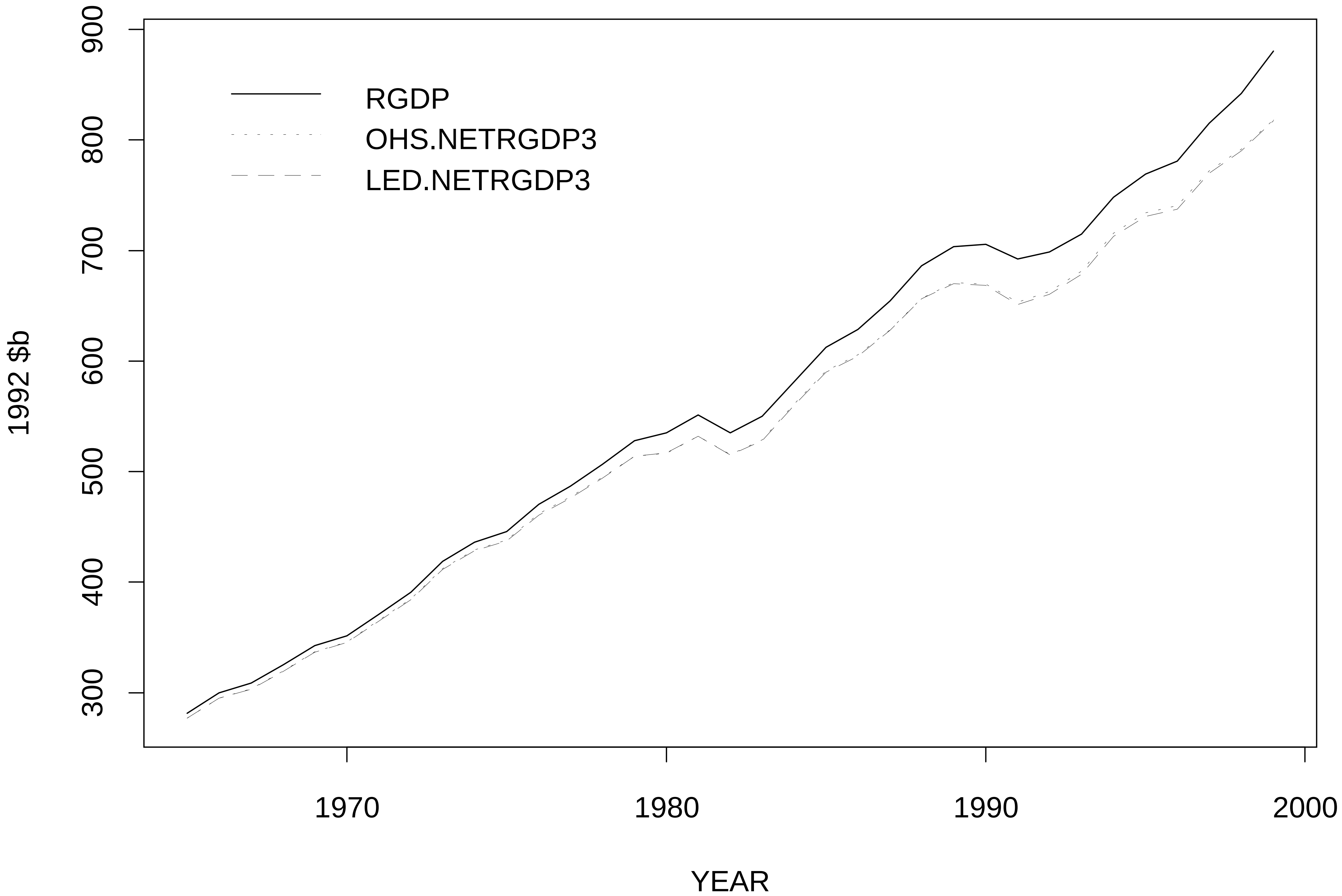

Figure 8: Real GDP Growth, Ex Post Inflation Models

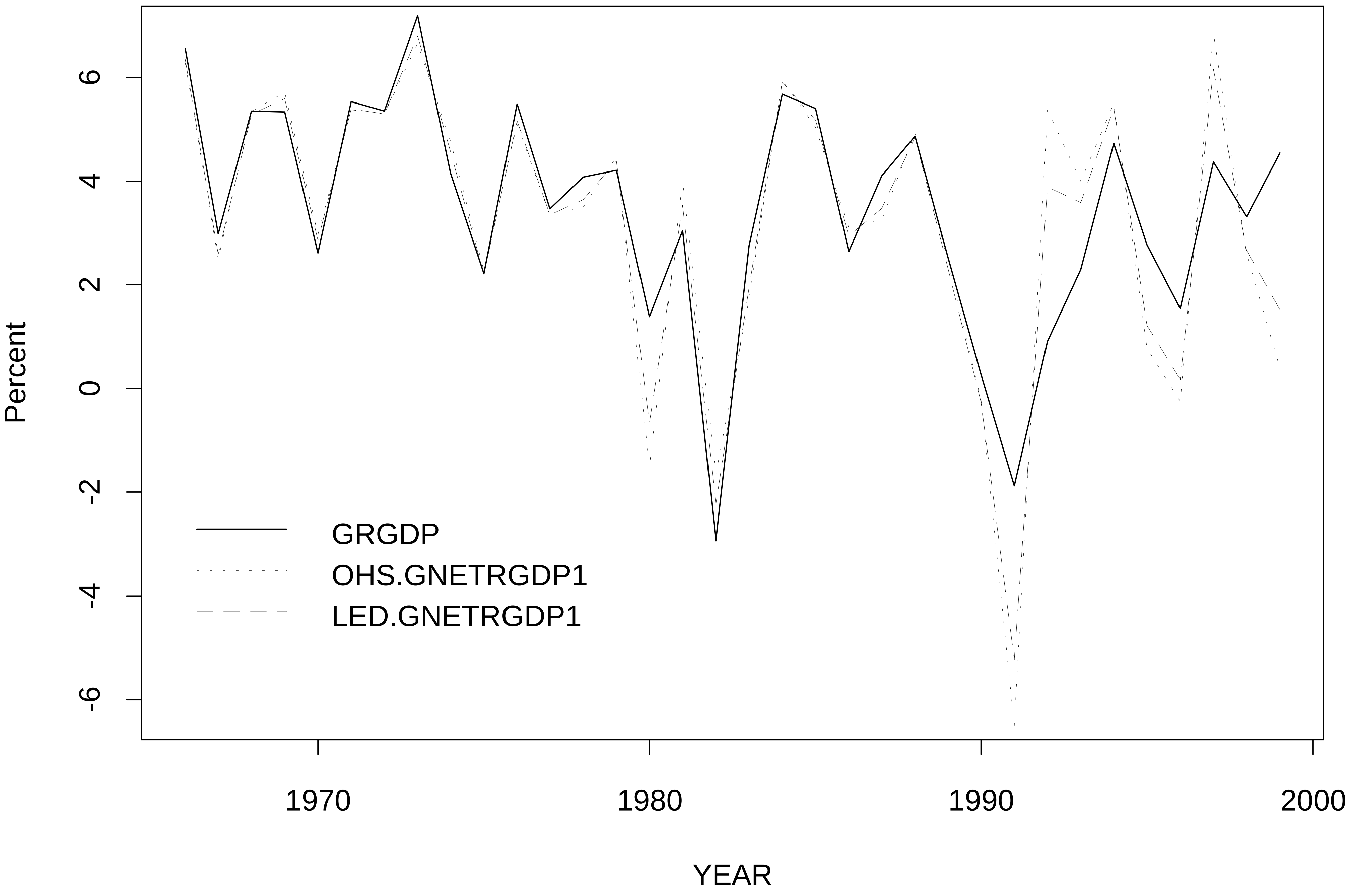

Figure 9: Real GDP Growth, General Inflation Models

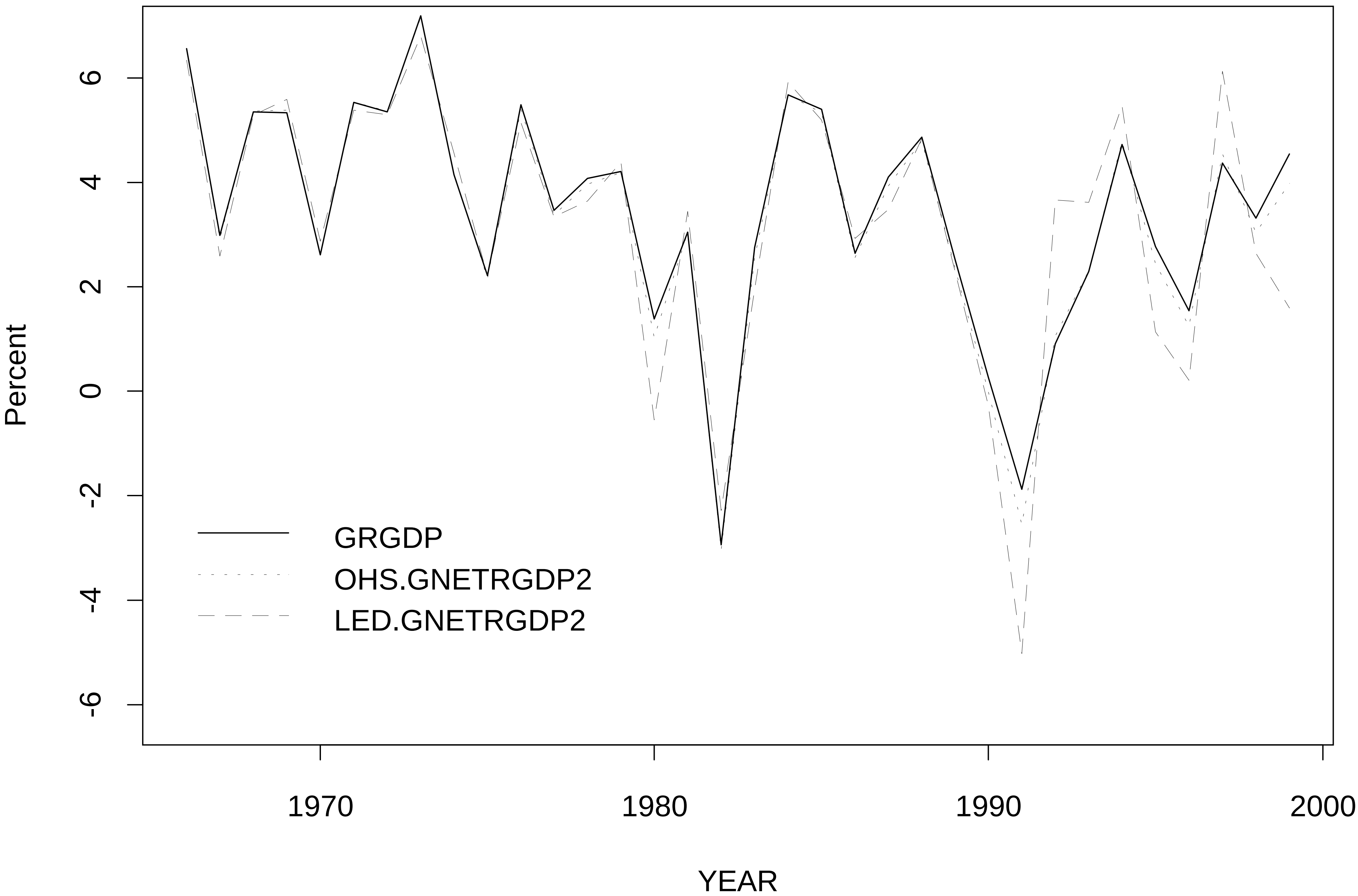

Figure 10: Real GDP Growth, Ex Ante Inflation Models