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Sector-Specific Technical Change

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Abstract: We provide a unified framework that links recent (and more traditional) literature on growth accounting with recent literature on the importance of shocks to the economy's ability to produce different final goods. Recent macroeconomic literature has used relative prices to proxy for relative technological change in measuring technological change in investment goods versus consumption goods. Even in a closed economy, this relative-price approach is not necessarily appropriate in empirically relevant cases such as where factor shares (including shares of different intermediate inputs) and factor prices might differ across producers, or where some sectors might have increasing returns to scale and (possibly) time-varying markups. With disaggregated data, one can relax these assumptions. In an open economy, terms of trade shocks also affect the economy's ability to provide consumption or investment goods. These shocks affect relative prices, but existing theory provides little guidance on how to interpret these shocks in the context of measuring consumption and investment sector technological innovations.

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I. Introduction

Theory tells us that the composition of technological change, in terms of which final goods production is affected, matters for the dynamics of the economy's response to technology change. For example, we show that a shock to the technology for producing consumption goods has no interesting business-cycle effects in a standard RBC model. All of the dynamics of hours and investment stressed by RBC theory come from investment-goods technology shocks.[2] In an open economy, terms-of-trade shocks affect the economy's ability to provide consumption and investment goods, even if no domestic producer has had a change in technology.

In this paper, we describe new evidence on the biases of technological change in favor of producing durables goods. Existing evidence in favor of the importance of biased change to growth and business cycles is based primarily on relative movements in the price deflators for investment and consumption goods. Our evidence, in contrast, is based on an augmented growth-accounting approach, where we estimate technology change at a disaggregated industry level and then use the input-output tables to aggregate these changes. Our decomposition clarifies the relationship between estimates in terms of producing industries and estimates in terms of final expenditure "sectors."

Our approach offers several advantages. First, we can relax and, indeed, test many of the assumptions necessary for relative-price movements to correctly measure relative changes in domestic technological change. For example, if markups change over time or if there are non-constant returns to scale over long horizons, then relative prices do not properly measure relative technical change. Second, we discuss extensions to the open economy, where the ability to

[2] Interestingly, this dichotomy typically does not hold in models with sticky prices. Thus, differences in the economy's response to consumptions and investment-specific shocks may also cast light on the importance of price stickiness in the macroeconomy.

import and export means that relative investment prices need not measure relative technologies in terms of *domestic* production. Third, we can better assess the reasons why the trend decline in the relative price of durable goods accelerated after the 1970s. We find that two factors played a role in explaining this accelerating trend. First, total factor productivity growth (TFP) slowed very sharply for non-durable consumption goods and services; indeed, even investment goods had slower TFP growth after the 1970s, just not as pronounced. Second, since the 1970s, an appropriately weighted measure of nominal input prices rose more quickly in the production of consumption goods than for investment goods. .

Finally, we discuss implications of this measurement for recent macroeconomic theories. These include theories of technological change, including stories of general purpose technology, and theories of how shocks propagate through the economy.

II. Consumption-Technology Neutrality

The character of both growth and business cycles depends on the sectoral distribution of technical change. In the neoclassical growth model, capital accumulation arises only if technical change expands the possibilities for producing capital goods. Indeed, as shown by Kimball (1994), with balanced growth, technology change that affects the consumption-producing sector alone has no impact on employment or capital accumulation at all. Hence, the nature of growth and is tightly connected to the sectoral distribution of technical change.

The response of a real business cycle model economy to an exogenous technology shock also depends on the sectors of the economy it affects. Hours and investment responses to a pervasive, sector-neutral, positive technology shock are well understood. They follow from the intertemporal substitution of current leisure and consumption for future consumption. The household is willing to do this because of the high returns to working and saving. These effects are amplified when technical change affects the investment sector alone, because current consumption is even more expensive relative to future consumption in this case (e.g., Fisher, 2005). Consumption-sector shocks have smaller effects on intertemporal substitution and so have much less effect on decision rules. As Fisher (1994, 1997) and Kimball (1994) discuss, if preferences are logarithmic, then the decision rules for investment and hours, as well as the allocation of capital and labor across producing consumption and investment goods, are invariant to the stochastic process of consumption-specific technology. More generally, for preferences which are consistent with balanced growth, hours and investment and factor allocations do not respond to a technology shock, if that shock is permanent, unanticipated, and only affects the consumption-sector. So the nature of business cycles is also tied to the sectoral distribution of technical change.

We now present a simple model to illustrate these points. We then discuss other recent macroeconomic work that has focused on the final-goods sector in which technical change occurs. The empirical evidence has been drawn almost exclusively from aggregate data, with heavy reliance on relative prices.

Consider the two-sector closed-economy neoclassical growth model. Suppose one sector produces consumption goods C, the other sector produces investment goods, J (We use J to differentiate investment from the identity matrix, which we use extensively later). Both sectors produce output by combining capital K and labor L with the same function F but separate Hicks-neutral technology parameters, Z_C and Z_I.

In particular, consider the social planner's problem for the following problem, where utility is logarithmic:

$$\begin{aligned} &\max_{N,C,X,I} E_0 \sum_{t=0}^{\infty} \beta^t [\ln(C_t) - v(L_t)] \\ &s.t. \quad C = Z_C \cdot F(K_C, L_N) \\ &\qquad J = Z_J \cdot F(K_J, L_J) \\ &\qquad K = K_C + K_J, \quad L = L_C + L_J \\ &\qquad K_{t+1} = J_t + (1-\delta)K_t \end{aligned} \tag{1}$$

We omit (most) time subscripts for simplicity. This setup appears in the recent literature in various places. For example, this is a two-sector version of the model in Greenwood, Hercowitz, and Krusell (GHK, 1997); Whelan (2000) discusses the mapping to GHK in greater detail. There are various ways to normalize the technology shocks. For example, GHK define $Z_J = Z_C q$, where $q = Z_J/Z_{C,.}$ GHK label Z_C as "neutral" technology and q as "investment specific," a labeling that has been widely followed since. A shock that raised Z_C but left q unchanged is neutral in that both Z_C and Z_I increase equally.

For the purposes of discussing consumption-technology neutrality, a different normalization is more natural. In particular, suppose we define $A = Z_C/Z_J$ as "consumption-specific" technology. Then the problem in (1) can be expressed as a special case of the following problem, where we have expressed the problem with a single aggregate budget constraint:

$$\begin{aligned} &\max_{N,C,X,I} E_0 \sum_{t=0}^{\infty} \beta^t [\ln(C_t) - v(L_t)] \\ &s.t. \quad C_t = A_t X_t \\ &\qquad X + J = F(K, L, Z) \\ &\qquad K_{t+1} = J_t + (1-\delta)K_t \end{aligned} \tag{2}$$

X is an index of inputs devoted to consumption (in the previous example, it would correspond to the production function F). Since $X=C/A,$ and A corresponds (in the decentralized equilibrium) to the relative price of investment to consumption, we can interpret X as consumption in investment-goods units (i.e., nominal consumption deflated by the investment deflator). This is essentially the same approach taken by GHK, except that given their normalization, they express everything (investment and output, in particular) in consumption units. But given logarithmic utility, we can express this problem as:

$$\begin{aligned}&\max_{N,C,X,I} E_0 \sum_{t=0}^{\infty} \beta^t [\ln(A_t) + \ln(X_t) - v(L_t)] \\ &s.t. \quad X + J = F(K, L, Z) \\ &\qquad K_{t+1} = J_t + (1-\delta)K_t\end{aligned} \tag{3}$$

Consumption-technology neutrality follows directly from this expression of the problem. In particular, because *ln(A)* is an additively separable term, *any* stochastic process for A has no effect on the optimal decision rules for *L*, *X,* or *J*. They do not induce capital-deepening or any of the "expected" RBC effects; e.g., employment doesn't change. Consumption jumps up, which immediately moves the economy to its new steady state.[3] They affect only real consumption and the relative price of consumption goods. In contrast, investment-sector technology shocks would have much more interesting dynamics. They induce long-run capital-deepening, and even in the short-run affect labor supply and investment dynamics.

Thus, consumption-sector technology shocks are "neutral." .This consumption-technology neutrality proposition has been implicit in two-sector formulations for a long time; the first explicit references we are aware of are Kimball (1994) and Fisher (1994). Nevertheless, it appears to be a little known result. One reason is that the seminal work by Greenwood, Hercowitz, and Krusell (1997) used a different normalization, as noted above; they focused on the response of the economy to "investment specific" shocks. A shock to consumption

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[3] Kimball (1994) discusses this case further, as well as the extension to King-Plosser-Rebello preferences.

technology alone (leaving investment technology unchanged) would then involve a positive neutral shock, combined with a negative investment-specific shock.[4]

The theoretical motivation for studying sectoral technical change is bolstered by a nascent empirical literature. Most of this literature has followed the GHK normalization of "neutral" and "investment specific" shocks. GHK used data on real equipment prices and argued that investment-specific, not sector-neutral, technical change, is the primary source of economic growth, accounting for as much as 60% of per capita income growth. Cummins and Violante (2000) also find that investment-specific technical change is a major part of growth using more recent data. Several papers also highlight the potential role sector-specific technology shocks in the business cycle. Greenwood, Hercowitz and Huffman (1988) were the first to consider investment-specific shocks in a real business cycle model. Other papers studying investment-specific shocks within the context of fully-specified models are Campbell (1998), Christiano and Fisher (1998), Fisher (1997), and Greenwood, Hercowitz and Krusell (2000). These authors attribute 30-70% of business cycle variation to permanent investment-specific shocks. In the structural VAR literature, Fisher (2005), extending the framework used by Gali (1999) to the case of investment-specific shocks, finds that investment-specific shocks explain 40-60% of the short-run variation in hours and output.

This prior work is based on a "top-down" measurement strategy that relies on NIPA investment and consumption deflators. Our paper contributes to the literature by providing new measures of sector-specific technical change that, in principle, are more robust. These new measures of technical change can be used to assess the veracity of the existing literature's

[4] Equivalently, a positive shock to investment-specific technology (with neutral technology unchanged) or a positive shock to neutral technology (leaving investment-specific technology unchanged) would *both* raise investment-technology in the two-sector formulation, and hence would lead to dynamic responses in the frictionless model.

findings. The next few sections discuss some of the challenges involved in linking this framework to the disaggregated data. We begin with a conceptual issue of how to treat terms-of-trade effects. We then discuss how we use the input-output tables to create the link between disaggregated productivity and aggregate final-use sectors.

III. Terms of Trade Effects

For an open economy, the relative price of investment goods captures not just relative technologies, but also terms-of-trade effects. More generally, terms-of-trade shocks affect the ability of an economy to produce consumption and investment goods, since one can export and import these kinds of goods. For example, we export financial services, which allow us to import (i) machine tools; (ii) consumption goods; and (iii) oil (an intermediate input into everything).

These examples point out an ambiguity in the meaning of "technology" in the context of final expenditure. In an open economy, terms-of-trade shocks affect the economy's ability to supply consumption and investment goods, even if no production function changes. For example, suppose a firm produces a particular product using capital, labor, and intermediates. The firm's ability to convert a given quantity of inputs into that product is not affected by relative prices. But the firm's ability to obtain the output of another firm does depend on relative prices. Similarly, an economy's ability to produce final output depends on its ability to trade with the rest of the world (other producers) and on what terms. In our measurement, we will incorporate these terms-of-trade effects into our estimation of sectoral technologies.

In a productivity context, it is controversial to label terms of trade changes "technology shocks," since they do not shift any production function for domestic output. On the other hand, from the standpoint of thinking about aggregate expenditure or the economy-wide budget constraint, trade is just a special (linear) technology: terms of trade changes allow consumers to have more consumption with unchanged labor input or investment. However, it is important to keep in mind that this form of technology is a special one. For example, rather than having unbounded trend growth, we expect the trade "technology" to be stationary (at least if purchasing power parity holds in the long run).

Once again, the information in the input-output matrix allows us to keep track of trade flows, and discern the impacts of changes in the terms of trade on different categories of final expenditures.

IV. Sectoral Technical Change from the Bottom Up

A. Preliminaries

The input-output tables allow us to track flows of goods and services, in order to map disaggregated productivity data into aggregated final-use sectors. The tables tell us the uses of each identified commodity—whether they flows to final uses (consumption, investment, government purchases, and net exports) or to intermediate uses (e.g., steel sold as an input into the auto production). Several issues arise in using the input-output and productivity data.

First, the standard use table shows the flows of *commodities* to final uses as well as to intermediate uses in *industry* (not commodity) production. But because of our interest in the sector of final use, we are inherently interested in the production of commodities, not the production of industries. Some industries produce multiple commodities. In our two-digit data, the largest deviation between industries and commodities is in printing and publishing: About 62 percent of the production of the printing and publishing industry (in 1977) is the commodity labeled printing and publishing; most of the rest is services (the detailed BEA accounts reported in Lawson et al (2002) indicate that this is advertising services). In this example, the same establishment will often produce both commodities. Hence, as a data issue, the input-output accounts record inputs according to the primary product of the establishment. But the so-called "make" table shows what commodities each industry produces, which allows us to produce a commodity-by-commodity use table. (The appendix discusses our specific manipulations.)

Second, productivity data (such as that obtained from the KLEM dataset of Jorgenson and his collaborators) is also in terms of industries; but final-use sales are in terms of commodities. So we need to convert industry productivity data into commodity productivity data. Again, the make table allows us to do that conversion. Suppose we have a column vector of industry productivity growth rates, dz^I. Conceptually, we interpret this vector of industry productivities as a "garbled" version of the column vector of commodity productivity growth rates, *dz*, that we are interested in, so that a weighted average of commodity technology growth equals industry technology growth, where the make table tells us the output-share weights . In particular, suppose we convert the make table *M* to row-share form, so that element m_{ij} corresponds to the share of output of industry *i* that consists of commodity *j*. Then $M\,dz_t = dz_t^I$. Thus, given the industry productivity-growth vector and the make table, the implied commodity productivity growth vector is $dz_t = M^{-1} dz_t^I$.

Third, the standard use table is in terms of domestically produced commodities and domestic industry production. But we can also import commodities to satisfy either intermediate or final demands; so given a focus on commodity uses, we want a use table that is in terms of total commodity supply and total commodity production. (For example, through imports, we could consume more than the total value of domestically produced consumption.) Total supply is, of course, either domestically produced or imported. The import information is already in the standard use table so, again, we must simply rearrange the information in the table.

We assume that have already incorporated the information from the make table to create a use table that is entirely in terms of commodities. For simplicity of presentation, we assume there are only two commodities in the economy and we ignore government purchases. The extension to more commodities and more final-use categories will be obvious.[5]

In simplified form, the use table (in nominal terms) represents the production and uses of domestically produced goods, and looks like (4) below. Rows represent uses of domestic production; columns (for commodities 1 and 2) represent inputs into domestic production. Row and column totals for the two commodities represent domestic production of the good.

	1	2	C	J	X	M	Row Total
1	$P_1 Y_1^1$	$P_1 Y_1^2$	$P_1 Y_1^C$	$P_2 Y_1^J$	$P_1^D Y_1^X$	$-P_1^M Y_1^M$	$P_1^D Y_1^D$
2	$P_2 Y_2^1$	$P_2 Y_2^2$	$P_2 Y_2^C$	$P_2 Y_2^J$	$P_2^D Y_2^X$	$-P_2^M Y_2^M$	$P_2^D Y_2^D$
K	$P_K^1 K^1$	$P_K^2 K^2$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$P_K K$
L	$P_L^1 L^1$	$P_L^2 L^2$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$P_L L$
Column total	$P_1^D Y_1^D$	$P_2^D Y_2^D$	$P_C C$	$P_J J$	$P_X X$	$-P_M M$	

(4)

Note that the domestic commodity price is P_i^D. The imported commodity price is P_i^M. The overall supply price of the commodity (a Divisia index of the domestic and imported prices) is simply P_i. In principle, the supply price of a commodity might differ for use as an intermediate input, consumption, or investment, since the mix of imported and domestic supply might differ. In practice, the data do not allow us to differentiate between uses of domestically produced versus imported commodities; so we assume all users face the same composite price. We assume that commodity exports are from domestic producers, with price P_i^D. Reading down

[5] For the purposes of discussion, we also ignore so-called non-competing imports. When we apply our framework, we aggregate non-competing imports with commodity imports as "trade" inputs into the production of domestic supply; and we consider non-competing consumption, investment, and government goods as the direct contribution of "trade" to these final uses. Our discussion also ignores indirect business taxes, which would be an additional row of "value added" necessary for row and column shares to be equal. On the production side, we will need factor shares in producer's costs, which do not include these taxes.

a commodity column (1 or 2 in the example above) gives payments to each factor input. Implicitly, any pure profits are attributed to one or more of the factors; most obviously, they have been attributed to capital, whose factor payment is measured as a residual to ensure that the value of output equals the value of inputs. (Note that we have omitted time subscripts for simplicity.)

Total supply of a commodity is the aggregation of domestic production and imports. In nominal terms, the total supply of the commodity (column sums and row sums for commodities 1 and 2) is $P_i Y_i = P_i^D Y_i^D + P_i^M Y_i^M$.

The purpose of exports, of course, is to obtain imports. We can think of the import-export sector (what we'll call the "trade" sector—not to be confused with wholesale and retail trade) as a commodity. Consider the following rearrangement of the information in the use table:

	1	2	Trade goods	C	J	NX	Row Total
1	$P_1Y_1^1$	$P_1Y_1^2$	$P_1^DY_1^X$	$P_1Y_1^C$	$P_2Y_1^J$	…	P_1Y_1
2	$P_2Y_2^1$	$P_2Y_2^2$	$P_2^DY_2^X$	$P_2Y_2^C$	$P_2Y_2^J$	…	P_2Y_2
Trade goods	$P_1^MY_1^M$	$P_2^MY_2^M$	…	…	…	P_XX $-P_MM$	P_XX
K	$P_K^1K^1$	$P_K^2K^2$	…	…	…	…	P_KK
L	$P_L^1L^1$	$P_L^2L^2$	…	…	…	…	P_LL
Column total	P_1Y_1	P_2Y_2	P_XX	P_CC	P_JJ	P_XX $-P_MM$	

(5)

Note that the "final use" columns for consumption and investment don't change. For trade goods, the technology is that we export goods in exchange for imports. We also use the "trade goods" to obtain pieces of paper that represent claims on the future: net exports. So the final-expenditure category for trade goods is net exports; those are conceptually a form of investment. So the inputs into producing trade goods (shown in the "trade goods" column) are exports of commodities 1 and 2. The trade-goods row shows the uses of trade-goods output: we obtain imports of commodities 1 and 2 (which augment domestic production and increase commodity supply) as well as net exports. These commodity imports are then an input into producing a supply of the commodity, as well as being part of the output of the commodity. (This is comparable to the fact that some of the output of commodity 1 is used as an input into commodity 1; so that part of the input-output table already represents commodities that are both inputs and output of the commodity.)[6]

Corresponding to this nominal use table is a real use table. In most cases, the relevant deflator is obvious; and where we aggregate goods (e.g., nominal consumption expenditure), we use Divisia aggregates that weight growth rates by nominal shares. The one exception to the "obvious" nature of the deflators is the deflator for overall trade-goods output. Nominal trade goods output equals the value of exports; that's the nominal value of the goods we supply to the rest of the world. The real output, though, is the real quantity of imports that we can get from those exports, so we deflate the nominal exports with the deflator for imports. Hence, growth in real trade goods equals growth in real exports *plus* the growth in the terms of trade. This is true for the final-use net-exports column, as well.

We can calculate technology change for each commodity, either using standard growth accounting to obtain a Solow residual or else using augmented growth accounting (as in Basu, Fernald, and Kimball, 2004) to obtain a "cleansed" residual. In any case, we essentially take growth in the real index of commodity supply and subtract growth in real inputs, possibly multiplied by an estimate of returns to scale, and possibly with a correction for utilization. Note that commodity imports are an intermediate input into the production of commodity supply, as well as being part of the commodity output. (By the convenient properties of Divisia indices,

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[6] We combine these imports with non-competing imports that are inputs into commodity production in the standard tables, with a row that corresponds to the commodity "non-competing imports." We will thus think about there being q commodities in total, in either the standard or our rearranged tables.

this simply leads to a rescaling of commodity TFP by the ratio of domestic production to total supply, much in the way that gross-output TFP is a scaled-down version of value-added TFP.)

For the trade sector, we assume the technology has constant returns to scale. Growth in real trade goods equals growth in exports *plus* the growth in the terms of trade; and growth in real trade inputs equals growth in exports. Hence, trade-commodity technology growth dz_{Trade} (dz_3 in the numbering above) is growth in the terms of trade, $(dp_X - dp_M)$.

Notationally, it will prove useful to transpose the use table and then take row shares. This yields the following:

$$\left[\begin{array}{r|ccc|cc} & 1 & 2 & \text{Trade goods} & K & L \\ \hline 1 & b_{11} & b_{12} & b_{13} & a_{1K} & a_{1L} \\ 2 & b_{21} & b_{22} & b_{23} & a_{2K} & a_{2L} \\ \text{Trade goods} & b_{31} & b_{32} & 0 & \cdots & \cdots \\ \hline C & b_{C1} & b_{C2} & 0 & \cdots & \cdots \\ J & b_{J1} & b_{J2} & 0 & \cdots & \cdots \\ NX & 0 & 0 & 1 & \cdots & \cdots \end{array}\right] = \left[\begin{array}{ccc} & & | \quad\ | \\ B & & a_K \quad a_N \\ & & | \quad\ | \\ [\text{—} \quad b_C \quad \text{—}] & & \\ [\text{—} \quad b_J \quad \text{—}] & & \\ [\text{—} \quad b_{NX} \quad \text{—}] & & \end{array}\right] \tag{6}$$

Reading across a row, the shares sum to one. For the net exports row, we simply define the "trade goods" share to be 1, to avoid dividing by zero in the case where net exports are zero. The lines in the vectors on the right show whether we define them as row or column vectors.

B. Aggregation

We define final-use-sector technology in the following way (adding government, defined in a way parallel to *C* and *J*):

$$\begin{aligned} dz_C &= b_C (I-B)^{-1} dz \\ dz_J &= b_J (I-B)^{-1} dz \\ dz_G &= b_G (I-B)^{-1} dz \\ dz_{NX} &= b_{NX} (I-B)^{-1} dz \end{aligned} \tag{7}$$

Why does this provide a reasonable approach to aggregation? In aggregating up from commodity-level technology growth, it is desirable to have a relatively mechanical aggregation procedure that is not too sensitive to the details of a particular model. The analogy is Domar weighting. However, Domar weighting, because it aims at a comprehensive aggregate, does not need to explicitly address the issue of what a commodity is used for. By contrast, in order to get an aggregate consumption technology measure or an aggregate investment technology measure, one cannot avoid the issue of what a commodity is used for. Here, to avoid strong model sensitivity, we take as our standard the usage shares in which a given commodity is distributed in the steady-state—or in practice, the trend values of the usage shares.

This strategy of "constant-share aggregation" is convenient, because it implies that when the quantity produced of a commodity increases by 1 percent, the amount of the commodity in each use increases by 1 percent. This leads to quite tractable aggregation formulas. In particular, suppose there are q commodities (including the virtual "trade good"). Let ΓC_M be a qxq matrix where the rows give the elasticities of the output of a particular commodity with respect to each of the commodities as an intermediate input. Think of Γ as a qxq diagonal matrix of returns to scale parameters; and think of C_M as a matrix with each row giving the cost shares of the various commodities used as intermediate inputs into producing a given commodity. Under the assumption of zero profits (which we will make in what follows), $C_M = B$. But what follows depends only on ΓC_M being the matrix of elasticities of the output of one commodity with respect to each of the commodities as an input.

Now suppose there are innovations dz to the vector of commodity technologies. First, the vector dz gives the direct or effect of commodity-level innovations on the q different commodity outputs. Second, under constant-share aggregation, the extra output of each commodity increases its use proportionately as an intermediate input into other commodities; this second-round effect is $\Gamma C_M dz$. Third, again under constant-share aggregation, these second round effects on the quantity of each commodity yields a third-round effect of $(\Gamma C_M)^2 dz$. In the end, as the technological improvements in the production of each commodity repeatedly work their way through the input-output matrix,there is an "input-output" multiplier of

$$[I + \Gamma C_M + (\Gamma C_M)^2 + (\Gamma C_M)^3 + ...]dz = [I + \Gamma C_M]^{-1} dz \tag{8}$$

In practice, we impose zero profits, which means that elasticities are proportional to the observed share matrix *B*. For the purposes of aggregation, we also set Γ equal to the identity matrix, at least at an initial step. When we use standard TFP—where constant returns is a necessary condition for it to measure technology—setting $\Gamma = I$ is quite natural. When we use Basu, Fernald, and Kimball (2004) residuals as a measure of technology, we could use their estimated Γ matrix. A concern there is that measurement error in estimating Γ is then inverted, so that positive and negative measurement error in Γ are not symmetric (in the way that positive and negative measurement error in the dz vector, for example, is symmetric and in the limit cancels out). We plan to revisit this estimation and aggregation issue in later drafts.

Finally, multiplying by the row vector of final-use shares (e.g., $dz_C = b_C (I - B)^{-1} dz$) arises from the obvious aggregation of the bundles of commodities used to make the final-goods consumption basket and the final-goods investment basket.

C. Relationship to existing measures plus a simple example

For the closed economy case where there are no intermediate inputs (i.e., one representative producer uses capital and labor to produce consumption goods; another produces investment goods), our definitions match the two-sector growth model.

In practice, the literature following GHK has used the relative price of consumption to investment to measure relative technologies. This definition naturally follows from the two-sector model, for example, under the assumption that factor shares and factor prices are the same (GHK, for example, discusses this case.) For intuition into our formulas, it is useful to consider how our definition of relative TFP corresponds to relative prices.

Suppose we use standard TFP growth as our measure of productivity growth. Then according to the standard dual results, for any industry/commodity, TFP growth equals a share-weighted average of real factor prices, or

$$dz_i = s_{Ki}dp_{Ki} + s_{Li}dp_{Li} + s_{Ni}dp_{Ni} - dp_i \, . \tag{9}$$

dp_{Ji} is growth in the input price for factor *J* in producing commodity *I;* s_{Ji} is its factor share, and dp_i is the growth in commodity price *i*. With all prices and shares in column-vector form, equations (4) and (9) imply that we can write relative technology growth as:

$$\begin{aligned} dz_J - dz_C &= (b_J - b_C)(I-B)^{-1}dz \\ &(b_J - b_C)(I-B)^{-1}[s_K dp_K + s_L dp_L + s_N dp_N - dp] \end{aligned} \tag{10}$$

But the share-weighted growth in the index of intermediate prices, $s_N dp_N$, is itself a function of the price vector *dp* and the intermediate-input shares *B:* $s_N dp_N = Bdp$. Hence, we can write the equation above as:

$$\begin{aligned} dz_J - dz_C &= (b_J - b_C)(I-B)^{-1}[s_K dp_K + s_L dp_L - (I-B)dp] \\ &= (b_J - b_C)(I-B)^{-1}[s_K dp_K + s_L dp_L] - (b_J - b_C)dp \, . \end{aligned} \tag{11}$$

The first term on the right-hand-side is the difference in share-weighted primary-input prices for capital and labor (after they have been passed through the I-O matrix $[I-B]^{-1}$); the second term is the difference in relative prices. Suppose all sectors face the same input prices, have the same shares of capital and labor in revenue, and have a similar input-output structure (in particular, suppose the row-sums of $[I-B]^{-1}$ are all equal).[7] Then the first relative-factor-price term is zero. In that case—which most macro models implicitly or explicitly assume—relative sectoral technologies show up one-for-one in relative prices. This relative-price and relative-TFP decomposition suggests that our definition is a natural extension of the GHK case.

For further intuition, consider the 2x2 case where there is only one non-trade commodity. Commodity 2 is the trade-commodity. Then b_{21} equals 1 (only commodity 1 is exported) and b_{22} equals zero (the trade good is not an input into itself). In this case, $(I\text{-}B)^{-1}$ is

$$\left[I-\begin{bmatrix} b_{11} & b_{12} \\ 1 & 0 \end{bmatrix}\right]^{-1} = \begin{bmatrix} 1-b_{11} & -b_{12} \\ -1 & 1 \end{bmatrix}^{-1} = \left(\frac{1}{(1-b_{11}-b_{21}}\right)\begin{bmatrix} 1 & b_{12} \\ 1 & 1-b_{11} \end{bmatrix} \tag{12}$$

The consumption-sector (and, for that matter, investment sector) technology shocks are:

$$\begin{aligned} dz_C &= b_C[I-B]^{-1}dz \\ &= [1 \quad 0]\begin{bmatrix} 1 & b_{12} \\ 1 & 1-b_{11} \end{bmatrix}\begin{bmatrix} dz_1 \\ dz_2 \end{bmatrix}\left(\frac{1}{1-b_{11}-b_{21}}\right) \\ &= (dz_1 + b_{12}dz_2)/(1-b_{11}-b_{21}) \end{aligned} \tag{13}$$

dz_1 is technology growth in the non-trade commodity; dz_2 is the change in the terms of trade $(dp_X - dp_M)$. Hence, the technology for producing consumption goods in the economy can improve if the economy becomes better at producing the commodity; or if the terms-of-trade improve. The terms-of-trade improvement means that by exporting an unchanged quantity of the commodity, the country can increase its consumption because it can import more. In the denominator, the b_{12} term represents imports of commodity 1; they are an "input" into supplying the commodity, and we have already counted them as part of the supply of the commodity. Together, the $(1\text{-}b_{11}\text{-}b_{12})$ term represents the standard Domar weight from intermediate goods (in this case, of the commodity itself).

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[7] Check: What seems to be necessary is that the rows of $(I\text{-}B)^{-1}$ be equal. If factor shares and factor prices are equated, then all elements of the vector of share-weighted input prices are equal. If the row-sums of $(I\text{-}B)^{-1}$ are also equal, then the consumption and investment share-weighted factor prices are also equal and cancel out.

The "trade technology" is:

$$\begin{aligned} dz_{NX} &= b_{NX}(I-B)^{-1}dz \\ &= \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & b_{12} \\ 1 & 1-b_{11} \end{bmatrix} \begin{bmatrix} dz_1 \\ dz_2 \end{bmatrix} \left(\frac{1}{1-b_{11}-b_{21}} \right) \\ &= (dz_1 + (1-b_{11})dz_2)/(1-b_{11}-b_{21}) \end{aligned} \tag{14}$$

If either sector becomes more productive, then trade technology improves.

V. Data

We use input-output data underlying the KLEM dataset produced by Dale Jorgenson and his collaborators.[8] These data provide consistent industry productivity (output and inputs) as well as commodity final-use data. The original data sources for the input-output data and industry gross output data are generally the Bureau of Labor Statistics. (The Jorgenson data uses older vintages of the BLS data, in addition to the data currently available on the BLS web site.) Investment includes consumer durables; consumption is non-durables and services.

The Jorgenson data offer several advantages. First, they provide a unified dataset that allows for productivity analysis by providing annual data on gross output and inputs of capital, labor, and intermediates. Second, the input data incorporate adjustments for quality or composition; e.g., capital services from different types of capital are taken to be proportional to their user cost, as standard first-order-conditions imply, not proportional to their relative purchase prices. Third, the productivity data are unified with annual input-output data that are measured on a consistent basis.

There are several potential caveats, however. First, the source data do not always match the BEA data. The input-output data do differ from the BEA I-O tables, for example; and the

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[8] The dataset updates Jorgenson, Gollop, and Fraumeni (1987). In addition to Dale Jorgenson, we have also discussed the data set with the following collaborators/co-authors: Barbara Fraumeni, Mun Ho, and Kevin Stiroh. Jon Samuels also helped with data availability.

final-use data are not always benchmarked to aggregate BEA totals. One place this shows up is in relative prices of consumption to investment. As shown in the top panel of Table 2, in the Jorgenson data, the relative price is essentially flat before 1977; from 1977-1996, the relative price of consumption goods rises about 1 percent per year relative to investment prices. In contrast, in the BEA final-use data, consumption prices rise about 1-1/2 percent per year faster than investment prices from 1977-1996. Second, there are no adjustments for other hedonics that this literature has often used (e.g., the Gordon series, or its extension by Cummins and Violante).

VI. Preliminary Results

Table 1 lists the 35 industries/commodities that we have in our dataset, plus the 36th "international trade" commodity. Our data do not comprise all of GDP, largely because they exclude the service flow from owner-occupied housing. The columns show the investment and consumption commodity shares (corresponding to the commodity vector b_{Ji}' and b_{Ci}') as well as the impact of running these shares through the input-output tables. Note that after incorporating the I-O flows, the column shares sum to much more than 100 percent. Intuitively, suppose all sectors increase their gross-output by 1 percent. Then they could sell 1 percent more to, say, investment users, which would boost investment by 1 percent as the first-round effect; but they also boost sales as an intermediate input into other uses, which further boosts overall investment beyond its initial effect.

In the investment shares, our data predate the accounting revisions to include software in investment. Since service industries (e.g., "Computer systems design and related services") undertake a lot of investment, including software would boost the direct importance of commodity 34, services, in investment. Nevertheless, the indirect effect of services is much larger than the direct effect, rising from a weight of 0.6 percent of investment to a weight of 11.6

percent. In general, sectors that sell primarily to final uses (such as construction) become relatively less important once passed through the I-O structure, taking into account that the sum of all the weights more than doubles. Sectors that sell primarily as intermediates (such as chemicals or finance) become relatively more important.

Table 2.B shows relative investment-to-consumption TFP, and shows the decomposition from equation (11) into relative output prices and relative factor prices. From 1977-1996, for example, consumption prices rose about 1 percent faster than investment prices (line 1). But weighted input prices in the consumption sector rose about 1/3 percentage point faster than in the investment sector (line 2), contributing non-negligibly to the relative output price movements. Finally, investment sector TFP rose about 2/3 percentage points faster than consumption TFP.[9]

We have not yet identified the major source of the relative factor price differences, but three candidates suggest themselves for investigation. First, there are notable differences in capital and labor shares across sectors. Second, the row-sums of the $[I-B]^{-1}$ matrix differ (the mean is 2.40, with a standard deviation of 0.45; the largest value is 3.35 for international trade, and the smallest value is 1.65 for wholesale-and-retail trade.). Third, in the Jorgenson dataset there are persistent deviations in labor and capital input prices, even after the Jorgenson adjustments for input composition/quality.

Implicit in some of the literature following GHK is a view that the increase in the pace of investment-sector relative-price declines after the 1970s reflected an increase in the pace of equipment-sector technical change. Even after accounting for input prices, we still find an increase in the pace of relative investment sector TFP. Does this relative performance actually reflect faster TFP growth in producing investment goods?

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[9] Implemented correctly, this should be an identity, which it is not in Table 2.B. There is one programming "approximation" we're already aware of, but we do not yet rule out that there may be others!

Table 3.A shows estimated TFP for final sectors. From 1959-77, consumption and investment TFP growth was virtually identical. From 1977-96, *both* measures slow substantially. Consumption TFP growth slows more, which thus opens up a relative TFP gap between the two sectors. But the picture is quite different from the picture sometimes painted in the macro literature on investment-specific technical change.[10] (Government TFP is more similar to consumption than to investment TFP, as one would expect..)

Table 3.B shows selected correlations of sectoral and relative TFP. The sectoral shocks themselves are very highly correlated. This is not too surprising; in addition to any “common” shocks, the final-sector shocks are weighted averages of the same vector of underlying commodity shocks, albeit with quite different weights.

GHK and also Fisher (2005) explicitly assume orthogonality of what they label “neutral” and “investment-specific” productivity innovations. In our two-sector framework, these labels correspond to the consumption-sector productivity shock and the relative investment-consumption shock, and this correlation is shown in line 2. Although the correlation is weakly positive from 1959-77, over the entire sample the correlation is, indeed, close to zero. In contrast, the relative shock is highly correlated with investment TFP, as shown in line 3.[11]

Table 4 provides preliminary estimates when we plug in estimates of industry technology innovations from Basu, Fernald, and Kimball (BFK, 2004). BFK try to control for factor utilization and deviations from constant returns to scale in their estimates. They do not have

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[10] The argument that faster relative investment-sector TFP reflects primarily a sharper slowdown in consumption-sector TFP is also noted in a paper by Marquis and Trehan.(check reference).

[11] The correlations for the entire period are not the averages of the correlations for the subperiods, because the standard deviations over the entire period exceed the average of the standard deviations for the subperiods. An interesting question that we have not yet pursued is what orthogonality of relative TFP and consumption TFP implies about the input-output structure of the economy.

estimates for agriculture, mining, or government enterprises, so we continue to use unadjusted industry TFP in those industries.[12]

Qualitatively speaking, the results from Table 4 look similar to the results in Table3. There is a sharp slowdown in consumption-sector technology change in the second half of the sample; indeed, consumption technology growth turns negative.[13] Investment technology now speeds up in the second half of the sample rather than declining. The correlation in the sectoral shocks is still reduced (not surprisingly, since BFK find that utilization changes are correlated across sectors) but remains substantial. The GHK and Fisher assumptions that consumption technology change and relative technology change are uncorrelated once again cannot be rejected in the data.

Figure 1A and 1B show cumulated innovations to sector-specific productivities. The top panel shows consumption and investment-sector TFP. Both series grow strongly in the pre-1970s period and are relatively flat in the 1970s. Figure 1B shows relative investment-to-consumption sector TFP and BFK technologies (for TFP, it is the difference between the lines in the top panel). For TFP, the two series begin to diverge in the early 1980s. For the BFK residuals, the two series begin to diverge in the early 1970s. (In the BFK case, the dating is potentially driven by the estimation, which tests for and finds a break in non-manufacturing technology growth in 1973, which is then imposed on the estimation; since non-manufacturing is disproportionately consumption relative to investment, it is no surprise that the BFK residuals suggest an early 1970s break.)

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[12] When we set technology in the missing sectors to be uniformly zero, the economy-wide weighted average technology innovation (measured as final-sector-share-weighted final-sector technologies) has a correlation of 0.998 with the aggregate series calculated as a Domar-weighted series by Basu, Fernald, and Kimball.

[13] Negative measured technology change could be consistent with stories of information technology as a general purpose technology, in which IT-using sectors diverted resources to investments in organizational capital or other forms of knowledge; it could also be consistent with unobserved quality change in consumption-intensive sectors such as finance.

Table 5 shows some preliminary dynamic responses using the BFK residuals. Once aggregated (taking a final-goods-share weighted average of the final-goods sector residuals summarized in Table 4.A), the first two columns show that contemporaneously, the shocks are negatively correlated with growth in hours worked in the non-farm business sector. The negative correlation is slightly less pronounced than what BFK report; the main reason for that appears to be the use of unadjusted TFP in agriculture, mining, and government enterprises. (Setting technology growth in those sectors to zero leads to results that are virtually identical to those reported by BFK).

Column (3) suggests that the negative contemporaneous relationship primarily reflects investment goods. The relative consumption-investment technology shock has a slight (but insignificant) contemporaneous effect. However, with one lag, both investment and relative consumption-to-investment technology shocks are positively related to hours.

VII. Conclusions (preliminary)

Theory suggests that the "final use" sector in which technology shocks occur matters for the dynamic response of those shocks. We point this out with the example of consumption-technology neutrality in the real-business-cycle model. This neutrality result was, perhaps, implicit in some previous work but has not been discussed explicitly, to the best of our knowledge.

We propose a method to measure sector-specific technologies that does not rely simply on relative price changes, as frequently used in the macro literature. In special cases, the relative-price measures are appropriate; but in general, they are not. Preliminary empirical results suggest that relative factor prices differ across final-use sectors, driving a wedge between relative output prices and relative sector-specific technologies. We also present very preliminary empirical results suggesting that the short-run dynamic responses are inconsistent with the simplest of two-sector models. Hence, we plan to explore the implications of alternative models.

Going forward, we also plan to explore sensitivity to benchmarking to BEA prices, as well as incorporating alternative hedonic adjustments.

VIII. Appendix: Further Details on I-O Manipulations

This appendix provides further details on how we combine the use and make tables to produce a commodity-by-commodity use table and commodity technology change measures. As in the text, we omit time subscripts for notational convenience.

As noted in the text, the standard use table shows the flows of *commodities* to final uses as well as to intermediate uses in *industry* (not commodity) production. We use the information in the make table to produce a commodity-by-commodity use table as follows. Each row of the make table corresponds to an industry; the columns correspond to commodities. So a row tells what commodities are produced by each industry. Consider the make table M in row-share form, so that element m_{ij} corresponds to the share of output of industry i that consists of commodity j. From the standard use table, we know the shares of each input (the q commodities plus capital and labor) in industry production; define that commodity-by-industry use matrix as U^I, where columns correspond to industries and each row corresponds to a separate input into that industry. (One of these input commodities is so-called non-competing imports.) Conceptually, this commodity-by-industry use table is a "garbled" version of the commodity-by-commodity use table, which we denote by U. The make table tells us the garbling: $UM' = U^I$ For example, suppose there are two industries, which produce using inputs of two commodities and one primary input, labor. These matrices have the following form:

$$UM' = \begin{pmatrix} u_{11} & u_{12} \\ u_{21} & u_{22} \\ u_{L1} & u_{L2} \end{pmatrix} \begin{pmatrix} m_{11} & m_{21} \\ m_{12} & m_{22} \end{pmatrix} = \begin{pmatrix} u_{11}m_{11} + u_{12}m_{12} & u_{11}m_{21} + u_{12}m_{22} \\ u_{21}m_{11} + u_{22}m_{12} & u_{21}m_{21} + u_{22}m_{22} \\ u_{L1}m_{11} + u_{L2}m_{12} & u_{L1}m_{21} + u_{L2}m_{22} \end{pmatrix} = U^I \tag{15}$$

The columns of U sum to one, and give the factor shares in producing each commodity. On the right hand side, the elements are industry factor shares, which are weighted averages of the commodity factor shares, where the weights are the shares of industry output accounted for by each commodity. For example, consider the upper left element, $u_{11}m_{11} + u_{12}m_{12}$. $u_{11}m_{11}$ is the factor share of commodity one in the production of commodity one, u_{11}, multiplied by the share of the output of industry one that consists of commodity one; $u_{12}m_{12}$ is the factor share of commodity one in the production of commodity two, multiplied by the share of industry one that consists of the output of commodity two. Thus, the sum of these two pieces tells us the factor share of commodity one in the production of the composite output of industry one. More generally, the factor shares in each observed industry equal the weighted average of the factor shares in producing each of the underlying commodities that the industry produces. It follows from this discussion that we can obtain the underlying commodity-by-commodity factor shares using the relationship: $U = U^I M'^{-1}$.

Second, we want a vector of disaggregated productivity innovations in terms of commodities rather than industries. Suppose we have a column vector of industry productivity growth rates, dz^I. We again interpret this as a garbled version of the column vector of commodity productivity growth rates, dz, that we are interested in; the make table again tells us the garbling: $M\, dz_t = dz_t^I$. In the two-commodity example:

$$\begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix} \begin{pmatrix} dz_{1,t} \\ dz_{2,t} \end{pmatrix} = \begin{pmatrix} m_{11}dz_{1,t} + m_{12}dz_{2,t} \\ m_{21}dz_{1,t} + m_{22}dz_{2,t} \end{pmatrix} = \begin{pmatrix} dz_{1,t}^I \\ dz_{2,t}^I \end{pmatrix} \tag{16}$$

The industry productivity growth rates are a share-weighted average of the commodity productivity growth rates, where the weights depend on what commodities the industry produces. Hence, given the industry productivity-growth vector and the make table, the relationship $dz_t = M^{-1} dz_t^I$ gives us the underlying commodity productivity growth vector.

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Table 1. Commodities final-goods shares, 1977 (percent)

		Final-use investment share, b_{Ji}	I-O Share of Investment, $b_{Ji}[I-B]^{-1}$	Final-use consumptiont share, b_{Ci}	I-O Share of Consumption, $b_{Ci}[I-B]^{-1}$
1	Agriculture	0.8	4.9	1.3	10.6
2	Metal mining	0.0	1.0	0.0	0.3
3	Coal mining	0.1	1.0	0.0	1.0
4	Oil and gas extraction	2.1	4.7	0.0	4.7
5	Non-metallic mining	0.0	0.7	0.0	0.3
6	Construction	28.1	29.4	0.8	2.8
7	Food and kindred product	0.3	3.6	11.4	18.2
8	Tobacco	0.1	0.2	0.8	1.1
9	Textile mill products	0.7	2.4	0.1	1.9
10	Apparel	0.6	1.4	3.7	5.0
11	Lumber and wood	0.8	5.1	0.0	1.1
12	Furniture and fixtures	2.6	2.9	0.0	0.0
13	Paper and allied	0.1	2.6	0.6	3.7
14	Printing, publishing and	0.6	1.3	0.7	2.0
15	Chemicals	0.5	7.6	1.9	8.1
16	Petroleum and coal products	0.5	3.8	3.8	7.2
17	Rubber and misc plastics	1.2	4.2	0.1	1.8
18	Leather	0.1	0.1	0.7	0.9
19	Stone, clay, glass	0.4	3.5	0.0	1.0
20	Primary metal	0.3	13.0	0.0	2.9
21	Fabricated metal	1.7	9.6	0.1	2.8
22	Machinery, non-electical	9.6	16.5	0.0	2.8
23	Electrical machinery	6.1	11.1	0.1	2.0
24	Motor vehicles	14.7	20.9	0.0	1.5
25	Transportation equipment	2.5	3.8	0.0	0.7
26	Instruments	3.1	4.1	0.1	0.9
27	Misc. manufacturing	1.7	2.1	0.5	1.0
28	Transportation	1.0	7.3	3.0	8.6
29	Communications	0.6	2.2	2.3	4.9
30	Electric utilities	0.0	2.1	2.5	4.4
31	Gas utilities	0.0	2.0	1.3	4.1
32	Wholesale and Retail Trade	16.4	27.9	23.2	31.2
33	Finance Insurance and Real Est.	1.9	8.3	12.6	23.4
34	Services	0.6	11.6	26.6	39.8
35	Government enterprises	0.0	0.6	0.6	1.7
36	International Trade	0.1	13.3	0.9	8.7
	COLUMN TOTALS	100.0	236.9	100.0	213.5

Notes: Investment and consumption shares are direct shares of the commodity in total final use. I-O share reflects indirect contributions via the input-output matrix, as well as direct effects. I-O shares sum to more than 100 percent. (compbjc.xls)

Table 2. Relative output prices, relative input prices, and relative sectoral TFP
(percent change, annual rate)

A. Prices of consumption relative to investment, BEA and Jorgenson datasets

	1959-1996	1959-1977	1977-1996
BEA	1.25		1.54
Jorgenson	0.50	-0.07	1.04

Notes: Relative price is price of non-durable consumption relative to investment plus consumer durables. Software investment and housing services are excluded from BEA calculation for comparability with Jorgenson dataset

B. Jorgenson data: Relative prices and relative sectoral TFPs

	1959-1996	1959-1977	1977-1996
(1) Relative price of consumption to investment	0.50	-0.07	1.04
(2) Relative share-weighted input prices (consumption relative to investment)	-0.04	0.26	-0.32
(3) Relative Sectoral TFP (investment relative to consumption)	0.37	0.01	0.71

Notes: In principle, the sum of the first two lines should equal the third line. At present, we are not treating imports (and trade “technology”) properly for this to be an identity. The discrepancy is large enough that there could be other programming issues that we’re checking on.

Table 3. TFP and Correlations

A. Final-goods sector TFP growth
(percent change, annual rate)

	1959-1996	1959-1977	1977-1996
(1) Consumption TFP, dz_C	0.68	1.36	0.06
(2) Investment TFP, dz_J	1.04	1.37	0.75
(3) Government TFP, dz_G	0.70	1.11	0.32
(4) Trade TFP, dz_{Trade}	1.33	1.47	1.21

B. Selected correlations of sectoral TFP

	1959-1996	1959-1977	1977-1996
(1) Corr(dz_J, dz_C)	0.86	0.90	0.84
(2) Corr($dz_J - dz_C$, dz_C)	0.07	0.26	0.06
(3) Corr($dz_J - dz_C$, dz_J)	0.56	0.66	0.59

Notes: TFP is calculated for domestic production in the 35 industries in the Jorgenson dataset, converted to a commodity-supply basis, and aggregated to final-use sectors as described in the text. Correlations in panel B are very similar if we replace consumption TFP with a weighted average of consumption and government TFP.

Table 4. Basu, Fernald, and Kimball Technology Residuals

A. Final-goods sector technology, using Basu, Fernald, Kimball industry shocks
(percent change, annual rate)

	1959-1996	1959-1977	1977-1996
(1) Consumption technology, dz_C	0.08	0.45	-0.26
(2) Investment technology, dz_J	0.65	0.46	0.82
(3) Government technology, dz_G	0.32	0.32	0.32
(4) Trade technology, dz_{Trade}	0.89	0.63	1.12

B. Selected correlations of sectoral technology

	1959-1996	1959-1977	1977-1996
(1) Corr(dz_J, dz_C)	0.63	0.64	0.73
(2) Corr(dz_J - dz_C, dz_C)	-0.11	-0.18	0.15
(3) Corr(dz_J - dz_C, dz_J)	0.70	0.64	0.78

Notes: Calculated using industry residuals from Basu, Fernald, and Kimball (2004). Basu, Fernald, and Kimball do not have estimates for agriculture, mining, and government enterprises; for those industries, technology is taken to be standard TFP.

Table 5. Preliminary Dynamics: Explaining Growth in Hours Worked

	(1)	(2)	(3)
dz_bfk_ag	-0.31 (0.19)	-0.47 (0.15)	
dz_bfk_ag(-1)		0.59 (0.26)	
dz_bfk_ag(-2)		0.39 (0.13)	
dz_bfk_investment			-0.48 (0.15)
dz_bfk_ investment (-1)			0.67 (0.23)
dz_bfk_ investment (-2)			0.19 (0.16)
dz_bfk_consumption - dz_bfk_investment			-0.16 (0.25)
dz_bfk_consumption - dz_bfk_investment (-1)			0.82 (0.34)
dz_bfk_consumption - dz_bfk_investment (-2)			-0.42 (0.27)
R^2	0.04	0.30	0.42

Notes: In all regressions, dependent variable is growth rate of hours worked in private business economy. Heteroskedastic and auto-correlation robust standard errors in parentheses. Sample is 1961-1996. dz_bfk_ag is share-weighted sectoral technology shocks, using BFK residuals. Dz_bfk_ag differs from series actually used by Basu, Fernald, and Kimball because it includes agriculture, mining, and government enterprises, which they omit; for those residuals, technology is taken to be standard TFP. For these regressions, consumption includes nondurables and services, plus government.

Figure 1.A. Consumption and Investment Sector TFP

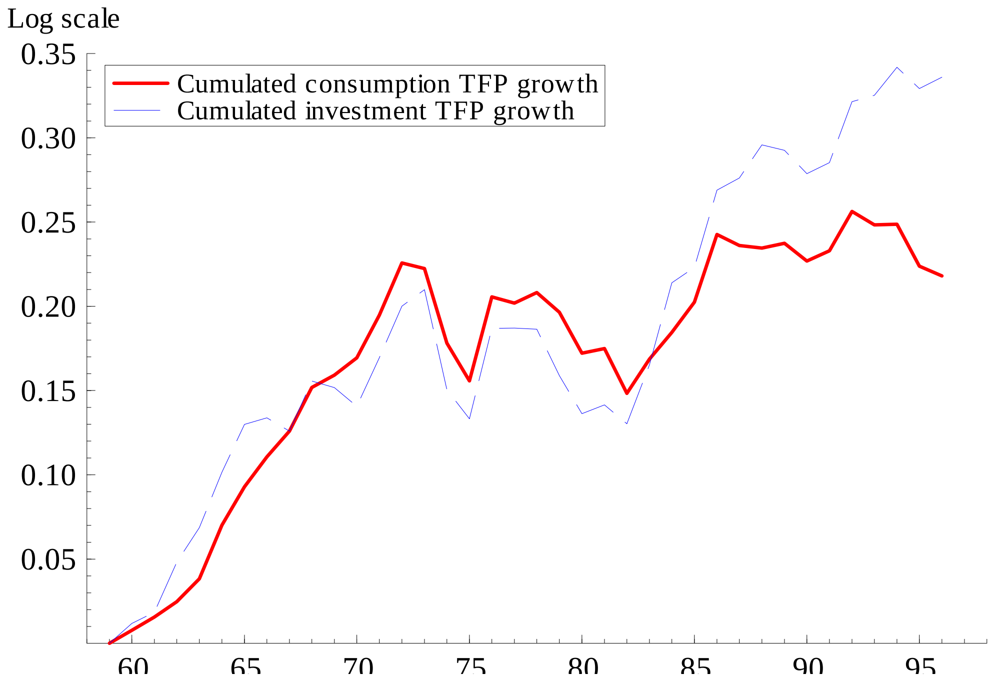

Figure 1.B. Investment Sector TFP and BFK Residuals relative to Consumption Sector TFP and BFK Residuals