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.

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, suppose different producers have different factor

shares or face different input prices; or suppose markups change over time. Then relative prices

do not properly measure relative technical change. Second, we discuss extensions to the open

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[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.

economy, where the ability to 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, in addition to some increases in the pace of investment goods total-factor-productivity (TFP) growth, TFP growth also slowed for non-durable consumption goods and services. Second, since the 1970s, an appropriately weighted measure of nominal input prices rose much 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 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 that 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 affects only 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_J.

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

$$\max_{N,C,X,I} E_0 \sum_{t=0}^{\infty} \beta^t [\ln(C_t) - v(L_t)]$$

$$s.t. \quad C = Z_C \cdot F(K_C, L_C)$$

$$J = Z_J \cdot F(K_J, L_J) \tag{1}$$

$$K = K_C + K_J, \quad L = L_C + L_J$$

$$K_{t+1} = J_t + (1-\delta)K_t$$

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 raises Z_C but leaves q unchanged is

neutral in that both Z_C and Z_J 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:

$$\max_{N,C,X,I} E_0 \sum_{t=0}^{\infty} \beta^t [\ln(C_t) - v(L_t)]$$

$$s.t. \quad C_t = A_t X_t \tag{2}$$

$$X + J = F(K, L, Z)$$

$$K_{t+1} = J_t + (1-\delta)K_t$$

X is an index of inputs devoted to consumption (in the previous example, it would

correspond to the production function $Z_J F(K_C, L_C)$. 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:

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

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 (2006), 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.[5]

This prior work is based on a "top-down" measurement strategy that relies on investment and consumption deflators (either directly from the BEA, or augmented with equipment deflators from Gordon (19xx), and Cummins-Violante (200s)). Our paper contributes to the literature by

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[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.

[5] Fisher's impulse response functions look similar to the subperiod results in Gali, Lopez-Salido, and Valles (2002), with technology shocks reducing hours worked in the pre-1979 period and raising them thereafter.

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 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, relative prices capture 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 (which, once refined into petroleum products, is 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, where "commodity" means a category of goods or services. These uses include final uses (consumption, investment, government purchases, and net exports) and 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 production by 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.[6]

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	$P_K^1 K^1$	$P_K^2 K^2$	…	…	…	…	$P_K K$
L	$P_L^1 L^1$	$P_L^2 L^2$	…	…	…	…	$P_L L$
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

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[6] 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.

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

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	$P_1 Y_1^1$	$P_1 Y_1^2$	$P_1^D Y_1^X$	$P_1 Y_1^C$	$P_1 Y_1^J$	…	$P_1 Y_1$
2	$P_2 Y_2^1$	$P_2 Y_2^2$	$P_2^D Y_2^X$	$P_2 Y_2^C$	$P_2 Y_2^J$	…	$P_2 Y_2$
Trade goods	$P_1^M Y_1^M$	$P_2^M Y_2^M$	…	…	…	$P_X X$ $-P_M M$	$P_X X$
K	$P_K^1 K^1$	$P_K^2 K^2$	…	…	…	…	$P_K K$
L	$P_L^1 L^1$	$P_L^2 L^2$	…	…	…	…	$P_L L$
Column total	$P_1 Y_1$	$P_2 Y_2$	$P_X X$	$P_C C$	$P_J J$	$P_X X$ $-P_M M$	

(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.)[7]

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 Tornquist 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

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[7] 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.

well as being part of the commodity output. (For Divisia indices, which the Tornquist

approximates in discrete time, 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:

$$
\begin{bmatrix}
& \begin{array}{ccc|cc}
& 1 & 2 & \text{Trade goods} & K & L \\
\hline
1 & b_{11} & b_{12} & b_{13} & a_{1K} & a_{1L} \\
2 & b_{21} & b_{22} & b_{23} & a_{2K} & a_{2L} \\
\text{Trade goods} & b_{31} & b_{32} & 0 & \dots & \dots \\
\hline
C & b_{C1} & b_{C2} & 0 & \dots & \dots \\
J & b_{J1} & b_{J2} & 0 & \dots & \dots \\
NX & 0 & 0 & 1 & \dots & \dots
\end{array}
\end{bmatrix}
=
\begin{bmatrix}
\begin{array}{c|cc}
& \vdots & \vdots \\
B & a_K & a_L \\
& \vdots & \vdots \\
\hline
[— \; b_C \; —] & & \\
[— \; b_J \; —] & & \\
[— \; b_{NX} \; —] & &
\end{array}
\end{bmatrix}
\tag{6}
$$

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*):

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

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 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:

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

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:

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

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 $[I\text{-}B]^{-1}$); 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 $[I\text{-}B]^{-1}$ are all equal).[8] 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.

However, equality of factor shares across producers is clearly counterfactual. Furthermore, in the presence of adjustment costs, factor prices movements might differ across firms (for capital, this is the shadow value of capital). Hence, it can be misleading to assume that the input-price effect is zero.

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

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

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

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

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[8] 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.

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).

The "trade technology" is:

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

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.[9] These data, which run 1960-2004, provide consistent industry productivity (output and inputs) as well as commodity final-use data for 35 industries/commodities. The original data sources for the input-output data and industry gross output data are generally the Bureau of Labor Statistics which has, for a long time, produced annual versions of both nominal and real (chained) I-O tables. (The Jorgenson data uses various older vintages of the BLS data,

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[9] 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 helped tremendously with data availability.

in addition to the data currently available on the BLS web site.) For the 35 commodities plus

non-traded imports, the data include final expenditure on consumer non-durables and services,

consumer durables, investment, government, and exports and imports.

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.

We have separate prices for domestic commodity production and for commodity imports.

For each commodity, we calculate a composite supply price as a Tornquist index, which we

apply to (most) uses of the commodity. The exception is exports (intermediate inputs into

"trade"),, where we deflate with the domestic price. In essence, we assume that all users of a

commodity consume the same composite of domestic and imported supplies of the commodity.[10]

There are several potential caveats to the Jorgenson data. First, the BLS source data do

not always match the BEA data. For example, the input-output data often differ, sometimes

substantially, from the quinqennial benchmark BEA I-O tables, for example; and the final-use

data are not always benchmarked to aggregate BEA totals. One place this shows up is in relative

prices of consumption to investment. In particular, the top panel of Table 2 compares the

relative price of nondurables and services consumption (plus government purchases) to

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[10] Relatively recently, the BEA has begun producing an "import matrix" that shows, for each commodity, the estimated industry uses of imports. But they create this table using the "assumption that each industry uses imports of a commodity in the same proportion as imports-to-domestic supply of the same commodity,",(http://www.bea.gov/industry/xls/1997import_matrix.xls, 'readme' tab) rather than using actual data on where imports flow. So the BEA makes the same assumption we do.

equipment investment. In the BEA data, this relative price rises sharply, especially over

(roughly) the past two decades. The Jorgenson data shows a qualitatively similar pattern of a

sharply-increasing relative price over the past two decades relative to the previous two decades,

but the magnitude of the relative price movements are smaller. This appears to reflect fewer

hedonic adjustments in the Jorgenson data; in addition, for trade, FIRE, and services

commodities—which account for almost a quarter of equipment and software investment in the

Jorgenson data—we use the "average" commodity price, which may be a poor approximation to

the actual purchase price paid for the investment component of these commodities (e.g., the

actual margins on investment goods). 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).

We plan to incorporate these hedonics in future work.

We also update the estimated industry technology residuals from Basu, Fernald, and

Kimball (BFK, 2006). In particular, we estimate the following regressions, using oil price

increases, government defense spending, and a measure of monetary innovations (from a VAR)

as instruments: $dy_i = c_i + \gamma_i dx_i + \beta dh_i + \varepsilon_i$, where dy is output growth, dx is share-weighted input

growth, and dh is hours-per-worker growth (as a proxy for utilization). These estimates control

for variations in factor utilization and deviations from constant returns to scale, both of which

can drive a wedge between technology and measured TFP. For each industry, technology is

measured as $c_i + \varepsilon_i$. See BFK (2006) for details on estimation.

VI.   Preliminary Results

Figure 1A shows the estimated levels of final-use-sector TFP that we estimate from our

data. Trade (net exports) TFP grows fastest; structures TFP is essentially flat over the sample.

Equipment investment TFP rises much faster than non-durables and services TFP. Figure 1B

shows the corresponding BFK measures. The figure suggests that, as one would expect, over

longer periods of time, the BFK measures are qualitatively similar to uncorrected TFP measures.

BFK, of course, focused on the differences in the properties of the technology residuals at higher

frequency.

What were the key properties of the data that underlie the plots in Figure 1? 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, for two main reasons: They exclude the

service flow from owner-occupied housing, and they exclude services produced directly by the

government (they do include government enterprises; and they include direct purchases by the

government of goods and services produced by non-government businesses). The columns show

the investment, consumption, and trade commodity shares (corresponding to the commodity

vector $b_{Ji}{'}$, $b_{Ci}{'}$, and $b_{NXi}{'}$) 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 case of international trade, the

key second-round "sales" are exports, which are an intermediate input into producing the

international-trade commodity. This is important, since export-oriented sectors have tended to

have faster-than-average TFP growth, which offsets the fact that the direct terms-of-trade effect

(dz_{36}) has fallen sharply over time.

Note that, in some cases, such as construction, the direct investment effect is similar to

the overall effect; in other cases, the overall effect is much larger than the direct effect. In

general, sectors that sell primarily to final uses (such as construction) become relatively less important once passed through the I-O structure. This is because there is little "second round" (and further) effect on the production of investment goods, coming from the use of construction goods, say, as an intermediate input. In contrast, sectors that produce a lot of intermediates (such as chemicals, finance, or services) become relatively more important when these second-round effects are taken into account.

Table 2.B shows relative investment-to-consumption TFP, and shows the decomposition based on equation (11) into relative output prices and relative factor prices. From 1982-2004, for example, prices for non-durable and services consumption rose more than 2 percentage-points per year faster than prices for equipment investment (line 1). This relative-price change substantially exceeds the relative pace of TFP growth (equipment relative to consumption, line 3). The difference reflects the fact that weighted input prices in the consumption sector *fell* nearly 2/3 percentage points relative to the investment sector (line 2). Hence, although equipment-investment TFP was much faster than consumption TFP (line 3), the typical macroeconomic shortcut of focusing on relative prices overstates those differences.[11]

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.

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[11] Implemented correctly, this should be an identity. It takes some care to implement the identity directly, which we have not yet done. So we define line 2 of Table 2.B as a residual.

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?

Table 3.A shows estimated TFP for final sectors. From 1960-82, nondurable/service consumption and overall investment TFP growth was very similar, although equipment TFP growth (line 3a) was somewhat faster. After 1982, consumption TFP growth slowed down somewhat, whereas investment TFP (especially for equipment) surged. Together, these trends imply a widening TFP gap between the two sectors..[12] (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 (equipment) "investment-specific" productivity innovations. In our two-sector framework, these labels correspond to the consumption-sector productivity shock and the relative equipment-investment-consumption shock; line 2 shows this correlation. The correlation is weakly positive over the full sample period (0.26)—significantly different from zero at the 10 percent level. For the first half of the sample, the correlation is 0.44, which is significant at the 5 percent level. Indeed, there is little a priori reason to expect orthogonality, again given that these are mixtures

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[12] In earlier data, we found that TFP in both sectors slowed down. Marquis and Trehan (atcheck reference) argued that faster relative investment-sector TFP reflecteds primarily a sharper slowdown in consumption-sector, consistent with that earlier data.

of common shocks. Nevertheless, the orthogonality with consumption TFP is a better

approximation than is orthogonality with investment TFP, as shown in line 4.[13]

Table 4 provides preliminary estimates when we plug in estimates of industry technology

innovations from the BFK procedure. They do not have estimates for agriculture, mining, or

government enterprises, so we continue to use unadjusted industry TFP in those industries.[14]

Qualitatively speaking, the results from Table 4 look similar to the results in Table 3.

There is a slightly sharper slowdown in consumption-sector technology change in the second

half of the sample Investment technology is now more constant over the sample. The

correlation in the sectoral shocks is reduced somewhat (not surprisingly, since BFK find that

utilization changes are correlated across sectors) but remains substantial. The evidence against

the GHK and Fisher assumptions of orthogonality of consumption and investment-specific

shocks is somewhat weaker.

Figure 2 shows relative investment-to-consumption sector TFP and BFK technologies;

these are the differences between the investment and consumption lines from Figure 1. In both

cases, the two series really begin to diverge after the early 1980s. in the early 1980s.

Table 5 shows some preliminary dynamic responses using the older vintage of BFK

residuals (*results need to be updated*). 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

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[13] 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.

[14] 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.

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:

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

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. Under the assumption that the commodity factor shares are equal—regardless of which industry produces the commodity—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.

IX.　　　References

Basu, Susanto, John Fernald, and Miles Kimball (2004). "Are Technology Improvements Contractionary?" NBER Working Paper.

Campbell, J, "Entry, Exit, Embodied Technology, and Business Cycles," Review of Economic Dynamics, 1, April 1998, 371-408.

Christiano, L. and J. Fisher, "Stock Market and Investment Good Prices: Implications for Macroeconomics," Chicago Fed Working Paper 98-6, 1998.

Cummins, J. and G. Violante, "Investment-Specific Technical Change in the United States (1947-2000): Measurement and Macroeconomic Consequences," Review of Economic Dynamics, 5(2), April 2002, 243-284.

Fisher, J, "Relative Prices, Complementarities and Co-movement Among Components of Aggregate Expenditures," Journal of Monetary Economics, 39 (August 1997), 449-74.

Fisher, Jonas (2005). "The Dynamic Effects of Neutral and Investment-Specific Technology Shocks." Working Paper, Federal Reserve Bank of Chicago (Draft dated May 16, 2005).

Galí, J, "Technology, Employment, and the Business Cycle: Do Technology Shocks Explain Aggregate Fluctuations?" American Economic Review, 89 (March 1999), 249-271.

Greenwood, J., Z. Hercowitz and G. Huffman, "Investment, Capacity Utilization and the Business Cycle," American Economic Review, 78 (June 1988), 402-17.

Greenwood, Jeremy, Zvi Hercowitz, and Per Krusell (1997). "Long-Run Implications of Investment-Specific Technological Change," *American Economic Review*, vol. 87(3), pages 342-62.

Greenwood, J., Z. Hercowitz and P. Krusell, "The Role of Investment-Specific Technological Change in the Business Cycle," European Economic Review, 2000.

Kimball, M, "Proof of Consumption Sector Neutrality." University of Michigan manuscript, August 1994.

Lawson, Ann M., Kurt S. Bersani, Mahnaz Fahim-Nader, and Jiemin Guo (2002). "Benchmark Input-Output Accounts of the United States." *Survey of Current Business*, December.

Whelan, Karl (2000). "Balanced Growth Revisited: A Two-Sector Model of Economic Growth." FEDS discussion paper, Board of Governors of the Federal Reserve System.

Table 1. Commodity final-goods shares (percent)

		Final-use invest. share, b_{Ji}	I-O Invest. share, $b_{Ji}[I-B]^{-1}$	Final-use cons. share, b_{Ci}	I-O cons. share, $b_{Ci}[I-B]^{-1}$	Final-use trade share, bT_i	I-O trade share, $b_T[I-B]^{-1}$
1	Agriculture	-0.3	2.8	1.2	9.6	0.0	13.2
2	Metal mining	0.1	0.7	0.0	0.2	0.0	0.8
3	Coal mining	0.1	0.6	0.0	0.7	0.0	1.5
4	Oil and gas extraction	2.7	5.6	0.0	4.6	0.0	4.8
5	Non-metallic mining	0.0	0.7	0.0	0.2	0.0	0.6
6	Construction	43.1	44.3	0.9	2.8	0.0	1.5
7	Food	0.3	2.5	10.2	15.4	0.0	8.2
8	Tobacco	0.0	0.1	0.9	1.2	0.0	1.2
9	Textile mill products	0.4	1.6	0.3	2.2	0.0	2.1
10	Apparel	0.0	0.4	3.4	4.1	0.0	1.3
11	Lumber and wood	0.7	5.1	0.0	0.8	0.0	2.2
12	Furniture and fixtures	1.6	2.1	0.0	0.1	0.0	0.6
13	Paper and allied	0.3	2.4	0.5	3.1	0.0	4.3
14	Printing, publishing and	0.1	0.7	0.6	1.8	0.0	1.3
15	Chemicals	0.4	5.9	2.2	7.1	0.0	14.1
16	Petrol. and coal products	0.2	2.7	2.7	5.0	0.0	4.4
17	Rubber and misc plastics	0.2	2.9	0.2	1.6	0.0	3.4
18	Leather	0.0	0.1	0.7	0.9	0.0	0.4
19	Stone, clay, glass	0.0	3.7	0.0	0.9	0.0	1.7
20	Primary metal	-0.1	10.4	0.0	2.2	0.0	10.7
21	Fabricated metal	1.0	9.0	0.1	2.2	0.0	6.9
22	Machinery, non-electrical	13.6	20.5	0.0	2.5	0.0	17.5
23	Electrical machinery	4.2	10.7	0.1	2.2	0.0	11.9
24	Motor vehicles	8.6	12.1	0.0	1.4	0.0	10.1
25	Transportation equipment	1.9	3.5	0.0	1.0	0.0	9.8
26	Instruments	4.3	5.5	0.1	0.9	0.0	4.6
27	Misc. manufacturing	0.5	0.9	0.5	0.9	0.0	1.2
28	Transportation	0.5	6.8	2.8	7.8	0.0	15.3
29	Communications	0.6	2.4	2.5	5.1	0.0	2.7
30	Electric utilities	0.0	2.2	2.9	5.1	0.0	2.9
31	Gas utilities	0.0	1.4	1.1	3.1	0.0	2.0
32	Whole. and Retail Trade	6.9	19.3	22.2	29.4	0.0	20.8
33	Fin., Ins., and Real Est (FIRE).	2.8	10.7	14.1	25.5	0.0	15.9
34	Services	5.1	19.4	28.0	43.2	0.0	16.9
35	Government enterprises	0.0	0.7	0.8	1.9	0.0	0.8
36	International Trade	0.0	13.5	0.9	8.9	100.0	115.4
	COLUMN TOTALS	100	234	100	205.6	100	333.1

Notes: shares shown are sample averages 1960-2004. Investment, consumption, and trade 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.

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

A. Prices of nondurable consumption and government relative to price of equipment
investment, BEA and Jorgenson datasets

	1960-2004	1960-1982	1982-2004
BEA	2.82	1.80	3.84
Jorgenson	1.17	0.24	2.11

Notes: Price index for consumption of non-durables and services plus government is calculated as a Tornquist price index. In Jorgenson, equipment investment is all investment less construction investment.   Housing services are excluded from Jorgenson, and should properly be excluded from the BEA calculation as well, for comparability with Jorgenson dataset

B. Jorgenson data: Relative prices and relative sectoral TFPs

	1960-2004	1960-1982	1982-2004
(1) Relative price of consumption (NDS plus G) to equipment investment	1.17	0.24	2.11
(2) Relative share-weighted input prices (equipment investment relative to consumption (NDS plus G))	-0.21	0.25	-0.64
(3) Relative Sectoral TFP (equipment investment relative to consumption of NDS plus G)	0.96	0.49	1.47

Notes: The third line equals the sum of the first two lines. Terms are defined, in order, using the equation: $(b_C - b_{J,E})dp + (b_{J,E} - b_C)(I - B)^{-1}[s_K dp_K + s_L dp_L] = (dz_{J,E} - dz_C)$

Table 3. TFP and Correlations

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

Sector	1960-2004	1960-1982	1982-2004
(1) Consumption (nondurables and service), dz_C	0.98	1.09	0.87
(2) Durables Consumption, dz_{CD}	1.83	1.73	1.94
(3) Investment, dz_J	1.19	0.86	1.51
3a. Equipment dz_{JE}	1.93	1.57	2.29
3b. Structures dz_{JS}	0.17	0.06	0.29
(4) Government, dz_G	0.94	0.90	0.99
(5) Trade, dz_{Trade}	2.51	3.08	1.95

B. Selected correlations of sectoral TFP

	1960-2004	1960-1982	1982-2004
(1) Corr(dz_J, dz_{CG})	0.85	0.90	0.82
(2) Corr(dz_{JE}, dz_{CG})	0.76	0.81	0.75
(3) Corr(dz_{JE} - dz_{CG}, dz_{CG})	0.26	0.44	0.01
(4) Corr(dz_{JE}- dz_{CG}, dz_J)	0.60	0.62	0.51

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 whether we use consumption TFP alone, or use 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)

Sector	1960-2004	1960-1982	1982-2004
(1) Consumption (nondurables and services), dz_C	1.12	1.29	0.95
(2) Durables Consumption, dz_{CD}	2.12	2.15	2.09
(3) Investment, dz_J	1.41	2.57	1.61
3a. Equipment dz_{JE}	2.18	2.01	2.36
3b. Structures dz_{JS}	0.36	0.29	0.43
(4) Government, dz_G	1.13	1.17	1.09
(5) Trade, dz_{Trade}	2.68	3.37	1.98

B. Selected correlations of sectoral technology

	1960-2004	1960-1982	1982-2004
(1) Corr(dz_J, dz_{CG})	0.83	0.87	0.82
(2) Corr(dz_{JE}, dz_{CG})	0.73	0.78	0.74
(3) Corr(dz_{JE} - dz_{CG}, dz_{CG})	0.23	0.41	-0.08
(4) Corr(dz_{JE} - dz_{CG}, dz_J)	0.61	0.65	0.46

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. See alson notes to Table 3.

Table 5. Preliminary Dynamics: Explaining Growth in Hours Worked (OLD DATA)

	(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.

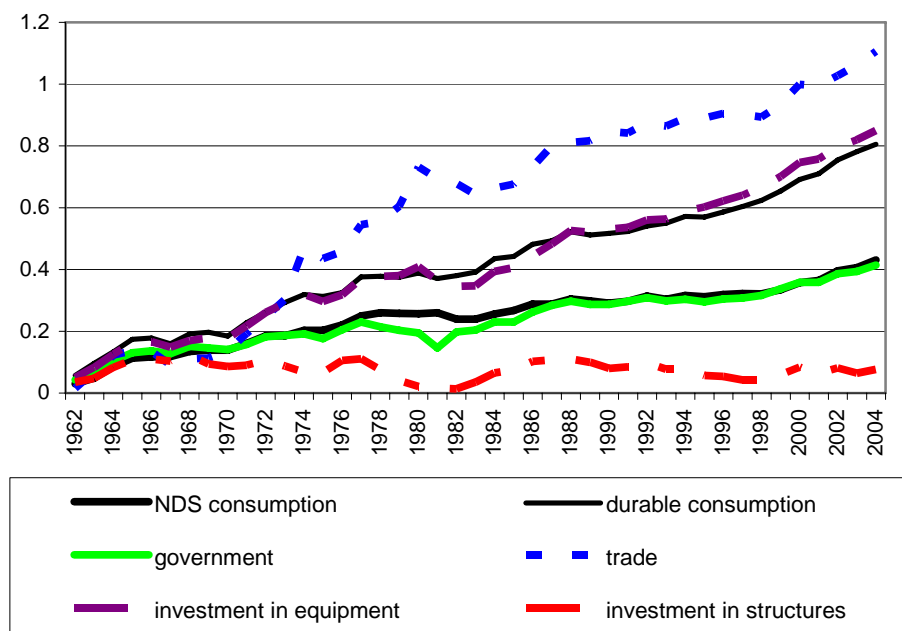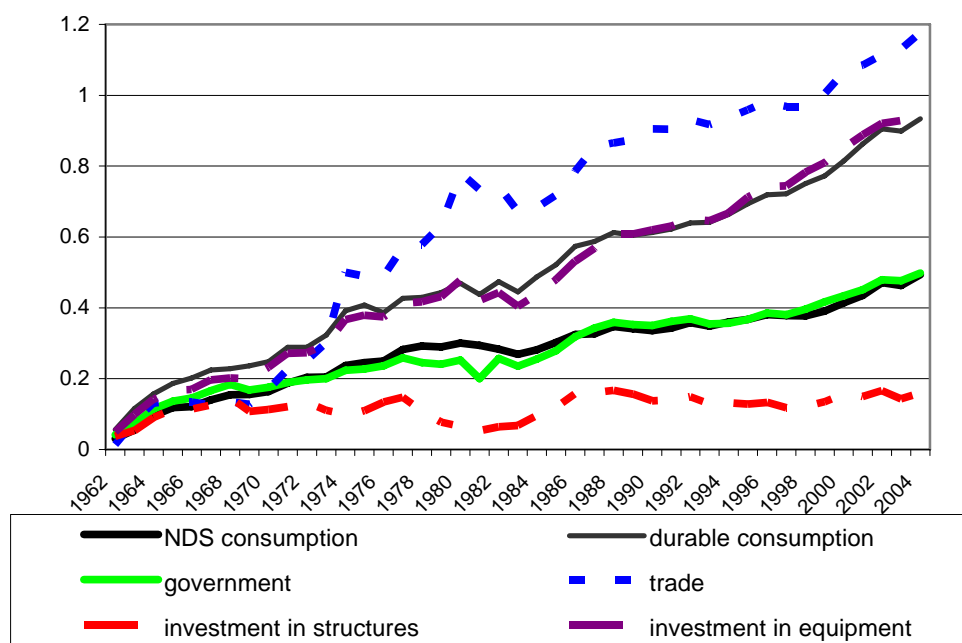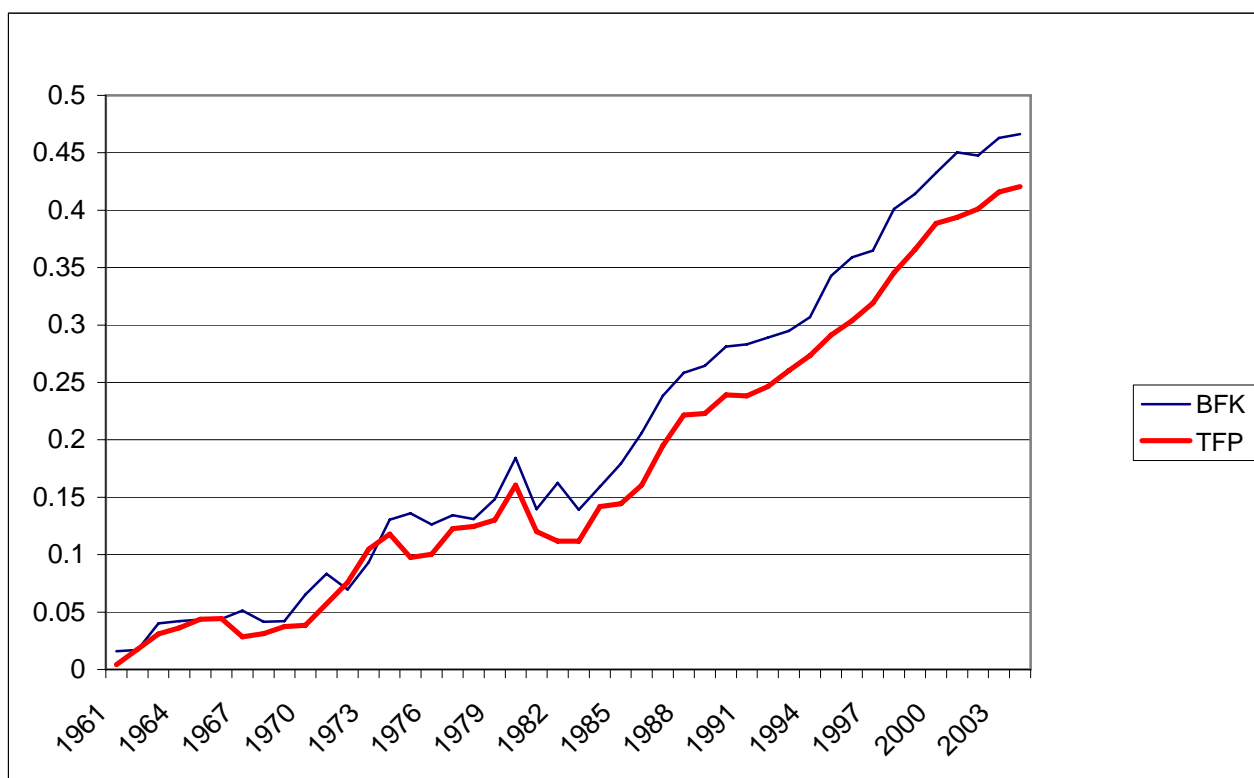Figure 1.A. Cumulated Sectoral TFP Series

Figure 1.B. Cumulated BFK Technology Series

Note: All series are calculated by cumulating log changes.

Figure 2. Relative equipment-investment and consumption TFP and BFK Technology

Notes: Shows cumulated difference between measured TFP/technology for equipment investment versus consumption (non-durables and services, plus government).