DISCUSSION PAPER SERIES

DP16857

Labor Share, Markups, and Input-Output Linkages - Evidence from the National Accounts
Berthold Herrendorf and Benjamin Bridgman
MACROECONOMICS AND GROWTH
Labor Share, Markups, and Input-Output Linkages - Evidence from the National Accounts

Berthold Herrendorf and Benjamin Bridgman

Discussion Paper DP16857
Published 04 January 2022
Submitted 21 December 2021

Centre for Economic Policy Research
33 Great Sutton Street, London EC1V 0DX, UK
Tel: +44 (0)20 7183 8801
www.cepr.org

This Discussion Paper is issued under the auspices of the Centre’s research programmes:

- Macroeconomics and Growth

Any opinions expressed here are those of the author(s) and not those of the Centre for Economic Policy Research. Research disseminated by CEPR may include views on policy, but the Centre itself takes no institutional policy positions.

The Centre for Economic Policy Research was established in 1983 as an educational charity, to promote independent analysis and public discussion of open economies and the relations among them. It is pluralist and non-partisan, bringing economic research to bear on the analysis of medium- and long-run policy questions.

These Discussion Papers often represent preliminary or incomplete work, circulated to encourage discussion and comment. Citation and use of such a paper should take account of its provisional character.

Copyright: Berthold Herrendorf and Benjamin Bridgman
Labor Share, Markups, and Input-Output Linkages - Evidence from the National Accounts

Abstract

The literature has suggested so many reasons for the decrease in the aggregate labor share that together they "explain" a multiple of the overall decrease [Grossman and Oberfield (2021)]. We study key causal forces and amplifying and offsetting effects in a multi-sector model with input-output linkages. We find that the decrease in the U.S. labor share reflects both sectoral forces, which can be identified with micro or NIPA data, and aggregation effects, which can be identified only with NIPA data. Specifically, the main force behind the decrease in the labor share was a similar increase in sectoral markups, which input-output linkages amplified importantly.

JEL Classification: D33, L4, O15

Keywords: Double marginalization, input-output linkages, Labor Share, Markups, Outsourcing, structural change

Berthold Herrendorf - berthold.herrendorf@asu.edu
Arizona State University and CEPR

Benjamin Bridgman - benjamin.bridgman@bea.gov
Bureau of Economic Analysis

Acknowledgements

An initial version of this paper was single-authored by Benjamin Bridgman and was called "Markups, Market Power, and Structural Change: Evidence from the National Accounts". For comments and suggestions, we thank Abe Dunn, Domenico Ferraro, Paul Gaggl, Gabriel Mathy, Devesh Raval, Erick Sager, James Traina, Akos Valentinyi, and Yu Zheng, along with the audiences at the Bureau of Labor Statistics, the CEPR STEG Conference on Data and Measurement, the Econometric Society NASM (Seattle), the Federal Trade Commission, Fudan University, and the Midwest Macro Meetings (East Lansing). Ted Kornegay provided excellent research assistance. The views expressed in this paper are solely those of the authors and not necessarily those of the U.S. Bureau of Economic Analysis or the U.S. Department of Commerce.
Labor Share, Markups, and Input-Output Linkages – Evidence from the National Accounts∗

Benjamin Bridgman (Bureau of Economic Analysis)
Berthold Herrendorf (Arizona State University, CEPR, CESifo)

December 22, 2021

Abstract

The literature has suggested so many reasons for the decrease in the aggregate labor share that together they “explain” a multiple of the overall decrease [Grossman and Oberfield (2021)]. We study key causal forces and amplifying and offsetting effects in a multi-sector model with input-output linkages. We find that the decrease in the U.S. labor share reflects both sectoral forces, which can be identified with micro or NIPA data, and aggregation effects, which can be identified only with NIPA data. Specifically, the main force behind the decrease in the labor share was a similar increase in sectoral markups, which input-output linkages amplified importantly.

Keywords: Double Marginalization; Input-Output Linkages; Labor Share; Markups; Outsourcing; Structural Change.

JEL classification: D33; L4; O15.

∗An initial version of this paper was single-authored by Benjamin Bridgman and was called “Markups, Market Power, and Structural Change: Evidence from the National Accounts”. For comments and suggestions, we thank Abe Dunn, Domenico Ferraro, Paul Gagli, Gabriel Mathy, Devesh Raval, Erick Sager, James Traina, Ákos Valentinyi, and Yu Zheng, along with the audiences at the Bureau of Labor Statistics, the CEPR STEG Conference on Data and Measurement, the Econometric Society NASM (Seattle), the Federal Trade Commission, Fudan University, and the Midwest Macro Meetings (East Lansing). Ted Kornegay provided excellent research assistance. The views expressed in this paper are solely those of the authors and not necessarily those of the U.S. Bureau of Economic Analysis or the U.S. Department of Commerce.
1 Introduction

It is well recognized that the share of national income paid to labor (labor share for short) has decreased in most industrialized countries. The decrease in the labor share is of interest because it tilts the distribution of national income towards the owners of capital and thereby may contribute to the rising income equality; see Grossman and Oberfield (2021) for further discussion. The decrease in the labor share is also of interest because it violates one of the Kaldor growth facts that the growth model was constructed to be consistent with; see Herrendorf et al. (2019) for an update of the Kaldor growth facts. Although a huge literature has emerged, there is no consensus yet as to what the main forces are behind the decrease in the labor share. In their recent review article, “The Elusive Explanation for the Declining Labor Share”, Grossman and Oberfield (2021) observed that by now we have enough candidates to “explain” a multiple of the overall decrease in the labor share.\(^1\) Grossman and Oberfield conjectured that several proximate causes may have the same fundamental cause and they concluded that progress requires a unifying framework that captures the causal and the offsetting forces and accounts for the important general equilibrium effects.

We develop such a unifying framework and connect it to the postwar National Income and Product Accounts of the U.S. (NIPA henceforth). The key feature of our framework is that it has multiple sectors with input-output linkages between them. Disaggregating into different sectors is crucial because the labor share differs across sectors [Valentinyi and Herrendorf (2008)] and evolves differently across sectors [Elsby et al. (2013)], suggesting that compositional effects and sectoral forces are important. Modeling input-output linkages is crucial because they can importantly amplify sectoral forces. We consider two types of sectoral forces: those that increase the sectoral markup and those that increase the sectoral labor intensity as measured by the sectoral output elasticity of labor. The former decrease and the latter increase the aggregate labor share. Decomposing the decrease in the aggregate labor share into the different components, we find that the main force behind it was a similar increase in sectoral markups that was strongly amplified through input-output linkages. Our finding implies that forces affecting mostly one sector cannot alone explain the decrease in the aggregate labor share.\(^2\)

A challenge for our analysis is to separately identify markups and the output elasticity of labor; see Bond et al. (2020) for further discussion. While it is straightforward to calculate

---

\(^1\) Important examples include: the increased costs of housing [Rognlie (2015)]; the inclusion of IPP capital in NIPA [Koh et al. (2021)]; increased market power as measured by aggregate markups [Farhi and Gourio (2018) and Barkai (2020)]; capital deepening resulting from a declining relative price of capital [Karabarbounis and Neiman (2014)] or from automation [Acemoglu and Restrepo (2018)]; increased competition from globalization [Elsby et al. (2013)]. See Grossman and Oberfield (2021) for a more complete list of the existing work on the labor share.

\(^2\) To avoid confusion, we note that in general the labor share, the markups, and the sectoral output elasticities are all endogenous. Here, we take the view common in the macro literature that the markups and the sectoral output elasticities are exogenous to the analysis (i.e., are determined by model parameters) whereas the labor share results endogenously.
the payments to labor and intermediate inputs, the remaining payments go to either capital or profits and must be separated to estimate markups and the output elasticity of labor. A natural way of doing that is to calculate the payments to capital as the product of the capital stock, which is reported in NIPA, and the user costs of capital, which are not reported in NIPA and must be calculated from additional sources. Two recent papers implemented the approach at the aggregate level. Barkai (2020) calculated the aggregate user costs of capital by adding technological and economic depreciation (i.e., decreases in the price of capital) to a reference interest rate. Farhi and Gourio (2018) calculated the user costs with the help of a growth model calibrated to match observable macro trends. The approach of Farhi and Gourio (2018) has two advantages in our context. First, it can be extended back to the 1950s whereas the reference interest rate used by Barkai becomes available only in the 1980s. Second, it leads to a measure of the user costs of capital that naturally includes the unobservable premia for different forms of risk.

Adopting the approach of Farhi and Gourio (2018), we find that after taking real estate out of the aggregate private economy, the aggregate labor share still fell by around 5 percentage points during the postwar period. Thus, the increased cost of housing is not the only force behind the decrease in the aggregate labor share. We continue by excluding real estate from the remaining analysis. This is as in Karabarbounis and Neiman (2018) and Barkai (2020) and has two main reasons. First, real estate is largely an imputed sector, given that owner-occupied housing is not part of market activity. Second, NIPA does not include land as part of the capital stock because it is not reproducible. Missing such an important input factor biases upward the markups in real estate [Rognlie (2015)].

We disaggregate the private economy without real estate into a sector producing goods and a sector producing services. This disaggregation is a natural starting point that is tractable while capturing the effects of input-output linkages and changes in the sectoral composition (structural change). The resulting model is a two-sector version of the one-sector model of Farhi and Gourio (2018).³ Gross output of each sector can be delivered to the final uses consumption and investment or it can be used as intermediate inputs in the producing sector or the other sector. Sectoral gross outputs are Dixit-Stiglitz aggregators of given sets of goods or services varieties. Each variety is produced by a monopolist who charges a sector-specific markup over marginal costs but is small relative to the rest of the economy (monopolistic competition). The production functions have constant returns and are Cobb-Douglas in capital, labor, and intermediate inputs from both sectors. The output elasticities of the different factors of production are also sector specific.

In the equilibrium of our model, the aggregate labor share depends on the sectoral markups, the sectoral output elasticities of labor, and the Domar weights, which capture the effects of the

---

³Our analysis could be generalized to finer disaggregations with more than two sectors. However, very fine disaggregations are problematic because the industry classification changed during the postwar period.
sectoral composition of final output as well as the input-output linkages between sectors. To measure how the sectoral forces affect the aggregate labor share, we connect our framework to the NIPA. Using the NIPA, instead of micro data, has the advantage that NIPA covers all market activity, captures the input-output linkages, and respects the standard adding up constraints. Using micro, or industry, data alone cannot achieve that.

We find that the direct effects of changes in sectoral markups and in the output elasticities of labor together “explain” a multiple of the decrease in the labor share, just as Grossman and Oberfield (2021) observed. Interestingly, the direct effect on the aggregate labor share of changes in the sectoral output elasticities of labor is more than twice as large as the direct effect of changes in sectoral markups. One might be tempted to conclude from this finding that forces which reduce the importance of the input factor labor in production (e.g., automation) must have been a key reason for the decrease in the aggregate labor share. Taking into account the input-output linkages and the sectoral composition, however, the picture changes dramatically: now the main forces behind the decrease in the postwar U.S. labor share is that both sectors’ markups increased by similar amounts and the increase was importantly amplified by the input-output linkages. This suggests that a convincing explanation for the decrease in the labor share must explain why markups increased in both sectors by similar amounts. The input-output linkages amplify the increases in the sectoral markups arises because they lead to double marginalization, that is, intermediate inputs are marked up when they are produced and when they are used; see for example Rotemberg and Woodford (1995) and Basu and Fernald (2002). Since the intermediate-input shares are sizeable in both sectors, double marginalization has a large quantitative effect and the aggregate markups come out close to twice as large as the sectoral markups.

We also find that forces that decrease the sectoral output elasticity of labor were not the main reason for the decrease in the postwar U.S. labor share. These forces fall into two categories: those that increase the value-added elasticity of capital (“capital deepening”) and those that increase the gross-output elasticity of intermediate inputs (“outsourcing”). We find that there was considerable capital deepening. However, it happened mostly in the goods sector and its effects on the aggregate labor share were largely offset by structural change that reallocated labor from the goods to the services sector.\(^4\) We cannot extrapolate whatever mechanism is underlying the manufacturing sector to the whole economy. In contrast, there was outsourcing of intermediate inputs in both sectors and structural change did not mute or amplify the effect of sectoral outsourcing much. However, sectoral outsourcing was not strong enough to have a first-order effect on the aggregate labor share. Our findings imply that understanding the labor share dynamics at the aggregate is different from understanding them in the manufacturing sector, and we cannot just extrapolate whatever forces we find for the manufacturing sector to

\(^4\)See Herrendorf et al. (2014) for a review of the literature on structural change.
the whole economy.

The rest of the paper is organized as follows. Section 2 lays out the model and Section 3 characterizes the equilibrium. Section 4 describes the calibration strategy and the data we use. Section 5 connects the model to the data. Sections 6 compares our results with the those in the literature. Section 7 concludes. An Appendix contains longer derivations and a detailed data description.

2 Model

In this section, we develop a multi-sector version of the model of Farhi and Gourio (2018). Our multi-sector model captures that the sectors produce gross output and that intermediate goods are marked up when they are produced and when they are used. Taking into account the resulting double marginalization is crucial for correctly measuring how sectoral markups affect the aggregate labor share.

2.1 Environment

There is a measure one of identical households, implying that all variables are interpreted as per capita variables. Households have the utility function of Epstein and Zin (1989) that separates the degree of risk aversion from the intertemporal elasticity of substitution:

\[ U_t = \left( (1 - \beta)C_t^{1-\sigma} + \beta \left[ E_t \left( U_{t+1}^{1-\theta} \right) \right] ^{\frac{1}{1-\sigma}} \right) ^{\frac{1}{1-\sigma}} \quad (1) \]

\( \beta \in (0, 1) \) is the discount factor; \( C_t \geq 0 \) is household consumption in period \( t \); \( \sigma \geq 0 \) is the inverse of the intertemporal elasticity of substitution in the deterministic case; \( \theta \geq 0 \) is the coefficient of relative risk aversion.

Final-output can be used for consumption and investment. Final output is a Cobb-Douglas aggregator of final goods and services:

\[ Y_t = Y_g^{\phi_g} Y_s^{\phi_s} \quad (2) \]

\( Y \) denotes final output; \( Y_g \) and \( Y_s \) denote final goods and services; \( \phi_g, \phi_s \geq 0 \) with \( \phi_g + \phi_s = 1 \) are the output elasticities of goods and services.

The production functions of final goods and services are Dixit-Stiglitz aggregators of different varieties:

\[ Y_{jt} = \left( \int_0^1 (Y_{j,i}) \frac{\phi_j}{\phi_j + \phi_s} \, di \right) ^{\frac{\phi_j}{\phi_j + \phi_s}} \quad (j \in \{g, s\}) \quad (3) \]
where \( Y_{jt} \) is the quantity of variety \( i \in [0,1] \) used in sector \( j \in \{g, s\} \); \( \varepsilon_j \) is the sector-specific elasticity of substitution. Since \( \varepsilon_j \) is sector specific, markups will be sector-specific too.

The production functions of gross output of the different varieties of goods and services are Cobb-Douglas in capital, labor, and intermediate inputs:

\[
G_{jt} = Z_{jt}(K_{jt})^{\alpha_K}(L_{jt})^{\alpha_L}(M_{jji}t)^{\alpha_{M_j}}(M_{j′jt})^{\alpha_{M_j′}}, \quad (j \neq j′ \in \{g, s\}, \ i \in [0,1]).
\]  

(4)

\( G_{jt} \) is gross output; \( K_{jt} \) and \( L_{jt} \) are capital and labor; \( M_{jji}t, \ M_{j′jt} \) are intermediate inputs produced in sectors \( j, j′ \) and used in the production of variety \( j_i \); the \( \alpha \)'s are the sector-specific output elasticities. There are constant returns: \( \alpha_K + \alpha_L + \alpha_{M_j} + \alpha_{M_j′} = 1 \); \( Z_{jt} \) is sector-specific, deterministic TFP; \( A_{jt} \) is sector-specific technical change, which evolves according to a random walk:

\[
A_{j,t+1} = A_{jt} \exp(\chi_{j,t+1}) \quad (j \in \{g, s\}).
\]  

(5)

\( \chi_{j,t+1} \) is an i.i.d. shock with mean zero that shifts productivity permanently and is common across all firms in sector \( j \). Farhi and Gourio (2018) use \( \chi_{j,t+1} \) to model rare disaster risk, which implies a risk premium although it materializes only occasionally. Note that to be comparable with Farhi and Gourio (2018), we have followed them and written the production function such that \( Z_{jt} \) is TFP whereas \( A_{jt} \) is labor-augmenting technical change. Given that the Cobb-Douglas functional form, of course, it could be rewritten so that \( Z_{jt} \) adds to sectoral labor-augmenting technical change or \( A_{jt} \) adds to sectoral TFP.

That the sectoral production functions are Cobb-Douglas will be crucial for constructing a balanced growth path. In particular, the sectoral and final-goods Cobb-Douglas production functions imply that, in equilibrium, there is an aggregate Cobb-Douglas production function. Moreover, all sectoral variables aggregate in closed form, i.e., the aggregate variables are appropriately weighted averages of the sectoral variables. We emphasize that this aggregation results goes beyond the usual one in multi-sector models with sectoral Cobb-Douglas production function which requires that the output elasticities are the same in all sectors. In contrast, here we allow the output elasticities to differ between sectors. We also note that the Cobb-Douglas assumption implies that a given parametrization of our model will not be able to match changing factor intensities at the sector level. We will address this concern by connecting different parametrizations of the model, each with different output elasticities, to the three different sub-periods of the postwar period.

Gross output of variety \( j_i \) is used as final output or as intermediate inputs by the two sectors:

\[
G_{jt} = Y_{jt} + M_{jji}t + M_{j′jt} \quad (j \in \{g, s\}).
\]  

(6)
$M_{j,t}$ and $M_{j',t}$ are intermediate inputs of variety $j_i$ used by sectors $j$ and $j'$. To avoid confusion, it is worth mentioning that value added is different from gross output and is given by:

$$p_{V_{ji}} V_{ji} = p_{G_{ji}} G_{ji} - p_{G_{ji}} M_{jji} - p_{G_{j'i}} M_{j'ji} \quad (j \neq j' \in \{g, s\}), \quad (7)$$

where $p_{V_{ji}}$ is the price of value added and $p_{G_{ji}}$ is the price of gross output of sector $j \in \{g, s\}$.

Capital is sector specific and accumulates according to:

$$K_{j,t+1} = [Q_t X_{jt} + (1 - \delta_j K_{jt}) \exp(\chi_{jt+1})] \quad (j \in \{g, s\}), \quad (8)$$

where $\delta_j \in [0, 1]$ is the sector-specific depreciation rate; $Q_t$ is the economy-wide marginal rate of transformation between output and investment, which captures that the quality of capital has been improving [Greenwood et al. (1997)]. Note that specification (8) assumes that the capital stock changes immediately after a shock to labor-augmenting technical change. Farhi and Gourio (2018) introduced this feature and interpreted it as a quality shock to existing capital that is in sync with the shock to labor-augmenting technical change. The technical reason for having it is that it shuts down the usual shock propagation through capital accumulation and keeps the economy on a balanced growth path even after a rare disaster shock happened. This feature implies that one can obtain an analytical solution for the equilibrium path without having to worry about transitional dynamics.

(8) implies that sectoral investment is described by:

$$X_{jt} = \exp(-\chi_{jt+1}) \frac{Q_{t+1}}{Q_t} Q^{-1}_t K_{j,t+1} - (1 - \delta_j) Q^{-1}_t K_{jt} \quad (j \in \{g, s\}). \quad (9)$$

Looking ahead to the equilibrium, $Q^{-1}_t$ will be the price of capital relative to final goods implying that $Q^{-1}_t K_{jt}$ is the capital stock in units of the numeraire final good. In the NIPA, $Q^{-1}_t K_{jt}$ is called the capital stock evaluated at current cost or at replacement costs.
Feasibility requires the usual adding up constraints:

\[ G_{jt} \equiv \int_0^1 G_{jt} \, dt \quad (j \in \{g, s\}), \quad (10) \]
\[ Y_{jt} \equiv \int_0^1 Y_{jt} \, dt \quad (j \in \{g, s\}), \quad (11) \]
\[ M_{j'jt} \equiv \int_0^1 M_{j'jt} \, dt \quad (j', j \in \{g, s\}), \quad (12) \]
\[ K_{jt} \equiv \int_0^1 K_{jt} \, dt \quad (j \in \{g, s\}), \quad (13) \]
\[ L_{jt} \equiv \int_0^1 L_{jt} \, dt \quad (j \in \{g, s\}), \quad (14) \]
\[ 1 = \sum_{j=g,s} L_{jt}, \quad (15) \]
\[ G_{jt} = Y_{jt} + \sum_{j' \in \{g,s\}} \int_0^1 M_{j'jt} \, dt \quad (j' \in \{g, s\}), \quad (16) \]
\[ Y_t = C_t + \sum_{j \in \{g,s\}} X_{jt}. \quad (17) \]

The state variables in period \( t \) are \{\( Q_t, Z_{jt}, A_{jt}, K_{jt} \}_{j=g,s} \}. \( Q_t \) and \{\( Z_{jt} \)\}_{j=g,s} grow at constant exogenous rates:

\[ Q_{t+1} = (1 + \gamma_Q)Q_t, \]
\[ Z_{j,t+1} = (1 + \gamma_Z)Z_{jt} \quad (j \in \{g, s\}). \]

\{\( A_{jt}, K_{jt} \)\}_{j=g,s} follow the laws of motion (5) and (8).

Since it should be obvious by now that \( j, j' \in \{g, s\} \), we will from now on not explicitly mention it every time \( j, j' \) show up.

### 2.2 Producer Problems

We start with the production of final-goods. The market for final goods is competitive and the representative firm maximizes profits:

\[
\max_{\{Y_{gt}, Y_{st}\}} Y^{g}_{gt} Y^{s}_{st} - P_{gt} Y_{gt} - P_{st} Y_{st},
\]
where the final good is the numeraire. The first-order conditions imply the usual Cobb-Douglas result that the values of goods and services are constant shares of the value of output:

\[ \frac{p_{G,j}Y_j}{Y_t} = \phi_j. \]  

(18)

We continue with the production of goods and services. The markets for goods and services are also competitive and profit maximization gives:

\[ \max_{(Y_{jt})_{t=0}^1} p_{G,j}\left( \int_0^1 (Y_{jt})^{\frac{\varepsilon_j}{\varepsilon_j-1}} \, di \right)^{-\frac{\varepsilon_j-1}{\varepsilon_j}} - \int_0^1 p_{G,j} Y_{jt} \, di. \]

The first-order condition implies the standard demand function for the produced variety:

\[ Y_{jt} = Y_j \left( \frac{p_{G,j}}{p_{G,j}} \right)^{\frac{\varepsilon_j}{\varepsilon_j-1}}. \]  

(19)

Each variety is produced by a monopolist. The equilibrium concept is monopolistic competition, that is, the monopolist takes aggregate variables as given but takes into account the demand function for the monopolist’s variety, (19). Taking \( r_{jt}, w_t, p_{G,j}, p_{G,j}' \) as given, profit maximization gives:

\[ \max_{(G_{jt}, K_{jt}, L_{jt}, M_{jjt}, M_{j't})} p_{G,j} G_{jt} - r_{jt} K_{jt} - w_t L_{jt} - p_{G,j} M_{jjt} - p_{G,j'} M_{j't} \quad \text{s.t. \ (4), (19)}. \]

The first-order conditions imply that the monopolist charges a markup over the rental prices. We denote the (gross) markup by \( \mu_j \). In equilibrium, it is given as:

\[ \mu_j \equiv \frac{\varepsilon_j}{\varepsilon_j - 1}. \]

(5)

Imposing that there be symmetry in equilibrium, \( j_i = j \), the first-order conditions can be written as:

\[ \frac{\alpha_K p_{G,j} G_{jt}}{K_{jt}} = \mu_j r_{jt}, \]

(20)

\[ \frac{\alpha_L p_{G,j} G_{jt}}{L_{jt}} = \mu_j w_t, \]

(21)

\[ \frac{\alpha_{M_{jj}} p_{G,j} G_{jt}}{M_{jjt}} = \mu_j p_{G,j}, \]

(22)

\[ \frac{\alpha_{M_{j't}} p_{G,j} G_{jt}}{M_{j't}} = \mu_j p_{G,j'}. \]

(23)

\[ ^{5} \text{This formula shows that, as we claimed in the introduction, sectoral markups are indeed determined by a parameter, and are therefore exogenous in our model.} \]
The first-order conditions reflect the usual result with monopolistic competition, that the marginal value product of each factor equals a markup up over its marginal costs. Combining the first-order conditions with the input-output linkages, we obtain the relationship between sectoral gross output and aggregate final output.

**Proposition 1** \( p_j G_j \) is proportional to \( Y_t \):

\[
p_{G_j} G_j t = \Phi_j Y_t, \tag{24}
\]

where \( \Phi_j \) is the Domar weight given by:

\[
\Phi_j = \frac{1}{1 - \frac{\alpha M_j}{\mu_j}} \left( \frac{\alpha_{M_j}}{\mu_j} \phi_j + \frac{\alpha {M_j}'}{\mu_j} \phi_j' \right) \left( 1 - \frac{\alpha M_j}{\mu_j} \right) - \frac{M_j}{\mu_j} \phi_j.
\]

**Proof.** See Appendix A.1.

Note that (18) and (24) imply that, in equilibrium, sectoral gross and final output are proportional to each other as well:

\[
\frac{G_j}{Y_j} = \frac{p_{G_j} G_j}{p_{G_j} Y_j} = \frac{\Phi_j Y_t}{\phi_j Y_t} = \frac{\Phi_j}{\phi_j} \implies G_j = \Phi_j Y_j. \tag{26}
\]

Next, we characterize the equilibrium labor allocation. (21) determines the sectoral labor share in gross output:

\[
\frac{w_t L_j}{p_{G_j} G_j} = \frac{\alpha L_j}{\mu_j}. \tag{27}
\]

Substituting (24) into (27) gives:

\[
\frac{w_t L_j}{\Phi_j Y_t} = \frac{\alpha L_j}{\mu_j}. \tag{28}
\]

Thus, sectoral labor is proportional to aggregate labor:

\[
L_j = \omega L_j = \omega L_j. \tag{29}
\]

Equation (28) also implies the decomposition of the aggregate labor share that we mentioned in the introduction and will use in the empirical part:

\[
\frac{w_t L_s}{Y_t} = \Phi_s \frac{\alpha L_s}{\mu_s} + \Phi_j \frac{\alpha L_j}{\mu_s}. \tag{30}
\]
2.3 Household Problem

The household problem is: \[ \max_{C_t,\{X_{jt}, K_{jt+1}\}_{j\in\{g,s\}}} \quad U_t = \left( (1 - \beta)C_t^{1-\sigma} + \beta \left( \frac{E_t \left( U_{t+1}^{1-\sigma} \right)}{\left( \frac{C_t}{C_{t+1}} \right)^{\frac{1}{\sigma}} \right)^{\frac{1}{\sigma}} \right) \right)^\frac{1}{1-\sigma} \]

subject to (9), \[ C_t + X_{gt} + X_{st} = r_{gt}K_{gt} + r_{st}K_{st} + w_t. \] (31)

We note that the household problem abstracts from taxes, which is as in Farhi and Gourio (2018). Taxes are not of first-order importance for the user cost calculations in our context; see the discussion in Barkai (2020).

Appendix A.2 shows that the first-order conditions imply the familiar Euler equation:

\[ 1 = E_t \left( D_{t+1}R_{t+1} \right), \] (32)

where \( D_{t+1} \) is the stochastic discount factor and \( R_{t+1} \) the stochastic return on capital:

\[ D_{t+1} \equiv \beta \left( \frac{C_{t+1}}{C_t} \right)^{-\sigma} \left( \frac{U_{t+1}}{E_t \left( U_{t+1}^{1-\sigma} \right)^{\frac{1}{\sigma}} \frac{C_{t+1}}{C_t}} \right)^{\frac{\sigma-\theta}{\sigma}}, \] (33)

\[ R_{jt+1} \equiv (1 - \delta_j + r_{jt+1}Q_{jt+1}) \frac{Q_t}{Q_{t+1}} \exp(\chi_{jt+1}). \] (34)

The stochastic discount factor does not only depend on the usual components \( \beta, C_{t+1}/C_t, \) and \( \sigma \) but also on the underlying risk and the degree of risk aversion \( \theta \). In the calibration that follows below, we will not separately identify the different components because it is not required for obtaining markups. Nonetheless, the fact that the different components are present will allow the model to match the usual targets and have a realistic risk premia. This is as in Farhi and Gourio (2018).

3 Risky Balanced Growth Path

3.1 Definition

Since there is rare disaster risk, we are looking for a risky balanced growth path ("RBGP" henceforth) instead of a standard BGP. In concrete terms, RBGP means that expected variables grow at constant trends including zero but there are unexpected, occasional level shifts of the trend. Put differently, growth along the RBGP comprises both a deterministic trend and a

---

6Note that Farhi and Gourio (2018) allow for population growth and a changing employment-to-population ratio. Since these features are not essential for what we do, we assume for simplicity that labor equals the population, which is normalized to one.
stochastic random walk. If there were no shocks, \( \chi_{jt} = 0 \), then the model would have a standard BGP along which all variables grow at constant rates including zero.

Let \( p_{K_t} \equiv Q_t^{-1} \) denote the price of capital relative to output and \( \rho_j \) the expected discount rate of sector \( j \)'s profits.

**Definition 1** A RBGP is an equilibrium path along which the following holds:

- \( Y_t, K_t, X_t, C_t, w_t, p_g_t/p_{st}, \{G_{jt}, Y_{jt}, K_{jt}, X_{jt}, M_{jt}, M_{jt}^j\}_{j, j' \in \{g, s\}} \) grow at constant expected rates;
- \( \{L_{jt}\}_{j \in \{g, s\}}, \rho_j, r_{jt}/p_{K_t} \) are constant.

In the rest of this section, we construct a RBGP. While the basic steps are the same as in Farhi and Gourio (2018), the construction is more involved because one must establish that despite the multi-sector structure, aggregate variables grow at constant expected rates. Crucial in this context is that the production functions for the varieties of each sector and the aggregator for the two sectoral final outputs are all of the Cobb-Douglas form. We will show that this implies that there is an aggregate Cobb-Douglas production function so that the proof of Farhi and Gourio (2018) applies. This is not a foregone conclusion in our model because the output elasticities of the production functions of varieties are sector specific.

### 3.2 Sectoral and Aggregate Capital

We start with the return on capital, \( r_{jt+1}/p_{K_{t+1}} \). Along the RBGP, \( r_{jt+1}/p_{K_{t+1}} \) is constant. Thus:

\[
1 = E_t\left(D_{t+1} R_{jt+1}\right) = E_t\left(D_{t+1} \exp(\chi_{jt+1})\right) \frac{1 - \delta_j + r_{jt+1}/p_{K_{t+1}}}{1 + \gamma Q}.
\]

We define the expected discount rate \( \rho_j \) as:

\[
\rho_j \equiv \frac{1}{E_t\left(D_{t+1} \exp(\chi_{jt+1})\right)} - 1.
\]

Substituting the definition into the previous equation and rearranging gives an expression for the expected discount rate:

\[
1 + \rho_j = \frac{1 - \delta_j + r_{jt+1}/p_{K_{t+1}}}{1 + \gamma Q}.
\]

(35)

We continue with capital along RBGP. Substituting (20) into (35), along the RBGP:

\[
1 + \rho_j = \frac{1 - \delta_j}{1 + \gamma Q} + \frac{\alpha_{K_j}}{\mu_j(1 + \gamma Q)} \frac{p_{G_{jt+1}} G_{jt+1}}{p_{K_{t+1}} K_{jt+1}}.
\]

(36)
Therefore, the sectoral capital-output ratio is given as:

\[
\frac{p_{K_{t+1}} K_{j_{t+1}}}{p_{G_{t+1}} G_{j_{t+1}}} = \frac{\alpha_{K_j}}{\mu_j (\rho_j + \delta_j + \gamma_Q)}.
\]  

(37)

Next, we show that capital is allocated to the sectors in fixed proportions. To this end, substitute (24) into (37) and rearrange:

\[
p_{K_{t+1}} K_{j_{t+1}} = \frac{\alpha_{K_j} \Phi_j}{\mu_j (\rho_j + \delta_j + \gamma_Q)} Y_{t+1}.
\]  

(38)

Therefore, \( K_{jt}/K_{jt} \) is constant and:

\[
K_{jt} = \omega_{K_j} K_t,
\]  

(39)

where \( \omega_{K_j} \in [0, 1] \) are relative weights that add up to one.

### 3.3 Capital-Output Ratios

To derive the aggregate capital-output ratio, we construct an aggregate version of the Euler equation. We start by substituting (24) and (39) into (36):

\[
1 + \rho_j = \frac{1 - \delta_j}{1 + \gamma_Q} + \frac{\alpha_{K_j} \Phi_j Y_{t+1}}{\mu_j (1 + \gamma_Q) \omega_{K_j} p_{K_{t+1}} K_{t+1}}.
\]  

(40)

Multiplying this equation with \( \omega_{K_j} \) and adding up implies that the aggregate capital-final-output ratio is constant too along the RBGP:

\[
1 + \rho = \frac{1 - \delta}{1 + \gamma_Q} + \frac{\alpha_K}{\mu (1 + \gamma_Q)} \frac{Y_{t+1}}{p_{K_{t+1}} K_{t+1}}.
\]  

(41)

where:

\[
\rho \equiv \sum_{j \in \{g,s\}} \omega_{K_j} \rho_j, \quad (42)
\]

\[
\delta \equiv \sum_{j \in \{g,s\}} \omega_{K_j} \delta_j, \quad (43)
\]

\[
\frac{\alpha_K}{\mu} \equiv \frac{\Phi_g \alpha_{K_g}}{\mu_g} + \frac{\Phi_s \alpha_{K_s}}{\mu_s}. \quad (44)
\]
(41) implies an aggregate version of (37) that determines the ratio of capital in units of final output to final output:

$$\frac{p_{K_i}K_{i+1}}{Y_{i+1}} = \frac{\alpha_K}{\mu(\rho + \delta + \gamma_Q)}.$$ (45)

Two remarks are in order. First, rewriting (44), we can see that the aggregate markup is a weighted harmonic mean of the sectoral markups:

$$\frac{1}{\mu} = \frac{\Phi_s\alpha_{K_s}}{\alpha_K} + \frac{\Phi_g\alpha_{K_g}}{\alpha_K}.$$ Second, (44) determines $\alpha_K/\mu$ but not $\alpha_K$ and $\mu$ individually. We will solve out for $\alpha_K$ below. It is important to realize that the Domar weights don’t add up to one and $\alpha_K \sum_{j=g,s} \Phi_j \alpha_{K_j}$. The reason for this is that the Domar weights don’t only reflect the sectoral weights in final output, but also the input-output linkages.

### 3.4 Trend Growth

To calculate the trend growth rates for output, capital, and intermediate inputs, we first establish that along the RBGP there is an aggregate Cobb-Douglas production function:

**Proposition 2** Along the RBGP, there is an aggregate Cobb-Douglas production function:

$$Y_t = \Omega Z_t^{\alpha_L} A_t^{\alpha_K}.$$ (46)

where $\Omega$ is a constant, $\alpha_L \equiv 1 - \alpha_K$, and:

$$\alpha_K = \left[ (1 - \alpha_{M_{ss}})\phi_g + \alpha_{M_{gs}} \phi_s \right] \alpha_{K_s} + \left[ (1 - \alpha_{M_{gg}})\phi_g + \alpha_{M_{sg}} \phi_s \right] \alpha_{K_g},$$

$$Z_t = \left[ \frac{(1 - \alpha_{M_{gg}})\phi_g + \alpha_{M_{sg}} \phi_s}{(1 - \alpha_{M_{ss}})\phi_g + \alpha_{M_{sg}} \phi_s} \right] \left[ \frac{(1 - \alpha_{M_{gg}})\phi_g + \alpha_{M_{sg}} \phi_s}{(1 - \alpha_{M_{ss}})\phi_g + \alpha_{M_{sg}} \phi_s} \right].$$

$$A_t = \left[ A_{Lg}^{\alpha_L} (1 - \alpha_{M_{gg}}) \phi_g + \alpha_{M_{sg}} \phi_s \right] A_{Ls}^{\alpha_L} (1 - \alpha_{M_{gg}}) \phi_g + \alpha_{M_{sg}} \phi_s.$$

**Proof.** See Appendix A.3.

That there is an aggregate Cobb-Douglas production function implies an aggregate first-order condition for labor of the usual form:

$$\frac{\alpha_L Y_t}{L_t} = \mu W_t.$$ (47)

13
Turning now to the growth rates along the RBGP, the aggregate Euler equation (41) implies that \( Y_t+1/(pK_t+1 K_t+1) \) is constant. Using (46), that \( \alpha_K + \alpha_L = 1 \), and that \( p_{K_t+1} = Q_{t+1}^{-1} \), the aggregate output-capital ratio can be expressed as:

\[
\frac{Y_{t+1}}{p_{K_{t+1}} K_{t+1}} = \frac{Z_{t+1} A_{t+1}^{\alpha_K} K_{t+1}^{1-\alpha_K}}{p_{K_{t+1}} K_{t+1}} = \frac{Z_{t+1}^{1-\alpha_K} A_{t+1}^{\alpha_K-1} Q_{t+1}^{-\alpha_K}}{Z_{t+1}^{1-\alpha_K} A_{t+1}^{\alpha_K-1} Q_{t+1}^{-\alpha_K}} = \Omega \left[ p_{K_{t+1}} K_{t+1}^\alpha \right].
\]

Since the left-hand side is constant, the numerator and the denominator of the right-hand side grow at the same rate:

\[
p_{K_{t+1}} K_{t+1} = T_{t+1} A_{t+1}^{k^*} \quad \text{where} \quad T_{t+1} = Z_{t+1}^{1/\alpha_K} Q_{t+1}^{1/\alpha_K},
\]

and the constant \( k^* \) is such that the aggregate Euler equation holds initially. Note that given we have assumed that \( Z_{t+1} \) and \( Q_{t+1} \) grow at constant rates, the trend growth rate, \( \gamma_T \), is constant along the RBGP. Note too that (39) implies that the sectoral capital stocks grow at the same rate as the aggregate capital stock.

Turning now to the growth rate of aggregate final output, the aggregate Euler equation (41) implies that \( Y_{t+1}/(p_{K_{t+1}} K_{t+1}) \) is constant so that, in expected terms, \( Y_{t+1} \) and \( p_{K_{t+1}} K_{t+1} \) grow at the same trend growth rates \( \gamma_T \) and:

\[
Y_t = T_t A_t y^*,
\]

\[
y^* \equiv (k^*)^{\alpha_K}.
\]

We finish with the remaining growth rates. (18) and (24) imply that

\[
\gamma_{pG_j} + \gamma_{G_j} = \gamma_{pG_j} + \gamma_Y = \gamma_T.
\]

Thus, \( \gamma_Y = \gamma_{G_j} \). Moreover, (22) and (23) imply that:

\[
M_{j\ell} = \frac{\alpha_{M_{j\ell}}}{\mu_j} G_{\ell} \quad \implies \quad \gamma_{M_{j\ell}} = \gamma_{G_j}, \quad (51)
\]

\[
M_{j\ell} = \frac{\alpha_{M_{j\ell}}}{\mu_j} \frac{p_{G_{\ell}} G_{\ell}}{\phi_j} G_{\ell} = \frac{\alpha_{M_{j\ell}}}{\mu_j} \phi_j G_{\ell} \quad \implies \quad \gamma_{M_{j\ell}} = \gamma_{G_{\ell}}. \quad (52)
\]

To obtain \( \{\gamma_{G_j}\}_{j \in \{g,d\}} \), we take the growth rates of the production functions while substituting in the previous equations:

\[
\gamma_{G_g} = \gamma_{Z_g} + \alpha_{K_g} \gamma_K + \alpha_{M_{g\ell}} \gamma_{G_{\ell}} + \alpha_{M_{g\ell}} \gamma_{G_{\ell}}. \quad (53)
\]

\[
\gamma_{G_d} = \gamma_{Z_d} + \alpha_{K_g} \gamma_K + \alpha_{M_{d\ell}} \gamma_{G_{\ell}} + \alpha_{M_{d\ell}} \gamma_{G_{\ell}}. \quad (54)
\]

14
These two equations have a unique solution for $\{\gamma_{G,j}\}_{j \in \{g,s\}}$ in terms of exogenous variables and $\gamma_K$, which we calculated above already.

### 3.5 Investment-Capital Ratios

We continue with investment. Along the RBGP, to a first-order approximation, the capital accumulation equation (9) becomes:

$$\frac{X_{jt}}{p_K K_{jt}} = \gamma_T + \delta_j + \gamma_Q.$$  \hfill (55)

Since the right-hand side is constant along the RBGP, $X_{jt}$ and $p_K K_{jt}$ grow at the same rates.

Equation (55) aggregates:

$$\gamma_T + \delta + \gamma_Q = \sum_{j=g,s} \omega_K j (\gamma_T + \delta_j + \gamma_Q) = \sum_{j=g,s} \omega_K j \frac{X_{jt}}{p_K K_{jt}} = \sum_{j=g,s} \frac{X_{jt}}{p_K K_{jt}} = \frac{X_t}{p_K K_t}.$$  

Thus, in current prices the aggregate-investment-to-capital ratio is given by the aggregate version of (55):

$$\frac{X_t}{p_K K_t} = \gamma_T + \delta + \gamma_Q.$$  \hfill (56)

### 3.6 Price-Profit Ratios

For the calibration, it is essential to calculate the values of a monopolist in each sector along the RBGP. We assume that all monopolist profits are passed back to the household in the form of dividends. Denoting the dividends of the representative monopolist in sector $j$ by $\Pi_{jt+1}$, the standard recursion implies:

$$p_{F,jt} = E_t \left( D_{t+1} \left( \Pi_{jt+1} + p_{F_{jt+1}} \right) \right).$$

Along the RBGP, the first-order conditions (20)–(23) imply that dividends are given as:

$$\Pi_{jt} = \frac{\mu_j - 1}{\mu_j} p_{G,j} G_{jt}.$$
Moreover, expected dividends are given as:

\[ E_t \pi_{jt+i} = \frac{\mu_j - 1}{\mu_j} E_t \left( p_{G_{jt+i}} G_{jt+i} \right) \]

\[ = E_t \left( \frac{\mu_j - 1}{\mu_j} \left( 1 + \gamma p_{G_{jt+i}} G_{jt+i} \right) \cdots \left( 1 + \gamma p_{G_{jt+i}} G_{jt+i} \right) \right) \]

\[ = (1 + \gamma T) \pi_{jt}. \]

Iterating forward while invoking the transversality condition yields a version of the Gordon growth formula:

\[ p_{F_t} = \pi_{jt} \sum_{i=1}^{\infty} \left( \frac{1 + \gamma_T}{1 + \rho_j} \right)^i \quad \Rightarrow \quad \frac{p_{F_t}}{\pi_{jt}} = \frac{1 + \gamma_T}{\rho_j - \gamma_T}. \tag{57} \]

We will use that relationship to calibrate the expected sectoral discount rate \( \rho_j \).

The previous relationships aggregate:

\[ \pi_t \equiv \sum_{j=g,s} \omega_{K,j} \pi_{jt}, \tag{58} \]

\[ \frac{1}{p_{F_t}} \equiv \sum_{j=g,s} \omega_{K,j} \pi_{jt} \frac{1}{p_{F_t}}, \tag{59} \]

\[ \frac{p_{F_t}}{\pi_t} = \frac{1 + \gamma_T}{\rho - \gamma_T}. \tag{60} \]

## 4 Calibration

We have shown that the sectoral shares are constant along a RBGP because the production functions are of the Cobb-Douglas form or are Dixit-Stiglitz aggregators of Cobb-Douglas production functions. Therefore, our model generates structural change only in the sense that the sectoral composition may differ across different model parameterizations. To capture the effects of structural change, we therefore assume that different subperiods represent different model parameterizations. As in Farhi and Gourio (2018), we consider the periods 1984–2000 and 2001–2016. Using the 2000–2001 as the transition years from one to the other period recognizes that around 2000 several trends changed. In addition, we consider 1957–1973 as the initial period. The choice of 1957 and 1973 as the first and last year of the initial period avoids the postwar boom and the decade after the first oil price shock, which cannot be captured well by a balanced growth paradigm.

The advantage of focusing on different RBGPs is that we can solve analytically for the parameter values of interest. The resulting formulas will be straightforward to connect to the data. The disadvantage is that we will only capture the effects of changes in the underlying
forces across the subperiods, but not within the subperiods. If we could measure the annualized effects, they would likely be stronger than the effects across subperiods.

4.1 Calibration Strategy

The calibration proceeds in the following four steps: we calibrate trend growth as average growth in “normal” times; we calibrate the sectoral depreciation from the sectoral investment-capital ratio; we calibrate the sectoral discount factor from the sectoral price-earnings ratio; we calculate markups as revenue over total factor payments; we calculate output elasticities as factor shares in factor payments.

First, we start by calibrating trend growth \( \gamma_T \). We calculate the trend growth rate as the average growth rate of aggregate final output during the years in which no rare disaster shocks materialize.

We continue with the calibration at the sectoral level. Second, given \( \gamma_T \), we calculate \( \delta_j + \gamma_Q \) from the investment-capital ratio (55):

\[
\delta_j + \gamma_Q = \frac{X_j}{pKj} - \gamma_T.
\]

Third, given \( \gamma_T \), we calculate \( \rho_j \) from the Gordon growth formula (57):

\[
\rho_j = \gamma_T + \frac{(1 + \gamma_T)\Pi_j}{pF_j}. \tag{61}
\]

Fourth, given \( \rho_j + \delta_j + \gamma_Q \), we calculate \( \mu_j \) and \( \alpha_j \) for each of the two sectors from the first-order conditions (21)–(23) and the capital-gross-output ratio (37):

\[
\frac{(\rho_j + \delta_j + \gamma_Q)pKj}{pG_jG_j} = \frac{\alpha_{Kj}}{\mu_j}, \tag{62}
\]

\[
\frac{wL_j}{pG_jG_j} = \frac{\alpha_{Lj}}{\mu_j}, \tag{63}
\]

\[
\frac{pG_jM_{ij}}{pG_jG_j} = \frac{\alpha_{M_{ij}}}{\mu_j}, \tag{64}
\]

\[
\frac{pG_jM_{ij}}{pG_jG_j} = \frac{\alpha_{M_{ij}}}{\mu_j}. \tag{65}
\]

Imposing that \( \alpha_{Kj} + \alpha_{Lj} + \alpha_{M_{ij}} + \alpha_{M_{ij}} = 1 \), we can solve for \( \mu_j \):

\[
\mu_j = \frac{pG_jG_j}{(\rho_j + \delta_j + \gamma_Q)pKj + wL_j + pG_jM_{ij} + pG_jM_{ij}}.
\]

The markup in sector \( j \) equals the value of sectoral output over the factor payments. The factor
payments include the imputed user costs of capital, which are consistent with the formula of Hall and Jorgenson (1967). Under perfect competition, the value of output equals the factor payments. Under imperfect competition, the markup increases the value of output above the factor payments. Since we will work with ratios in sectoral gross output, it is worth pointing out that (66) can be restated as:

$$\mu_j = \frac{1}{(\rho_j + \delta_j + \gamma_Q) p_k K_j} + \frac{wL_j}{p_G_j} + \frac{p_G M_{jj}}{p_G_j} + \frac{p_G M'_{jj}}{p_G_j}.$$  \hspace{1cm} (66)

To calculate $\alpha_{K_j}$, $\alpha_{L_j}$, $\alpha_{M_{jj}}$, and $\alpha_{M'_{jj}}$, we substitute the expression for $\mu_j$ into (62)–(65), which gives:

$$\alpha_{K_j} = \frac{(\rho_j + \delta_j + \gamma_Q) p_k K_j}{(\rho_j + \delta_j + \gamma_Q) p_k K_j + wL_j + p_G M_{jj} + p_G M'_{jj}},$$  \hspace{1cm} (67)

$$\alpha_{L_j} = \frac{wL_j}{(\rho_j + \delta_j + \gamma_Q) p_k K_j + wL_j + p_G M_{jj} + p_G M'_{jj}},$$  \hspace{1cm} (68)

$$\alpha_{M_{jj}} = \frac{p_G M_{jj}}{(\rho_j + \delta_j + \gamma_Q) p_k K_j + wL_j + p_G M_{jj} + p_G M'_{jj}},$$  \hspace{1cm} (69)

$$\alpha_{M'_{jj}} = \frac{p_G M'_{jj}}{(\rho_j + \delta_j + \gamma_Q) p_k K_j + wL_j + p_G M_{jj} + p_G M'_{jj}}.$$  \hspace{1cm} (70)

The output elasticities of the different factors equal the cost shares of the different factors, that is, the individual factor payments divided by the total factor payments. This is a standard result for Cobb-Douglas production functions.

We stress that the individual components of the sum $\rho_j + \delta_j + \gamma_Q$ do not matter for the calibrated parameter values. In particular, we do not have to worry about what part of depreciation is technological, $\delta_j$, and what part is economic, $\gamma_Q$. Instead, it is just the sum of the two that enters the calibration. This implies that our assumption that $\gamma_Q$ is common to both sectors is not restrictive. Note also that:

$$\rho_j + \delta_j + \gamma_Q = (1 + \gamma_T) \frac{\Pi_j}{p_F_j} + \frac{X_j}{p_k K_j}.$$  \hspace{1cm} (71)

The values of $\Pi_j/p_F_j$ and $X_j/(p_k K_j)$ on the right-hand side are of first-order quantitative importance for the sum on the left-hand side and the calibration. In contrast, since $\gamma_T$ is small, its exact value is not of first-order importance.

Since along the RBGP there is an aggregate Cobb-Douglas production function, the aggregate calibration is essentially as in Farhi and Gourio (2018) and proceeds in the same four steps as the sectoral calibration. In the second step, given $\gamma_T$, we calculate the aggregate depreciation...
rate $\delta + \gamma Q$ from the aggregate investment-capital ratio (56):
\[
\delta + \gamma Q = \frac{X}{p_K K} - \gamma T.
\]
Given $\gamma T$, in the third step we calculate aggregate $\rho$ from the aggregate Gordon growth formula (60):
\[
\rho = \gamma T + \frac{(1 + \gamma T)\Pi}{p_F},
\]
where $p_F$ and $\Pi$ are calculated according to (58)–(59). Given $\rho + \delta + \gamma Q$, the fourth step involves solving (45) and (47) for the aggregate markup and output elasticities while using that $\alpha_K + \alpha_L = 1$:
\[
\mu = \frac{Y}{(\rho + \delta + \gamma Q)p_K K + wL},
\]
\[
\alpha_K = \frac{(\rho + \delta + \gamma Q)p_K K}{(\rho + \delta + \gamma Q)p_K K + wL},
\]
\[
\alpha_L = \frac{wL}{(\rho + \delta + \gamma Q)p_K K + wL}.
\]
We can see that the aggregate results are close relatives of the sectoral results. The aggregate markup equals the value of final output divided by the aggregate factor payments (recall that the price of final output was normalized to one). The aggregate output elasticities of capital and labor equal the cost shares of aggregate capital and labor.

4.2 Implementing the Calibration Strategy

In implementing the four calibration steps, we focus on the private sector without real estate, which is as in Karabarbounis and Neiman (2018), Barkai (2020), and De Loecker et al. (2020a). The rationale for excluding real estate from the analysis is that it looks unusual [Rognlie (2015) and Gutierrez and Philippon (2017)]. Specifically, since owner-occupied housing is not part of market activity, real estate is a largely imputed sector. In addition, the NIPA do not include land in its measure of the capital stock although land is an important input into producing real estate services and the scarcity of land contributed to price increases of real estate. Therefore, omitting land from the capital stock artificially inflates markups in real estate [Rognlie (2015)].

If not mentioned otherwise, the data for the calibration are taken from the U.S. NIPA and the input-output tables. As we pointed out already, the advantage of using NIPA data in our context is that they are constructed with the standard adding up constraints and NIPA identities in mind, implying that they capture how sectoral forces aggregate. Moreover, they include information

---

7 Appendix B contains a detailed data documentation.
about the input-output linkages, which micro, or industry data, do not have. Although our aggregate model is essentially that of Farhi and Gourio (2018), there are several important differences between our calibration and theirs. Most importantly, of course, we disaggregate to the sectoral level whereas they only consider the aggregate economy. The portions of the economy that are included in the measurement are also different. As mentioned above, we use the private sector except for real estate whereas they use the entire private sector. Crucially, we calculate labor income and the labor share in a way that is consistent with excluding real estate. In contrast, Farhi and Gourio (2018) use the corporate labor share although it represents only part of the private sector.

Table 1: Calibration targets

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(wL/Y)</td>
<td>0.741</td>
<td>0.708</td>
<td>0.692</td>
</tr>
<tr>
<td>(wL_g/(p_G G_g))</td>
<td>0.290</td>
<td>0.257</td>
<td>0.229</td>
</tr>
<tr>
<td>(wL_s/(p_G G_s))</td>
<td>0.477</td>
<td>0.453</td>
<td>0.435</td>
</tr>
<tr>
<td>(p_M M_g/(p_G G_g))</td>
<td>0.501</td>
<td>0.514</td>
<td>0.518</td>
</tr>
<tr>
<td>(p_M M_g/(p_G G_g))</td>
<td>0.125</td>
<td>0.128</td>
<td>0.130</td>
</tr>
<tr>
<td>(p_M M_s/(p_G G_s))</td>
<td>0.299</td>
<td>0.316</td>
<td>0.342</td>
</tr>
<tr>
<td>(p_M M_s/(p_G G_s))</td>
<td>0.073</td>
<td>0.079</td>
<td>0.086</td>
</tr>
<tr>
<td>(X/(p_K K))</td>
<td>0.102</td>
<td>0.109</td>
<td>0.105</td>
</tr>
<tr>
<td>(X_g/(p_K K_g))</td>
<td>0.124</td>
<td>0.114</td>
<td>0.111</td>
</tr>
<tr>
<td>(X_s/(p_K K_s))</td>
<td>0.089</td>
<td>0.107</td>
<td>0.103</td>
</tr>
<tr>
<td>(p_F/\Pi)</td>
<td>28.06</td>
<td>35.46</td>
<td>55.51</td>
</tr>
<tr>
<td>(p_F/\Pi)</td>
<td>32.35</td>
<td>39.75</td>
<td>54.46</td>
</tr>
<tr>
<td>(p_F/\Pi)</td>
<td>27.22</td>
<td>34.68</td>
<td>55.71</td>
</tr>
<tr>
<td>(p_K K_g/Y_g)</td>
<td>1.394</td>
<td>1.476</td>
<td>1.515</td>
</tr>
<tr>
<td>(p_K K_s/Y_s)</td>
<td>1.107</td>
<td>1.548</td>
<td>1.884</td>
</tr>
<tr>
<td>(p_K K_s/Y_s)</td>
<td>1.589</td>
<td>1.446</td>
<td>1.406</td>
</tr>
</tbody>
</table>

Table 1 summarizes the key data observations for the calibration. While the labor share at the aggregate level shows the usual decrease, the labor share in the goods sector shows a much larger decrease than at the aggregate level. When aggregated, the decrease in the goods sector is mitigated by what happens in the services sector, whose labor share does not decrease as much, and by the increase in the final-output share of services. These observations are consistent with those of Alvarez-Cuadrado et al. (2018). The main difference between their work and ours is that they abstracted from markups and focused on the role of differences in sectoral substitution elasticities between capital and labor and in the sectoral capital biases of

---

8We calculate the labor shares, \(w_j L_j/(P_G G_j)\), according to the standard methodology that involves splitting proprietors income between capital and labor income according to the economy-wide proportions; see Gollin (2002) and Valentinyi and Herrendorf (2008) for the details.
technical change. The intermediate-good shares, $p_{Mj} M_j j'/(p_{Gj} G_j')$, increased in both sectors. The implied outsourcing of services was considerably stronger in the services sector than in the good sector.

The investment-capital ratio, $X_j/(p_K K_j)$, has not changed much at the aggregate level and the sectoral level. The capital-output ratio $p_K K_j/(p_G G_j)$ has gone up considerably in the goods sector and has decreased sufficiently in the services sector so as to offset most of the increase in the good sectors so that the aggregate capital-output ratio increases only somewhat. Note that the capital-output ratios are smaller than conventionally found because we have excluded a sizeable part of the capital stock – real estate capital.

The price-dividend ratio has increased considerably, which the calibration will translate into a decrease in the expected discount rate. Of course, the price-dividend ratio, $p_{Fj}/\Pi_j$, is not in NIPA. As Farhi and Gourio, we obtain it from Kenneth French's stock data library; see Appendix B.2. French reports prices and dividends of all public firms and assigns each of them to the main industry in which it was active. Dividends are the difference between reported returns with and without dividends. There are two concerns with using the price-dividend ratio in the calibration. First, one might wonder how well firms from the services sector are represented in stock data. Perhaps surprisingly, they are well represented indeed: during the first calibration period 1957–1973, one third of all listed firms are in the services sector and during the two other calibration periods half of them are. Second, the price-dividend ratio is for firms whereas the NIPA data are for establishments. The distinction is relevant in our context because firms in the goods sector also produce some in-house services, for example in their headquarters. Unfortunately, it is impossible to calculate separate price-earnings ratios for in-house services produced in the goods sector. This is not likely to be a serious issue for our calibration because in-house services are a small part of total services.

Table 2: Calibrated parameters for the private sector without real estate

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_T$</td>
<td>0.025</td>
<td>0.026</td>
<td>0.017</td>
</tr>
<tr>
<td>$\gamma_Q$</td>
<td>-0.007</td>
<td>-0.019</td>
<td>-0.013</td>
</tr>
<tr>
<td>$\delta$</td>
<td>0.084</td>
<td>0.102</td>
<td>0.102</td>
</tr>
<tr>
<td>$\delta_g$</td>
<td>0.106</td>
<td>0.107</td>
<td>0.108</td>
</tr>
<tr>
<td>$\delta_s$</td>
<td>0.072</td>
<td>0.100</td>
<td>0.099</td>
</tr>
<tr>
<td>$\rho$</td>
<td>0.061</td>
<td>0.054</td>
<td>0.035</td>
</tr>
<tr>
<td>$\rho_g$</td>
<td>0.057</td>
<td>0.052</td>
<td>0.035</td>
</tr>
<tr>
<td>$\rho_s$</td>
<td>0.063</td>
<td>0.055</td>
<td>0.035</td>
</tr>
</tbody>
</table>

Table 2 reports the parameter values that are pinned down by the first three calibration steps.
We obtain $\gamma_T$ from NIPA as the average growth rate of real output per capita. We estimate $\gamma_T$ only for the first part of the last period, 2001–2006. This is consistent with the view that the Great Recession constituted a realization of a rare disaster shock, $\chi_t$, that changed the level of trend output growth. Given that (71) implies that the value of $\gamma_T$ is not of first-order importance for the results, this interpretation is not crucial for the results. We find that trend growth is around 2.5 percent in the first two periods and 1.7 percent in the last period.

We obtain $\gamma_Q$ from NIPA as the inverse of the average growth rate of the price of investment relative to output. Consistent with conventional wisdom, investment-specific technical change is strongest in the 1980s and 1990s; see for example Duernecker et al. (2021). In our context, this manifests itself in the absolute value of $\gamma_Q$ being twice as large in the middle period than in the other two periods.

The depreciation rates are between 7% and 11%, which is reasonable given that we exclude real estate, which has a much lower depreciation rate, from the analysis. Note that the depreciation rate increased over time, which is consistent with the observation of Bridgman (2018) that intellectual property product has high depreciation rates and is growing as a share of overall capital.

The expected discount rate $\rho_j$ fell from around 6% to around 3.5%. This is broadly in line with what Farhi and Gourio (2018) found for the aggregate for the last two periods. They argued that the inclusion of a risk premium in $\rho$ implies that its recent values are somewhat higher than those from Aaa interest rates used by Barkai (2020).

Note that in the model $\rho_j$ applies to all firms whereas in the data it applies to publicly listed firms only. This leads to two concerns. First, it is sometimes claimed that the publicly listed firms have lower user costs of capital than the other firms. If that is correct, then our calibrated $\rho_j + \delta_j + \gamma_Q$ is downward biased; compare expression (66). Second, it is often claimed that in recent decades firms increased their retained earnings, which decreased dividends and increased firm prices. If these retained earnings had been paid out, then the price-dividend ratio would have increased by less, $\rho_j$ and $\rho$ would have fallen less. These considerations mean that our calibrated values of $\mu_j$ and $\mu$ will be an upper bound and our calibrated labor shares will be a lower bound to the actual values. So, if anything, the recent labor shares may be somewhat higher than what we find. Be that as it may, in the discussion of Table 6 below we will see that the potential bias cannot be very large, as our aggregate labor share estimates are in the same ballpark as other estimates in the literature.
Table 3: Calibrated parameters for the private sector without real estate – continued

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu$</td>
<td>1.072</td>
<td>1.097</td>
<td>1.137</td>
</tr>
<tr>
<td>$\mu_g$</td>
<td>1.040</td>
<td>1.049</td>
<td>1.078</td>
</tr>
<tr>
<td>$\mu_s$</td>
<td>1.033</td>
<td>1.050</td>
<td>1.066</td>
</tr>
<tr>
<td>$\alpha_L$</td>
<td>0.794</td>
<td>0.777</td>
<td>0.787</td>
</tr>
<tr>
<td>$\alpha_{Lg}$</td>
<td>0.302</td>
<td>0.270</td>
<td>0.247</td>
</tr>
<tr>
<td>$\alpha_{Lg}/(\alpha_{Kg} + \alpha_{Lg})$</td>
<td>0.807</td>
<td>0.754</td>
<td>0.702</td>
</tr>
<tr>
<td>$\alpha_{Kg} + \alpha_{Lg}$</td>
<td>0.374</td>
<td>0.358</td>
<td>0.352</td>
</tr>
<tr>
<td>$\alpha_Ls$</td>
<td>0.493</td>
<td>0.475</td>
<td>0.464</td>
</tr>
<tr>
<td>$\alpha_{Ls}/(\alpha_{Ks} + \alpha_{Ls})$</td>
<td>0.785</td>
<td>0.785</td>
<td>0.811</td>
</tr>
<tr>
<td>$\alpha_{Ks} + \alpha_{Ls}$</td>
<td>0.628</td>
<td>0.605</td>
<td>0.572</td>
</tr>
<tr>
<td>$\phi_g$</td>
<td>0.460</td>
<td>0.283</td>
<td>0.194</td>
</tr>
<tr>
<td>$\Phi_g$</td>
<td>1.018</td>
<td>0.726</td>
<td>0.572</td>
</tr>
<tr>
<td>$\Phi_s$</td>
<td>0.933</td>
<td>1.153</td>
<td>1.289</td>
</tr>
</tbody>
</table>

5 Results

5.1 Determinants of the Labor Share

Table 3 displays the parameters implied by the fourth calibration step. Between 1957–1973 and 2001–2016, markups in both sector increased by roughly similar amounts and they roughly doubled. While aggregate markups also roughly doubled, we find that the levels of markups in both sectors are only around half of what they are at the aggregate. The reason for the difference is double marginalization, that is, the sectoral markups are not only applied to the rental prices of capital and labor but also to the purchase prices of intermediate inputs. As a result, intermediate inputs get marked up when their producers sell them and when their users sell their output. Average sectoral markups must therefore be smaller than aggregate markups [Basu (2019)]. Our analysis shows that the difference is very large: sectoral markups are around half of aggregate markups. We emphasize that taking the input-output structure into account is of first-order importance for this result. If instead we wrote down a model without input-output linkages in which each sector produces value added without intermediate inputs, then the sectoral markups would be considerable higher and the markup in the goods sector would actually exceed the aggregate markup considerably. The details of this exercise including the resulting parameter values can be found in Appendix C.9

9There is a mounting body of work on the implications of input-output linkages for a variety of macro phenomena other than markups. Valentinyi (2021) reviews the recent literature and discusses its potential implications for the literature on productivity and structural change. An example from the literature on structural change is Herrrendorf et al. (2013). An example from the literature on misallocation is Hang et al. (2020). They found a result similar in spirit to ours: there is less sectoral misallocation in a gross-output model than in the corresponding
Our conclusion about the effects of double marginalization rest on the assumption that most intermediate inputs are produced outside of vertically integrated firms that do not charge markups to themselves on intermediate inputs produced within the firm. While NIPA data do not allow us to assess how restrictive this assumption is, evidence presented by Atalay et al. (2014) for the goods sector suggests that the vast majority of intermediate inputs are traded outside vertically integrated firms.

The finding that sectoral markups are smaller than the aggregate markups exacerbates the well known puzzle why micro estimates of markups tend be larger than macro estimates. For example, an elasticity of substitution of 4 is common parameter choice in the industrial organization literature; see for example Broda and Weinstein (2006). Such a choice leads to markups of $\varepsilon/(\varepsilon - 1) = 1.25$, which are considerable larger than our aggregate markups. Given that disaggregate markups get amplified by the input-output linkages, that cannot systematically be the case in the whole economy. Part of the tension may come from the fact that the industrial organization literature tends to focus on industries which produce well defined, single products (e.g., concrete) or which have relatively large markups (e.g., beer). Be that as it may, recent studies of markups in Compustat find similar or even larger firm-level markups as the industry studies; see for example Edmond et al. (2018), Traina (2018), and De Loecker et al. (2020b). Since Compustat is representative of a sizeable part of the economy, selection is less of an issue than with industry studies. In the current paper, we have nothing to offer that could resolve this puzzle. But we do note that our analysis highlights that taking the input-output structure into account is of first-order importance for the aggregation of sectoral to aggregate markups. Simple cost- or revenue-weighted averages miss the important amplification of sectoral markups that results from input-output linkages.\(^{10}\)

Turning now to the output elasticity of labor, it decreased by 5.9 percentage points in the goods sector and 2.0 percentage points in the services sector between 1957–1973 and 2001–2016. There are two sets of forces behind the decrease in the labor share: those that increase the value-added elasticity of capital ("capital deepening") and those that increase the gross-output elasticity of intermediate inputs ("outsourcing"). We find that there was considerable capital deepening in the goods sector but not in the services sector or at the aggregate. In particular, $\alpha_{Lg}/(\alpha_{Kg} + \alpha_{Lg})$ decreased from 0.807 to 0.702; $\alpha_{Ls}/(\alpha_{Ks} + \alpha_{Ls})$ increased from 0.785 to 0.811; $\alpha_L$ decreased from 0.794 to 0.787. In sum, the forces behind capital deepening were entirely concentrated in the goods sector.

Two underlying forces that may lead to capital deepening in the goods sector: decreases in the relative price of capital [Karabarbounis and Neiman (2014)]; automation [Acemoglu and

\(^{10}\)See Syverson (2019) for further issues regarding the integration of the micro and the macro literature on markups.
For decreases in the relative price of capital to lead to capital deepening, the elasticity of substitution between capital and labor must be larger than one. Herrendorf et al. (2015) found that, while the elasticity of substitution is indeed larger than one in U.S. agriculture, it is considerably smaller than one in the large remaining part of the goods-producing sector. Oberfield and Raval (2021) found that the elasticity of substitution is less than one in U.S. manufacturing. The evidence on the elasticity of substitution casts doubt on the possibility that the substitution of increasingly cheap capital for labor is behind capital deepening in the goods sector. A more likely story is that automation reduced the output elasticity of labor in the goods sector but not in the services sector. Interestingly, the effects of capital deepening in the goods sector did not translate to the aggregate $\alpha_L$, which hardly changed. The reason is that structural change reallocated labor from the goods sector to the services sector, which offset the capital deepening in the goods sector.

Outsourcing happened in both sectors, but it was stronger in the services sector. In particular, $\alpha_{K_s} + \alpha_{L_s} = 1 - \alpha_{M_{sg}} + \alpha_{M_{gs}}$ decreased from 0.374 to 0.352 whereas $\alpha_{K_g} + \alpha_{L_g}$ decreased from 0.628 to 0.572. Together, capital deepening and outsourcing decrease the output elasticity of labor in both sectors, with a larger decrease in the goods sector than in the services sector.

Structural change reduced the final output share of goods by a lot from 0.460 to 0.194. The Domar weight moved accordingly: $\Phi_g$ decreased from 1.018 to 0.572 whereas $\Phi_s$ increased from 0.933 to 1.289. Note that, as usual, the Domar weights do not add up to one.

### 5.2 Decomposition of the Labor Share Decrease

We now decompose the change in the aggregate labor share into changes in sectoral markups, changes in the sectoral output elasticities of labor, changes in the sectoral output elasticities of intermediate goods (outsourcing), and changes in the sectoral composition of final output (structural change).

<table>
<thead>
<tr>
<th>Table 4: Decomposition of changes in aggregate labor share – bottom up</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data</strong></td>
</tr>
<tr>
<td>First-order effect of $\mu_j$</td>
</tr>
<tr>
<td>$\alpha_{L_j}$</td>
</tr>
<tr>
<td>$\Phi_j$</td>
</tr>
<tr>
<td>Second-order effect of $\alpha_{L_j}, \Phi_j$</td>
</tr>
<tr>
<td>$\mu_j, \alpha_{L_j}$</td>
</tr>
<tr>
<td>$\Phi_j, \mu_j$</td>
</tr>
<tr>
<td>Third-order effect of $\alpha_{L_j}, \mu_j, \Phi_j$</td>
</tr>
</tbody>
</table>

A natural starting point for the decomposition is to take the Taylor expansion of Equa-
We call that the “bottom-up” approach. Note that given the functional form of the right-hand side, the third-order Taylor expansion is exact. Table 4 reports the first-, second-, and third-order effects. The first two lines reveal that measuring the direct (first-order) effects implies that changes in markups reduce the aggregate labor share by 2.4 percentage points whereas changes in the output elasticity of labor reduce it by a full 8 percentage points. Since both direct effects add up to over 10 percentage points, they do exactly what Grossman and Oberfield (2021) observed: together they “explain” more than twice the 4.9 percentage points decrease in the aggregate labor share. The table also shows that a sizeable part of the direct effects is offset by indirect effects. For starters, the first-order effects of changes in the Domar weight offset 4 percentage points of the total direct effect. The second- and third-order effects that result from the interaction of the output elasticity of labor with the Domar weights offset another 1.4 percentage points of the direct effect. These results highlight that identifying the forces behind the decrease of the aggregate labor share requires a unifying framework like ours that captures causal and offsetting forces and accounts for aggregation effects.

One complication with interpreting the bottom-up approach is that changes in the Domar weights reflect changes in the final output shares (structural change), of changes in the output elasticities of the intermediate inputs (which are linked to changes in the output elasticities of labor), and of changes in the markups. To see this, recall Equation (25):

$$
\Phi_j \equiv \frac{1}{(1 - \frac{\alpha_{jt}}{\mu_j})^2} \left( \frac{\alpha_{j't}}{\mu_j} \phi_j + \frac{\alpha_{jt} \phi_j}{\mu_j} \right) - \frac{\alpha_{j't} \alpha_{jt}}{\mu_j}. 
$$

While the Taylor expansion of this expression with respect to all right-hand side variables is somewhat involved, it is straightforward to take the first-order Taylor expansion with respect to the final output weights, $\phi_j$. This implies that the aggregate labor share increases by 2.7 percentage points due to changes in $\Phi_j$ that result from changes in $\phi_j$. How changes in $\mu_j$ and $\alpha_{j't}$ affect affecting $\Phi_j$, however, is somewhat hard to disentangle, and so the bottom up approach does not yield estimates for the full individual effects of $\mu_j$ and of $\alpha_{j't}$. To measure them, we use a “top-down” approach instead.

The top-down approach shuts down one or more forces at a time by fixing the corresponding parameters at the values of the first period. This captures the total effects on the aggregate labor share of the first-, second-, and third-order effects related to the change in the parameter. Table 5 reports the results. Without changes in sectoral markups, the labor share would have decreased
Table 5: Decomposition of changes in aggregate labor share – top down

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>0.741</td>
<td>0.708</td>
<td>0.692</td>
</tr>
<tr>
<td>$\mu_j$</td>
<td>0.741</td>
<td>0.726</td>
<td>0.735</td>
</tr>
<tr>
<td>$\alpha_{Lj}$</td>
<td>0.741</td>
<td>0.725</td>
<td>0.719</td>
</tr>
<tr>
<td>$\alpha_{Mjj}$, $\alpha_{Mjj}'$</td>
<td>0.741</td>
<td>0.711</td>
<td>0.700</td>
</tr>
<tr>
<td>$\phi_j$</td>
<td>0.741</td>
<td>0.700</td>
<td>0.664</td>
</tr>
<tr>
<td>$\mu_j, \phi_j$</td>
<td>0.741</td>
<td>0.718</td>
<td>0.711</td>
</tr>
<tr>
<td>$\alpha_{Lj}, \phi_j$</td>
<td>0.741</td>
<td>0.720</td>
<td>0.698</td>
</tr>
<tr>
<td>$\alpha_{Mjj}, \alpha_{Mjj}', \phi_j$</td>
<td>0.741</td>
<td>0.703</td>
<td>0.671</td>
</tr>
</tbody>
</table>

by 4.3 percentage points less ($0.735 - 0.692 = 0.043$). Without changes in output elasticity of labor, the labor share would have decreased by 2.7 percentage points less ($0.719 - 0.692 = 0.027$). Without outsourcing, the labor share would have decreased by 0.8 percentage points less ($0.692 - 0.700 = 0.008$). Without structural change, the labor share would have decreased by 2.8 percentage points more ($0.692 - 0.664 = 0.008$).

Several remarks are at order. First, the top-down approach shows that the total effect of changes in sectoral markups on the aggregate labor is a 4.9 percentage point decrease. Since the bottom-up approach gave a direct effect on the aggregate labor share was a 2.4 percentage point decrease, markups must have an additional indirect effect of 2.5 percentage points through affecting the Domar weights. Second, as with the bottom up approach, the parameter changes that decrease the labor share in the top-down approach add up to more than the 4.9 percentage point decrease of the labor share. In particular, they decrease the labor share by $7.8 = 4.3 + 2.7 + 0.8$ percentage points. The excess decrease of 2.9 percentage points is offset by the effect of structural change, which increases the labor share by 2.8 percentage points. Note that without rounding errors, the two numbers should be exactly the same.

Our results have some important implications. First, double marginalization hugely amplifies the effects of the fairly even changes in $\mu_j$. Taking into account the input-output linkages is therefore crucial for our results and one cannot properly aggregate firm or industry level effects using just micro data. Instead, NIPA data is required to capture the quantitatively important roles played by structural change and the input-output linkages. Second, together the individual forces explain a multiple of the labor share decrease because aggregation effects offset some of them. A particular aggregation effect comes from the changes in the sectoral composition that result from structural change. It is important to realize that structural change offsets mostly the forces of capital deepening. To see this, we go back to Table 3. The table shows that, whereas both sectoral and aggregate markups roughly double, the aggregate output elasticity of labor, $\alpha_{L}$, remains almost constant. The reason for the difference is that, given the sectoral
markups increase by similar amounts, changes in the sectoral composition do not matter much for how the sectoral changes aggregate. In contrast, given that capital deepening happens only in the goods sector, it is mostly offset by the reallocation of labor to the services sector. We conclude that to understand the reasons for the decrease in the aggregate labor share, we need an explanation for why markups increased by similar amounts in both sectors.

Our results are related to those of Giannoni and Mertens (2019). While our focus here is on the postwar period, they studied the shorter period 1996–2016, which largely overlaps with our third period 2001–2016. Their results can therefore be interpreted as shedding light on what happened without our third period. Like us, they also find that while outsourcing may affect the industry labor share, it does not affect the aggregate labor share much because labor that is outsourced in one industry shows up in another. Unlike us, they find that during 1996–2009 decreases in the output elasticity of labor played the main role in the decrease in the aggregate labor share, and increases in markups played an important role only during 2009–2016. Given our methodology we cannot speak to what happened within one of our sub-periods. Given their methodology they cannot speak to what happened during the longer postwar period. We therefore view the two studies as offering evidence for different frequencies, which nicely complement each the other.

6 Comparison with Literature

To lend credibility to our results, this subsection establishes that our calibration yields parameter values for the aggregate labor share and the aggregate markups that are broadly in line with those in the macro literature.

6.1 Aggregate Labor Share

Table 6 compares our aggregate labor share estimates with those of the literature. The second line repeats the first line of Table 1 for comparison. The last line reports what our framework implies if we followed Farhi and Gourio (2018) in using the corporate labor share but all other data from the entire private sector. The results are broadly in line with what other authors found, which is reassuring. The difference between the first two lines reflects the fact that real estate is relatively capital intensive, and so the labor share increases in all three periods when one takes real estate out. However, the labor share still decreases by 4.9 percentage points without real estate, compared to its 6.2 percentage points decrease with real estate. This implies that what happened within real estate is not the main reason for the decrease in the labor share. The difference between the first and last lines is more sizeable. This reflects that the corporate labor share is larger than the labor share in the private sector and that it decreased by less (6.2 versus
3.9 percentage points). We conclude that it is not ideal to use the corporate labor share when the rest of the model is calibrated to the entire private sector.

Table 6: Labor share for different parts of the private sector

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Private sector</td>
<td>0.657</td>
<td>0.618</td>
<td>0.595</td>
</tr>
<tr>
<td>Private sector without real estate</td>
<td>0.741</td>
<td>0.708</td>
<td>0.692</td>
</tr>
<tr>
<td>Private sector without FIRE</td>
<td>0.738</td>
<td>0.706</td>
<td>0.692</td>
</tr>
<tr>
<td>Corporate sector without FIRE</td>
<td>0.699</td>
<td>0.697</td>
<td>0.651</td>
</tr>
<tr>
<td>Private sector with corporate labor share</td>
<td>0.699</td>
<td>0.701</td>
<td>0.660</td>
</tr>
<tr>
<td>– Farhi-Gourio type estimates</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 6.2 Aggregate Markups

As a second consistency check, Table 7 compares our aggregate markup estimates with those of the literature. The second line repeats the second line of Table 3 for comparison. The third line reports the markups our framework implies if instead of using the calibrated $\rho_j$, we followed Barkai (2020) and used the Aaa interest rate from Moody’s. Note that the Aaa interest rate is not available during the first period, which explains the blank space in the table. The last line reports what our framework implies if we followed Farhi and Gourio (2018) in using the corporate labor share but all other data from the entire private sector. Again, the results are broadly in line with what the other authors found. Moreover, in the final period the markup estimates are fairly similar to each other, ranging from 12.8% to 14.5%. In contrast, in the first period, there is somewhat more variation in the markup estimates; our method implies a markup of 7.5% whereas using the private sector with the corporate labor share implies the lower estimate of 3.7%. It is important to realize that this difference is expected because the initial corporate labor share is larger than the labor share of the private sector with real estate.

Equation (72) implies that the estimate of aggregate markups decreases as a result:

$$
\mu \downarrow = \frac{1}{(\rho + \delta + \gamma q) \frac{pxk}{y} + \frac{wL}{y}} \uparrow
$$

Table 7 also shows that markups are larger for the private sectors with real estate than without real estate (lines one versus two). One explanation for why including real estate increases

---

11 Following the methodology of Barkai (2020), Esfahani et al. (2020) calculated disaggregate markups at the industry level for many countries from World KLEMS data on input-output tables. Since these data are available for 1996–2014, their period of investigation is close to the last period of our calibration, that is, 2001–2016. Therefore, their analysis does not speak to what happened since the 1950s.
Table 7: Markups for different parts of the private sector

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Private sector</td>
<td>1.071</td>
<td>1.121</td>
<td>1.194</td>
</tr>
<tr>
<td>Private sector without real estate</td>
<td>1.072</td>
<td>1.097</td>
<td>1.137</td>
</tr>
<tr>
<td>Private sector without real estate and with Barkai type user costs</td>
<td>1.101</td>
<td>1.151</td>
<td></td>
</tr>
<tr>
<td>Private sector without FIRE</td>
<td>1.070</td>
<td>1.093</td>
<td>1.128</td>
</tr>
<tr>
<td>Corporate sector without FIRE</td>
<td>1.088</td>
<td>1.086</td>
<td>1.138</td>
</tr>
<tr>
<td>Private sector with corporate labor share</td>
<td>1.037</td>
<td>1.080</td>
<td>1.145</td>
</tr>
<tr>
<td>– Farhi-Gourio type estimates</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

markups is that NIPA includes land income in $Y$ but not in $K$. Hence, $p_KK_j/Y_j$ is underestimated for real estate, which biases the markups in real estate upwards:

$$
\mu_j \uparrow = \frac{1}{(\rho_j + \delta_j + \gamma Q)\frac{p_KK_j}{Y_j} + \frac{w_jL_j}{Y_j}}
$$

6.3 Intellectual Property Product

It is also of interest to study the effect on the aggregate labor share of the recent inclusion in the NIPA of the investment in intellectual property product (IPP). IPP investment comprises the expenditure on software, research and development, and entertainment, literary, and artistic originals. The revision of 1999 included software in NIPA and the revision of 2013 included the rest of IPP in NIPA. IPP investment is a sizeable, and growing, subset of unmeasured investment that importantly affects the aggregate labor share.

Koh et al. (2021) studied what happens to the aggregate labor share when one takes IPP investment and the related factor income out of the NIPA, which captures how NIPA was constructed before 1999. They found that without IPP investment, the aggregate labor share hardly decreased over the postwar period. We now show that our analysis is consistent with their results. Since they analyzed the aggregate economy, and since it is challenging to apportion IPP investment to the two sectors, we will analyze only the aggregate effects of taking IPP investment out.

Excluding IPP in the measurement of markups requires two modifications to Equations (72)–(74): first, one must take the user costs paid to the stock of unmeasured capital, $r^*K^*$, out of factor payments; second, one must expense IPP investment, $X^*$, thereby taking it out of total GDP.\(^2\) Given that the income and product approaches to measuring GDP must give the same answer, the two modifications must conceptually be equal in value: $r^*K^* = X^*$. Since

\(^2\)The detailed steps are explained in Koh et al. (2021).
\( Y > rK + wL, \) (72) implies that excluding unmeasured capital increases aggregate markups:

\[
\mu = \frac{Y}{rK + wL} < \frac{Y - X^*}{rK - r^*K^* + wL} = \mu^*.
\]

Moreover, (74) implies that excluding unmeasured capital increases the aggregate output elasticity of labor:

\[
\alpha_L = \frac{wL}{rK + wL} < \frac{wL}{rK - r^*K^* + wL} = \alpha_L^*.
\]

Table 8 reports the results. As expected, the aggregate markup and the aggregate output elasticity of labor are both larger without than with IPP capital. Moreover, without IPP capital, both markups and the output elasticity of labor increase. Interestingly, the two increases largely offset each so that the aggregate labor share declines by only one percentage point from 0.743 to 0.732, instead of from 0.741 to 0.692. This is a version of the finding of Koh et al. (2021). Our decomposition adds to their analysis the point that without IPP capital the aggregate output elasticity of labor increases, whereas with IPP capital it remains almost constant. This is intuitively plausible: excluding an increasingly important part of the capital – IPP capital – leads to a increasingly large output elasticity of labor.

Table 8: Aggregate calibration without IPP capital and real estate

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( wL/Y^* )</td>
<td>0.743</td>
<td>0.732</td>
<td>0.732</td>
</tr>
<tr>
<td>( \alpha_L^* )</td>
<td>0.814</td>
<td>0.815</td>
<td>0.839</td>
</tr>
<tr>
<td>( \mu^* )</td>
<td>1.097</td>
<td>1.114</td>
<td>1.146</td>
</tr>
</tbody>
</table>

7 Conclusion

We have developed a unifying framework to study why the labor share decreased in the postwar U.S. Our framework captures key causal forces and important amplifying and offsetting effects. We have found that the main force behind the decrease in the postwar U.S. labor share is increases in both sectors’ markups that are amplified through input-output linkages. In contrast, forces that lead to capital deepening (e.g., automation) were concentrated in the goods sector and were therefore largely offset by structural change. Our analysis implies that input-output linkages and structural change are essential, and that micro data alone are not sufficient, for estimating the effects of sectoral forces on the aggregate labor share.

\footnote{Atkeson (2020) arrived at a similar conclusion regarding the effect of unmeasured capital on markups.}
Our analysis suggests several directions for future work. First, it would be useful to do the decomposition also for finer industry disaggregations and investigate what patterns arise in the aggregation of more disaggregate force behind the labor share decrease. While we have focused on the two-sector split between goods and services as a useful and tractable first step, there is nothing that prevents our methodology from being applied to finer industry disaggregations with many industries. Second, it would be valuable to extend our analysis beyond the U.S. to other countries. Since our calibration procedure has limited data requirements, that should be feasible. We plan to turn to some of these tasks next.

References


A Proofs and Derivations

A.1 Proof of Proposition 1

$p_{jt}G_{jt}$ are linked to each other $Y_{jt}$ through the feasibility constraint. (16) implies:

$$p_{Gj}G_{jt} = p_{Gj}Y_{jt} + p_{Gj}M_{jjt} + p_{Gj}M_{jj}'.$$

Using (18), (22), and (23) gives:

$$p_{Gj}G_{jt} = \phi_j Y_t + \frac{\alpha_{Mjj}}{\mu_j} p_{Gj}G_{jt} + \frac{\alpha_{Mjj}'}{\mu_j'} p_{Gj}G_{jt}'.$$

Denoting column vectors and matrices in boldface,

$$p_{Gt}G_{jt} \equiv \begin{bmatrix} p_{Ggt}G_{jt} \\ p_{Gst}G_{jt} \end{bmatrix}, \quad \phi \equiv \begin{bmatrix} \phi_g \\ \alpha M_{gg} \mu_g \\ \alpha M_{gs} \mu_g \\ \alpha M_{sg} \mu_g \\ \alpha M_{ss} \mu_g \end{bmatrix}, \quad \Omega \equiv \begin{bmatrix} \alpha M_{gg} \mu_g \\ \alpha M_{gs} \mu_g \\ \alpha M_{sg} \mu_g \\ \alpha M_{ss} \mu_g \end{bmatrix},$$

this implies:

$$p_{Gt}G_{jt} = \phi + \Omega p_{Gt}G_{jt}.$$

If $\Omega$ is invertible, then:

$$p_{Gt}G_{jt} = [I - \Omega]^{-1} \phi,$$

where $[I - \Omega]^{-1}$ is the so called Leontief inverse. Solving for the Leontief inverse gives:

$$[I - \Omega]^{-1} = \begin{bmatrix} 1 - \frac{\alpha_{Mgg}}{\mu_g} & -\frac{\alpha_{Mgs}}{\mu_g} \\ -\frac{\alpha_{Msg}}{\mu_g} & 1 - \frac{\alpha_{Mss}}{\mu_g} \end{bmatrix}^{-1}$$

$$= \frac{1}{(1 - \frac{\alpha_{Mgg}}{\mu_g})(1 - \frac{\alpha_{Mss}}{\mu_g}) - \frac{\alpha_{Msg}}{\mu_g} \frac{\alpha_{Mgs}}{\mu_g} \left[ 1 - \frac{\alpha_{Mgg}}{\mu_g} \frac{\alpha_{Mss}}{\mu_g} \right]}. $$

Plugging the Leontief inverse into (A.1) implies that, in equilibrium, sectoral gross output is proportional to aggregate final output:

$$p_{Gj}G_{jt} = \Phi_j Y_t \quad \text{where} \quad \Phi_j \equiv \frac{\left(1 - \frac{\alpha_{Mjj}'}{\mu_j'} \right) \phi_j + \frac{\alpha_{Mjj}'}{\mu_j'} \phi_j'}{\left(1 - \frac{\alpha_{Mjj}}{\mu_j} \right) \left(1 - \frac{\alpha_{Mjj}'}{\mu_j'} \right) - \frac{\alpha_{Mjj}'}{\mu_j'} \frac{\alpha_{Mjj}'}{\mu_j}}.$$

QED
A.2 Derivation of the Euler equation

Substituting out \(X_{jt}\) in the household problem (31) by using (9), the problem simplifies to:

\[
\max_{C_t, K_{jt+1}, \mu(t)} \quad U_t = \left(1 - \beta \right) C_t^{1-\sigma} + \beta \left[ E_t \left(U_{t+1}^{1-\theta} \right) \right] \frac{1-\sigma}{1-\theta} \\
\text{s.t.} \quad C_t = \sum_{j \in \{g, s\}} \left[ \frac{1 - \delta_j}{Q_t} K_{jt} + \frac{K_{jt+1}}{Q_t \exp(\chi_{jt+1})} \right] + w_t.
\]

Substituting the constraint into the life-time utility function gives:

\[
\max_{K_{jt+1}} \quad U_t = \left(1 - \beta \right) C_t^{1-\sigma} \left[ \frac{1 - \delta}{Q_t} + r_{jt} \right] K_t + w_t N_t - \frac{K_{jt+1}}{Q_t \exp(\chi_{jt+1})} \frac{1-\sigma}{1-\theta} + \beta \left[ E_t \left(U_{t+1}^{1-\theta} \right) \right] \frac{1}{1-\sigma} \\
\text{s.t.} \quad C_t = \sum_{j \in \{g, s\}} \left[ \frac{1 - \delta_j}{Q_t} Q_t^{1-\theta} + r_{jt} \right] K_{jt} - \frac{K_{jt+1}}{Q_t \exp(\chi_{jt+1})} + w_t.
\]

The first-order conditions are:

\[
0 = -U_t^{\sigma} \left(1 - \beta \right) C_t^{\sigma-\sigma} + U_t^{\sigma} \beta \left[ E_t \left(U_{t+1}^{1-\theta} \right) \right] \frac{1-\sigma}{1-\theta} E_t \left[ U_{t+1}^{1-\theta} \right] + \beta \left[ E_t \left(U_{t+1}^{1-\theta} \right) \right] \frac{1}{1-\sigma} \\
\frac{\partial U_{t+1}}{\partial K_{t+1}} \sigma = U_t^{\sigma} \left(1 - \beta \right) C_t^{\sigma-\sigma} \left( \frac{1 - \delta}{Q_t} + r_{t+1} \right)
\]

Hence,

\[
\frac{C_t^{\sigma-\sigma}}{Q_t \exp(\chi_{jt+1})} = \beta E_t \left[ C_t^{\sigma-\sigma} \left( \frac{1 - \delta}{Q_t} + r_{t+1} \right) \right] \left[ \frac{U_{t+1}}{E_t \left(U_{t+1}^{1-\theta} \right) \frac{1}{1-\sigma}} \right]^{\sigma-\theta}
\]

Rewriting this gives the Euler equation (32) stated in the text:

\[
1 = E_t \left(D_{t+1} R_{t+1}\right)
\]

where

\[
D_{t+1} \equiv \beta \left( \frac{C_{t+1}}{C_t} \right)^{1-\sigma} \left[ \frac{U_{t+1}}{E_t \left(U_{t+1}^{1-\theta} \right) \frac{1}{1-\sigma}} \right]^{\sigma-\theta}
\]

\[
R_{t+1} \equiv (1 - \delta + r_{t+1} Q_{t+1}) \frac{Q_t}{Q_{t+1}} \exp(\chi_{jt+1})
\]

A.3 Proof of Proposition 2

(26) implies that along the RBGP \(Y_{jt}\) is proportional to \(G_{jt}\), which we write as \(Y_{jt} \propto G_{jt}\). Thus,

\[
Y_t \propto G_{gt} G_{jt}^\phi.
\] (A.2)
(22) implies that $M_{jt} \propto G_{jt}$ and (23) implies that:

$$M_{jt} = \frac{\alpha_{M_{jt}}}{\mu_j} \frac{p_{G_{jt}}}{p_{G_{jt}'}} G_{jt}.$$  

Using (24), the previous equation implies that $M_{jt} \propto G_{jt}$. (29) and (39) imply that $L_{jt} \propto 1$ and $K_{jt} \propto K_t$. Substituting all these equilibrium relationships into (4) gives:

$$G_{jt} \propto Z_{jt}^{\alpha_{K_{jt}}} A_{jt}^{\alpha_{L_{jt}}} G_{jt}^{\alpha_{M_{jt}}} \left( j, j' \in \{g, s\} \right).$$

We can solve this equation for $G_{jt}$:

$$G_{jt} \propto Z_{jt}^{1-\alpha_{M_{jt}}} K_t^{\alpha_{K_{jt}}} A_{jt}^{\alpha_{L_{jt}}} G_{jt}^{\alpha_{M_{jt}}} \left( j, j' \in \{g, s\} \right).$$

Substituting the same equation for $G_{jt}$ into the previous equation:

$$G_{jt} \propto Z_{jt}^{1-\alpha_{M_{jt}}} K_t^{\alpha_{K_{jt}}} A_{jt}^{\alpha_{L_{jt}}} \left[ Z_{jt}^{1-\alpha_{M_{jt}'}} K_t^{\alpha_{K_{jt}'}} A_{jt}^{\alpha_{L_{jt}'}} G_{jt}^{\alpha_{M_{jt}'}} \right].$$

Solving for $G_{jt}$, we find:

$$G_{jt} \propto \left[ Z_{jt}^{1-\alpha_{M_{jt'}}} Z_{jt}^{\alpha_{M_{jt}}} K_t^{\alpha_{K_{jt}}} (1-\alpha_{M_{jt'}}) \alpha_{K_{jt'}} A_{jt}^{\alpha_{L_{jt}}} (1-\alpha_{M_{jt'))} A_{jt}^{\alpha_{L_{jt}}} G_{jt}^{\alpha_{M_{jt}}} \right]^{1/(1-\alpha_{M_{jt'}}) - \alpha_{M_{jt'}}}.$$  

Substituting the previous equation for $G_{st}$ and $G_{s't}$ into (A.2) gives us the aggregate Cobb-Douglas production function (46).  QED

B Data Documentation

B.1 NIPA Data

The full suite of industry data by NAICS industries is not available for the full post WWII period. We project previous shares of the missing components using previous industry classifications (SIC87 and SIC72).

B.1.1 Gross Output and Value Added by NAICS

B.1.2 Compensation of Employees, Gross Operating Surplus, Indirect Business Taxes

   1947–1986: SIC72 Historical Accounts to calculate the COE and IBT shares of VA by Industry. We multiply these shares by NAICS VA.

B.1.3 Proprietors’ Income

   1947–1986: SIC72 Historical Accounts to calculate Proprietor’s Income share of GOS and we multiply these shares by NAICS GOS.

B.1.4 Real Output

   To obtain 1984–2000 sample, we use growth rates from the 1997–2018 source.

B.1.5 Price Indices

Investment price change is investment price growth minus total price growth.
   Investment prices from NIPA Table 5.3.4. Price Indexes for Private Fixed Investment by Type, June 25, 2020 release. We use Private Investment (line 1) for private sector and Non-Residential Private Investment (line 2) for Non-Real Estate/Non-FIRE investment.
   Total prices change is GDP deflator (line 1), NIPA Table 1.1.4. Price Indexes for Gross Domestic Product, June 25, 2020 release.

B.1.6 Fixed Assets

Capital stock by industry from Fixed Assets Table 3.1ESI. Current-Cost Net Stock of Private Fixed Assets by Industry, August 8, 2019 release.
   Investment by industry from Table 3.7ESI. Investment in Private Fixed Assets by Industry, August 8, 2019 release.
B.2 Financial Data

Price-Dividend ratio taken from Kenneth R. French’s data library: https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html

We use the 38 Industry Portfolio data.

B.3 Population

Non-institutionalized population, ages 16+, Census Bureau. FRED series CNP16OV.

C Value-added versus Gross-output Model

While we have estimated markups in a full-blown gross-output model that takes into account intersectoral input-output linkages, most of the literature on structural change abstracts from them and assumes that each sector produces value added. Such value-added models are popular because they are very tractable; see for example the canonical model in the review article of Herrendorf et al. (2014). In this appendix, we shall establish that using a value-added model would severely bias the estimates.

The value-added version of our model can be obtained as a special case of the gross-output version by setting $\alpha_{M_{jj}} = \alpha_{M_{jj}}' = 0$, $j, j' \in \{g, s\}$. To see the implications, we rewrite the first-order conditions (22)–(23) as:

\[
p_{G_j} M_{jjt} = \frac{\alpha_{M_{jj}}}{\mu_j} p_{G_j} G_{jt}, \quad (A.3)
\]

\[
p_{G_j'} M_{jj't} = \frac{\alpha_{M_{jj}}'}{\mu_j} p_{G_j'} G_{jt}'. \quad (A.4)
\]

Thus, $\alpha_{M_{jj}} = \alpha_{M_{jj}}' = 0$ implies that, in equilibrium, $M_{jjt} = M_{jj't} = 0$. Imposing symmetric equilibrium, equations (6)–(7) then simplify to:

\[
G_{jt} = Y_{jt} = V_{jt}.
\]

That is, if $\alpha_{M_{jj}} = \alpha_{M_{jj}}' = 0$, then sectoral gross output equals sectoral final output equals sectoral value added. In this case, the gross-output model reduces to the special case of the value-added model and so it is straightforward to obtain the relevant calibration equations for the value-added model.

The first three calibration steps are the same in the value-added model as in the gross-output model. In contrast, the fourth calibration step changes. Denoting value-added parameters by a
tilde, we have at the sectoral level:

\[
\tilde{\mu}_j = \frac{p_{V_j} V_j}{(\rho_j + \delta_j + \gamma_Q)p_K K_j + wL_j}, \tag{A.5}
\]

\[
\tilde{\alpha}_{Kj} = \frac{(\rho_j + \delta_j + \gamma_Q)p_K K_j}{wL_j}, \tag{A.6}
\]

\[
\tilde{\alpha}_{Lj} = \frac{wL_j}{(\rho_j + \delta_j + \gamma_Q)p_K K_j + wL_j}. \tag{A.7}
\]

At the aggregate level, the calibration of \(\tilde{\alpha}_K\) and \(\tilde{\alpha}_L\) remains unchanged whereas the calibration of \(\tilde{\mu}\) changes to:

\[
\tilde{\mu} = \frac{V}{(\rho + \delta + \gamma_Q)p_K K + wL}. \tag{A.8}
\]

Comparing the value-added markups with the gross-output markups from before, we obtain the following result:

**Proposition 3** The aggregate markups are the same in the value-added model and the gross-output model: \(\tilde{\mu} = \mu\). In contrast, if markups are positive, then the sectoral markups are larger in the value-added model than in the gross-output model: \(\tilde{\mu}_j > \mu_j\).

**Proof.** We start by showing that the aggregate markups are the same in the gross-output and value-added model. The result follows because, in a closed economy like ours, aggregate value added equals aggregate final output. The reason, of course, is that total intermediate inputs produced must equal total intermediate inputs used; see (12). Choosing final output as the numeraire, it thus follows:

\[
V_t = \sum_{j \in \{g, s\}} p_{V_j} V_{jt} = \sum_{j \neq f \in \{g, s\}} \left( p_{G_f} G_{jt} - p_{G_f} M_{jft} - p_{G_f} M_{jft} \right)
= \sum_{j \neq f \in \{g, s\}} p_{G_f} (G_{jt} - M_{jft} - M_{jft}) = \sum_{j \in \{g, s\}} p_{G_f} Y_{jt} \equiv Y_t.
\]

Thus,

\[
\tilde{\mu} = \frac{V}{(\rho + \delta + \gamma_Q)p_K K + wL} = \frac{Y}{(\rho + \delta + \gamma_Q)p_K K + wL} = \mu.
\]

We now turn to showing that sectoral markups are smaller in the gross-output model than in the value-added model. Starting with the gross-output model, we first substitute the first-order conditions (22)–(23) into (7):

\[
p_{V_j} V_{jt} = p_{G_f} G_{jt} \left( 1 - \frac{\alpha_{Mj} + \alpha_{Mj}}{\mu_j} \right). \tag{A.9}
\]
Sector $j$’s share of total value added is:

$$\frac{p_{V_j}}{V_t} = \frac{p_{G_j} G_{jt} \left(1 - \frac{\alpha_{M_j} + \alpha_{M_j}' j}{\mu_j}\right)}{\sum_{j=g,s} p_{G_j} G_{jt} \left(1 - \frac{\alpha_{M_j} + \alpha_{M_j}' j}{\mu_j}\right)}.$$

Since $p_{G_j} G_{jt} = \Phi_j Y_t$, this expression simplifies to:

$$\frac{p_{V_j}}{V_t} = \frac{\Phi_j \left(1 - \frac{\alpha_{M_j} + \alpha_{M_j}' j}{\mu_j}\right)}{\sum_{j=g,s} \Phi_j \left(1 - \frac{\alpha_{M_j} + \alpha_{M_j}' j}{\mu_j}\right)}.$$

In the value-added model, in contrast, $\tilde{\mu}_j$ is given by (A.5) from above. Using (A.9), we get:

$$\tilde{\mu}_j = \frac{p_{G_j} G_{jt} \left(1 - \frac{\alpha_{M_j} + \alpha_{M_j}' j}{\mu_j}\right)}{r_t K_{jt} + w_t L_{jt}}.$$

Using the first-order conditions (20)–(21) gives:

$$\tilde{\mu}_j = \frac{\mu_j}{\alpha_{K} + \alpha_{L}} \left(1 - \frac{\alpha_{M_j} + \alpha_{M_j}'}{\mu_j}\right).$$

Since $1 = \alpha_{K} + \alpha_{L} + \alpha_{M_j} + \alpha_{M_j}'$, we end up with:

$$\tilde{\mu}_j - \mu_j = (\tilde{\mu}_j - 1) \left(\alpha_{M_j} + \alpha_{M_j}'\right).$$

Thus, $\tilde{\mu}_j > \mu_j$, QED

The result that aggregate markups are the same is intuitive. Since at the aggregate level of a closed economy, intermediate inputs produced equal intermediate inputs used, final output equals total value added, $V = Y$, aggregate markups must be the same in both cases. The result that sectoral markups are larger in the value-added model is intuitive too. With value added, the aggregate markups result from firms marking up the payments to capital and labor once. With gross output, the aggregate markups result from firms marking up the payments to capital and labor once and the payments to intermediate goods twice. Since sectoral gross-output markups are applied twice to intermediate inputs, they must be smaller than value-added markups.

Table C.1 contains the quantitative results for the value-added calibration. The first observation is that, as expected, $\tilde{\alpha}_L = \alpha_L / (\alpha_K + \alpha_L)$; compare Table 3

Reassuringly, regarding markups, the result of the Table are consistent with the implications of Proposition 3. In particular, as in the gross-output model, aggregate markups went up by the 7 percentage points. Moreover, the levels of aggregate and sectoral markups roughly doubled. Different from the gross-output model, however, the levels of the sectoral markups are way
higher in the value-added model. For example, markups in the goods sector now go up all the way to 22\% whereas before they went up to only 8\%.

Our results show that the value-added model leads to a severe upward bias in the estimates of the sectoral markups, because it erroneously attributes the effect of double marginalization to sectoral markups. Our results have the important implication that the value-added model is fine for estimating aggregate markups, but the gross-output model with input-output linkages is essential for correctly estimating sectoral markups and how they aggregate to the economy-wide markups. This leads to an obvious tension with the literature on structural change, which typically employs versions of the value-added models; see Herrendorf et al. (2014) for a review. Although that is more tractable, our results show that employing value-added models can be very misleading in the presence of distortions (here the monopoly distortion that leads to markups).

We end the discussion by implementing the same decomposition as for gross output. To this end, note that (25) implies that without intermediate inputs, the Domar weights collapse into the final expenditure shares: $\Phi_{jt} = \tilde{\phi}_{jt}$. Substituting this into (30) gives the value added decomposition of the labor share:

$$w_t L_t \frac{Y_t}{Y} = \tilde{\phi}_g \tilde{\alpha}_{Lg} \tilde{\mu}_g + \tilde{\phi}_s \tilde{\alpha}_{Ls} \tilde{\mu}_s.$$  

(A.10)

Table A1 reports the results:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tilde{\phi}_g$</td>
<td>0.460</td>
<td>0.283</td>
<td>0.194</td>
</tr>
<tr>
<td>$\tilde{\alpha}_L$</td>
<td>0.794</td>
<td>0.777</td>
<td>0.787</td>
</tr>
<tr>
<td>$\tilde{\alpha}_{Lg}$</td>
<td>0.809</td>
<td>0.754</td>
<td>0.702</td>
</tr>
<tr>
<td>$\tilde{\alpha}_{Ls}$</td>
<td>0.789</td>
<td>0.789</td>
<td>0.812</td>
</tr>
<tr>
<td>$\tilde{\mu}$</td>
<td>1.072</td>
<td>1.097</td>
<td>1.137</td>
</tr>
<tr>
<td>$\tilde{\mu}_g$</td>
<td>1.108</td>
<td>1.138</td>
<td>1.222</td>
</tr>
<tr>
<td>$\tilde{\mu}_s$</td>
<td>1.046</td>
<td>1.071</td>
<td>1.107</td>
</tr>
</tbody>
</table>
Table A1: Decomposition of changes in aggregate labor share – top down

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>0.743</td>
<td>0.716</td>
<td>0.702</td>
</tr>
<tr>
<td>Constant</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\bar{\mu}_j$</td>
<td>0.743</td>
<td>0.733</td>
<td>0.749</td>
</tr>
<tr>
<td>$\bar{\alpha}_{L,j}$</td>
<td>0.743</td>
<td>0.729</td>
<td>0.703</td>
</tr>
<tr>
<td>$\bar{\phi}_j$</td>
<td>0.743</td>
<td>0.703</td>
<td>0.660</td>
</tr>
</tbody>
</table>