Markups, Input-Output Linkages, and Structural Change: Evidence from the National Accounts*

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January 23, 2021

Abstract

We examine aggregate and sectoral markups in the U.S. NIPA. Taking into account input-output linkages, we obtain the following results. Since the 1950s, aggregate markups have doubled and sectoral markups have at least doubled, but they are both smaller than what many micro estimates suggest. Moreover, double marginalization implies that sectoral markups are *much smaller* than aggregate markups, which worsens the puzzle why many micro estimates are so large. Lastly, changes in the sectoral composition ("structural change") reduced aggregate markups by two percentage points whereas changes in the input-output linkages ("outsourcing") increased aggregate markups by one percentage point.

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

JEL classification: D33; L4; O15.

*A previous 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, 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.

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1 Introduction

Increasing market power has been blamed for many adverse macroeconomic trends in the U.S. economy, including widening inequality, low investment rates, and low TFP.[1] Although a sizeable literature has developed, the evidence for increasing market power as a significant macroeconomic force is mixed. Some argue that it is [e.g., De Loecker et al. (2020)] whereas others disagree [e.g., Karabarbounis and Neiman (2018)]. The dividing line between the two views tends to depend on whether the estimates of market power are based on micro or macro data; microdata suggest larger increases and larger market power than macro data.

In this paper, we examine markup, the most common measure of market power, in the National Income and Product Accounts of U.S. since the 1950s. The NIPA are the ideal data source in our context, as they cover all market activity, respect the standard adding up constraints, and can be linked directly to macroeconomic indicators. Our question is whether the effects of aggregation help to reconcile the discrepancy between the micro and macro estimates. A promising possibility is that structural change reallocates economic activity towards parts of the economy with relatively low markups, thereby introducing an extensive margin that mitigates large markups at the disaggregate level. The obvious example in point is the goods sector, which has relatively high markups. Since the goods sector is shrinking over time, its high markups have a decreasing effect on the aggregate markups.

To assess the quantitative importance of the extensive margin for aggregate markups, it is essential to take into account the input-output linkages among the different sectors and how they change ("outsourcing"). Input-output linkages lead to double marginalization, that is, intermediate inputs are marked up when they are produced and when they are used [Rotemberg and Woodford (1995) and Basu and Fernald (2002)]. Double marginalization is more potent the higher are the intermediate-input shares of the industries with high markups. The obvious example in point again is the goods sector, which does not only have large markups but also a large intermediate-inputs share. The effect of double marginalization also has a time-series dimension. Outsourcing increases the intermediate-input share, which in turn increases the importance of double marginalization.[2]

We develop a framework that takes into account the effects on aggregate markups of the sectoral composition, the input-output linkages, and the extensive margin resulting from their changes. In contrast, obtaining aggregate markups by averaging over the micro estimates ignores the extensive margin. We disaggregate the economy into the goods and services sectors.

[1] Baker and Salop (2015) and Khan and Vaheesan (2017) talked about inequality, Gutierrez and Philippon (2017) and Gonzalez and Mathy (2017) about low investment, and Baqaee and Farhi (2018) about low TFP. A large literature examining the implications of increasing market power has developed; see for example Eggertsson et al. (2018), Gutierrez (2017), and Barkai (2020). Basu (2019) offers an excellent review of the literature.

[2] Giannoni and Mertens (2019) noted before us that outsourcing amplifies sectoral markups, but they did not quantify the effects of outsourcing on aggregate markups.

This is the simplest sector split that has been used in the literature on structural change because it is tractable while capturing the essence of structural change in developed countries like the U.S. We note that our analysis could be generalized to finer industry splits.

We find the following headline results. Since the 1950s, aggregate markups have doubled but they fall way short of what the micro studies tend to suggest. Sectoral markups have doubled in the goods sector and have more than doubled in the services sector. Nonetheless, they are much *smaller* than aggregate markups because the amplification through double marginalization turns out to be very large quantitatively. The existing micro studies miss the amplification when they calculate aggregate markups as averages of firm or industry markups. Lastly, while structural change did reduce aggregate markups by two percentage points, outsourcing increased aggregate markups by one percentage point. Overall, our findings *worsen* the puzzle why the micro estimates are so much larger than the macro estimates. Sectoral markups are much *smaller*, instead of much larger, than aggregate markups and the mitigating effect of structural change on sectoral markups is partly offset by the amplifying effect on sectoral markups of outsourcing.

Turning to the nuts and bolts of our analysis, we start by clarifying how we obtain markups from NIPA data. While it is straightforward to calculate the incomes accruing to labor and intermediate inputs, the remaining revenue represents the sum of the income accruing to capital and pure profits, neither of which is directly observed. A natural approach is to calculate the payments to capital as the product of the capital stock, which is reported in NIPA, and the user cost of capital, which are not reported in NIPA. Two recent papers took this approach. Barkai (2020) calculated the aggregate user costs of capital by adding technological depreciation and economic depreciation (i.e., price declines 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. Here, we adopt the approach of Farhi and Gourio (2018) because it has two advantages in our context. First, it leads to a measure of the user costs of capital that naturally includes the unobservable premia for different forms of risk. Second, it can be extended back to the 1950s whereas the data for Barkai's approach become available only in the 1980s. Having a relatively long time series is essential for assessing the quantitative importance of the extensive margin on aggregate markups.

To quantify the effects of the extensive margin on aggregate markups, we develop a two-sector version of the growth model developed by Farhi and Gourio (2018). Like their model, our version features disaster risk, which leads to a risk premium, and monopolistic competition, which leads to markups. Moreover, aggregate markups equal the ratio of final output divided by the payments to the production factors capital and labor. Unlike their model, our version captures the extensive margin, that is, how the sectoral composition and the input-output linkages affect the aggregation of sectoral to aggregate markups. In particular, our version has three new features: there are two sectors that produce gross output of goods and services; there are input-output linkages between the two sectors, which leads to double marginalization; disaster risk and markups are both sector specific. Sectoral mark ups equal the ratio of sectoral gross output divided by the payments to capital, labor, and intermediate inputs.

We connect our model to the private U.S. economy during 1957–1973, 1984–2000, and 2001–2016. By private U.S. economy we mean the entire economy except for the government and real estate. We leave real estate out because it showed very unusual trends that are partly driven by land not included in NIPA capital [Rognlie (2015) and Gutierrez and Philippon (2017)]. Moreover, it has a large imputed part – owner-occupied housing. The periods 1984–2000 and 2001–2016 are as in Farhi and Gourio (2018) and capture that around 2000 several trends changed. We also consider the initial period 1957–1973, which begins after the postwar boom and ends before the first oil price shock. We follow Farhi and Gourio (2018) in assuming that each of the three periods represents a balanced growth path equilibrium with possibly different sectoral compositions, disaster risks, monopoly powers, and degrees of outsourcing. Proceeding in this way allows us to obtain analytical solutions for the key macro statistics of the model, which are straightforward to connect to the data.

We find that since the 1950s aggregate markups doubled from 7% to 14%, suggesting a considerably increase in market power. Moreover, since the 1980s, aggregate markups increased by 40% from 10% to 14%, which is broadly in line with recent macro results of Farhi and Gourio (2018) and Barkai (2020). Although aggregate markups of 14% are much lower than what the micro studies tend to find, our calibration method ensures that they are consistent with the stylized facts and macro trends of the U.S. economy. A simple back-of-the-envelope calculation illustrates this. Suppose that labor payments are 60% of GDP, depreciation is 5% of the capital stock, the net return on capital is 4%, and the capital-output ratio is 3.[3] Total payments to capital then equal $27\% = 3(0.05 + 0.04)100\%$ of GDP, which leaves $13\% = (100 - 60 - 27)\%$ for pure profits and implies that the aggregate markup equal $15\% = (13/87)100\%$. 15% is within one percentage point of what we find for our last sample period. The back-of-the-envelope calculation implies that much larger aggregate markups than what we find would violate the economy-wide adding up constraint; if 75% of GDP are paid out as compensation for labor and depreciation, then there are only 25% of GDP left to cover the user costs of capital and pure profits. The extreme case of zero user costs of capital gives us a very loose upper bound for aggregate markups that is consistent with NIPA data: $30\% = 25/75\%$. In other words, it is hard to how micro estimates in excess of 30% could reflect aggregate markups.[4]

We find that sectoral markups have at least doubled since the 1950s. In particular, the

[3] We are aware that these numbers change somewhat when one excludes real estate but use them anyways for illustrative purposes.

[4] Note that our approach interprets the entire residual after the payments to capital and labor as profits. Karabarbounis and Neiman (2018) took a more agnostic view that the residual is "factorless income" and discussed what could be included in it. But they still found that aggregate markups are not as large as the micro estimates suggest.

sectoral markups went up from 1.04 to 1.08 in the goods sector and 1.03 to 1.07 in the services sector. Interestingly, the levels of the sectoral markups are much *smaller* than of aggregate markups. The discrepancy between sectoral and aggregate markups is due to the quantitatively large effects of double marginalization, which are driven by quantitatively large intermediate-input shares. For example, in the 2000–2016 period, the intermediate-input shares in sectoral gross output were 60% in the goods sector and 40% in the services sector.

Lastly, we find that changes in the sectoral composition and in the input-output linkages importantly affected the aggregation of sectoral markups to aggregate markups. In particular, structural change reduced aggregate markups by two percentage points because it reallocated resources to the services sector that has a lower markup and a lower intermediate-input share than the goods sector. In contrast, outsourcing increased aggregate markups by one percentage point because it generated additional double marginalization in the services sector.

We stress that taking into account the input-output linkages between the sectors is essential for our findings. This becomes obvious when we consider the special case of our model without intermediate inputs. Since the sectors then produce value added instead of gross output, we call the special case the value-added model. We establish that the value-added model erroneously attributes to sectoral markups the effect of double marginalization on aggregate markups. Therefore, it concludes that the sectoral markups must be much higher than they really are. Interestingly, however, the estimates of aggregate markups are the same irrespective of whether or not we take the input-output linkages into account. The reason is that, on the aggregate level of a closed economy, total final output equals total value added because intermediate inputs produced equal intermediate inputs used. We conclude that while the value-added model is suitable for estimating *aggregate* markups, employing the gross-output model with input-output linkages is essential for correctly estimating *sectoral* markups.

We conclude with a road map for the rest of the paper. Section 2 lays out the model and Section 3 characterizes the balanced-growth-path equilibrium. Section 4 connects the model to the data and presents our results. Sections 5 and 6 discuss our results and the related literature. Section 7 concludes. An Appendix contains longer derivations and a data description.

2 Model

2.1 Environment

In this section, we develop a multi-sector version of the model of Farhi and Gourio in which rare disaster risk gives rise to a risk premium. 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 this "double marginalization" is crucial for correctly estimating sectoral markups.

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:

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

$\beta \in (0,1)$ 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:

$$Y_t = Y_{gt}^{\phi_g} Y_{st}^{\phi_s}. \tag{2}$$

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:

$$Y_{jt} = \left(\int_0^1 (Y_{j_it})^{\frac{\varepsilon_j - 1}{\varepsilon_j}} di\right)^{\frac{\varepsilon_j}{\varepsilon_j - 1}} \qquad (j \in \{g, s\}), \tag{3}$$

where Y_{j_it} is the quantity of variety $i \in [0,1]$ used in sector $j \in \{g, s\}$; ε_j is the sector-specific elasticity of substitution, which will give rise to sector-specific markups.

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

$$G_{j_it} = Z_{jt}\left(K_{j_it}\right)^{\alpha_{K_j}}\left(A_{jt}L_{j_it}\right)^{\alpha_{L_j}}\left(M_{jj_it}\right)^{\alpha_{M_{jj}}}\left(M_{j'j_it}\right)^{\alpha_{M_{j'j}}} \qquad (j \neq j' \in \{g, s\},\ i \in [0,1]). \tag{4}$$

G_{j_it} is gross output; K_{j_it} and L_{j_it} are capital and labor; M_{jj_it}, $M_{j'j_it}$ are intermediate inputs produced in sectors j, j' and used in the production of variety j_i; $\alpha_{K_j}, \alpha_{L_j}, \alpha_{M_{jj}}, \alpha_{M_{j'j}}$ are the sector-specific output elasticities that add up to one. Z_{jt} is sector-specific, deterministic TFP; A_{jt} is sector-specific technical change, which evolves according to a random walk:

$$A_{j,t+1} = A_{jt}\exp(\chi_{j,t+1}) \qquad (j \in \{g, s\}). \tag{5}$$

$\chi_{j,t+1}$ 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 materialize only occasionally.[5]

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

$$G_{j_it} = Y_{j_it} + M_{j_ijt} + M_{j_ij't} \qquad (j \in \{g, s\}). \tag{6}$$

M_{j_ijt} and $M_{j_ij't}$ 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:

$$p_{V_{j_it}} V_{j_it} = p_{G_{j_it}} G_{j_it} - p_{G_{jt}} M_{jj_it} - p_{G_{j't}} M_{j'j_it} \qquad (j \neq j' \in \{g, s\}), \tag{7}$$

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

Capital is sector specific and accumulates according to:

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

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 when there is 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 after a rare disaster shock, which permits an analytical solution for the equilibrium path.

(8) implies that sectoral investment is described by:

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

Looking ahead to the equilibrium, Q_t^{-1} will be the price of capital relative to final goods. Therefore, $Q_t^{-1} K_{jt}$ is the capital stock in units of the numeraire final good. In the national accounts, $Q_t^{-1} K_{jt}$ is called the capital stock evaluated at current cost or the capital stock evaluated at replacement costs.

[5]Note that to be comparable with Farhi and Gourio (2018), we have followed them and written the production function such that Z_{jt} is sectoral TFP whereas A_{jt} is labor-augmenting technical change. Of course, given that the Cobb-Douglas functional form, it could be rewritten so that Z_{jt} adds to sectoral labor-augmenting technical change or A_{jt} adds to sectoral TFP.

Feasibility requires the usual adding up constraints:

$$K_{jt} = \int_0^1 K_{j_it} di \qquad (j \in \{g, s\}), \tag{10}$$

$$1 = L_t = \sum_{j \in \{g,s\}} \int_0^1 L_{j_it} di, \tag{11}$$

$$M_{j'jt} \equiv \int_0^1 M_{j'j_it} di \qquad (j', j \in \{g, s\}), \tag{12}$$

$$Y_t = C_t + \sum_{j \in \{g,s\}} X_{jt}, \tag{13}$$

$$G_{jt} = Y_{jt} + \sum_{j' \in \{g,s\}} \int_0^1 M_{j'j_it} di \qquad (j' \in \{g, s\}), \tag{14}$$

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

$$\begin{aligned} Q_{t+1} &= Q_t(1 + \gamma_Q), \\ Z_{j,t+1} &= Z_{jt}(1 + \gamma_{Z_j}) \qquad (j \in \{g, s\}). \end{aligned}$$

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

Since it should be obvious by now that the indexes $j, j' \in \{g, s\}$, we will not explicitly mention it anymore 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 profit maximization gives:

$$\max_{\{Y_{gt}, Y_{st}\}} Y_{gt}^{\phi_g} Y_{st}^{\phi_s} - P_{gt} Y_{gt} - P_{st} Y_{st},$$

where the final good is the numeraire. The first-order conditions imply the usual Cobb-Douglas result that the demands for goods and services are constant shares of output:

$$\frac{p_{G_{jt}} Y_{jt}}{Y_t} = \phi_j. \tag{15}$$

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

$$\max_{\{Y_{j_i t}\}_{i\in[0,1]}} p_{G_{jt}} \left(\int_0^1 (Y_{j_i t})^{\frac{\varepsilon_j - 1}{\varepsilon_j}} di \right)^{\frac{\varepsilon_j}{\varepsilon_j - 1}} - \int_0^1 p_{G_{j_i t}} Y_{j_i t} di.$$

The first-order condition implies a demand function for each variety:

$$Y_{j_i t} = Y_{jt} \left(\frac{p_{G_{j_i t}}}{p_{G_{jt}}} \right)^{-\varepsilon_j}. \tag{16}$$

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 its variety, (16). Taking r_{jt}, w_t, $p_{G_{jt}}$, $p_{G_{j't}}$ as given, profit maximization gives:

$$\max_{\{G_{j_i t}, K_{j_i t}, L_{j_i t}, M_{j j_i t}, M_{j' j_i t}\}} p_{G_{j_i t}} G_{j_i t} - r_{jt} K_{j_i t} - w_t L_{j_i t} - p_{G_{jt}} M_{j j_i t} - p_{G_{j' t}} M_{j' j_i t} \quad \text{s.t.} \quad (4),\ (16).$$

The first-order conditions imply that the payments to the production factors include a mark up over the rental prices. We denote the (gross) markup of price of marginal costs by:

$$\mu_j \equiv \frac{\varepsilon_j - 1}{\varepsilon_j}.$$

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

$$\frac{\alpha_{K_j} p_{G_{jt}} G_{jt}}{K_{jt}} = \mu_j r_{jt}, \tag{17}$$

$$\frac{\alpha_{L_j} p_{G_{jt}} G_{jt}}{L_{jt}} = \mu_j w_t, \tag{18}$$

$$\frac{\alpha_{M_{jj}} p_{G_{jt}} G_{jt}}{M_{jjt}} = \mu_j p_{G_{jt}}, \tag{19}$$

$$\frac{\alpha_{M_{j'j}} p_{G_{jt}} G_{jt}}{M_{j'jt}} = \mu_j p_{G_{j't}}. \tag{20}$$

Combining the first order conditions with the input-output linkages, we can show that sectoral gross output is proportional to aggregate final output.

Proposition 1 *$p_{jt} G_{jt}$ is proportional to Y_t:*

$$p_{G_{jt}} G_{jt} = \Phi_j Y_t \qquad \textit{where} \qquad \Phi_j \equiv \frac{\left(1 - \frac{\alpha_{M_{j'j'}}}{\mu_{j'}}\right)\phi_j + \frac{\alpha_{M_{jj'}}}{\mu_{j'}}\phi_{j'}}{\left(1 - \frac{\alpha_{M_{jj}}}{\mu_j}\right)\left(1 - \frac{\alpha_{M_{j'j'}}}{\mu_{j'}}\right) - \frac{\alpha_{M_{jj'}}}{\mu_{j'}}\frac{\alpha_{M_{j'j}}}{\mu_j}}. \tag{21}$$

Proof. See Appendix A.1.

Note that (15) and (21) imply that, in equilibrium, sectoral gross and final output are proportional to each other as well:

$$\frac{G_{jt}}{Y_{jt}} = \frac{p_{G_{jt}} G_{jt}}{p_{G_{jt}} Y_{jt}} = \frac{\Phi_j Y_t}{\phi_j Y_t} = \frac{\Phi_j}{\phi_j} \qquad \Longrightarrow \qquad G_{jt} = \frac{\Phi_j}{\phi_j} Y_{jt}. \tag{22}$$

Next, we characterize the equilibrium labor allocation. (18) determines the sectoral labor share in gross output:

$$\frac{w_t L_{jt}}{p_{G_{jt}} G_{jt}} = \frac{\alpha_{L_j}}{\mu_j}. \tag{23}$$

Substituting (21) into (23) gives:

$$\frac{w_t L_{jt}}{\Phi_j Y_t} = \frac{\alpha_{L_j}}{\mu_j}.$$

Thus, the ratios of sectoral labor are constant and sectoral labor is proportional to aggregate labor:

$$L_{jt} = \omega_{L_j} L = \omega_{L_j}. \tag{24}$$

2.3 Household problem

The household problem is:[6]

$$\begin{aligned} \max_{C_t, \{X_{jt}, K_{jt+1}\}_{j \in \{g,s\}}} \quad & U_t = \left((1-\beta) C_t^{1-\sigma} + \beta \left[E_t \left(U_{t+1}^{1-\theta} \right) \right]^{\frac{1-\sigma}{1-\theta}} \right)^{\frac{1}{1-\sigma}} \\ \text{s.t.} \quad & (9), \quad C_t + X_{gt} + X_{st} = r_{gt} K_{gt} + r_{st} K_{st} + w_t. \end{aligned} \tag{25}$$

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

$$1 = E_t \left(D_{t+1} R_{t+1} \right), \tag{26}$$

[6]Note 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.

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

$$D_{t+1} \equiv \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \left[\frac{U_{t+1}}{\left[E_t \left(U_{t+1}^{1-\theta} \right) \right]^{\frac{1}{1-\theta}}} \right]^{\sigma-\theta}, \tag{27}$$

$$R_{jt+1} \equiv \left(1 - \delta_j + r_{jt+1} Q_{t+1} \right) \frac{Q_t}{Q_{t+1}} \exp(\chi_{jt+1}). \tag{28}$$

We emphasize that the stochastic discount factor does not only depend on the usual components β, C_{t+1}/C_t, and σ but also on the underlying risk and the degree of risk aversion θ. In the calibration that follows below, we will not separately identify the different components because it is not required for obtaining mark ups. 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, the model will have 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 occasional, unexpected level shifts of the trend. Put differently, growth along the RBGP comprises both a deterministic trend and a 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 ρ_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_{gt}/p_{st}, $\{G_{jt}, Y_{jt}, K_{jt}, X_{jt}, M_{jjt}, M_{jj't}\}_{j,j' \in \{g,s\}}$ *grow at constant expected rates;*
- $\{L_{jt}\}_{j \in \{g,s\}}$, ρ_{jt}, r_{jt}/p_{K_t} *are constant.*

In the rest of this section, we construct a RBGP.

3.2 Sectoral and aggregate capital

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

$$1 = E_t\Big(D_{t+1}R_{jt+1}\Big) = E_t\Big(D_{t+1}\exp(\chi_{j,t+1})\Big)\frac{1-\delta_j + r_{jt+1}/p_{K_{t+1}}}{1+\gamma_Q}.$$

We define the expected discount rate ρ_j as:

$$\rho_j \equiv \frac{1}{E_t\Big(D_{t+1}\exp(\chi_{j,t+1})\Big)} - 1.$$

Substituting the definition into the previous equation and rearranging gives:

$$1+\rho_j = \frac{1-\delta_j + r_{jt+1}/p_{K_{t+1}}}{1+\gamma_Q}. \tag{29}$$

We continue with capital along RBGP. Substituting (17) into (29), along the RBGP:

$$1+\rho_j = \frac{1-\delta_j}{1+\gamma_Q} + \frac{\alpha_{K_j}}{\mu_j(1+\gamma_Q)}\frac{p_{G_{jt+1}}G_{jt+1}}{p_{K_{t+1}}K_{jt+1}}. \tag{30}$$

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

$$\frac{p_{K_{t+1}}K_{jt+1}}{p_{G_{jt+1}}G_{jt+1}} = \frac{\alpha_{K_j}}{\mu_j(\rho_j+\delta_j+\gamma_Q)}. \tag{31}$$

Next, we show that capital is allocated to the sectors in fixed proportions. To this end, substitute (21) into (31) and rearrange:

$$p_{K_{t+1}}K_{jt+1} = \frac{\alpha_{K_j}\Phi_j}{\mu_j(\rho_j+\delta_j+\gamma_Q)}Y_{t+1}. \tag{32}$$

Therefore, $K_{jt}/K_{j't}$ is constant and:

$$K_{jt} = \omega_{K_j}K_t. \tag{33}$$

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 (21) and (33) into (30):

$$1+\rho_j = \frac{1-\delta_j}{1+\gamma_Q} + \frac{\alpha_{K_j}}{\mu_j(1+\gamma_Q)}\frac{\Phi_j Y_{t+1}}{\omega_{K_j}p_{K_{t+1}}K_{t+1}}. \tag{34}$$

Multiplying the last equation with ω_{K_j} and adding up implies that the aggregate capital-final-output ratio is constant too along the RBGP:

$$1 + \rho = \frac{1 - \delta}{1 + \gamma_Q} + \frac{\alpha_K}{\mu(1 + \gamma_Q)} \frac{Y_{t+1}}{p_{K_{t+1}} K_{t+1}}, \tag{35}$$

where:

$$\rho \equiv \sum_{j \in \{g,s\}} \omega_{K_j} \rho_j, \tag{36}$$

$$\delta \equiv \sum_{j \in \{g,s\}} \omega_{K_j} \delta_j, \tag{37}$$

$$\frac{\alpha_K}{\mu} \equiv \frac{\Phi_g \alpha_{K_g}}{\mu_g} + \frac{\Phi_s \alpha_{K_s}}{\mu_s}. \tag{38}$$

(35) implies an aggregate version of (31) that determines the ratio of capital in current prices to final output:

$$\frac{p_{K_{t+1}} K_{t+1}}{Y_{t+1}} = \frac{\alpha_K}{\mu(\rho + \delta + \gamma_Q)}. \tag{39}$$

Two remarks are at order. First, rewriting (38), we can see that the aggregate markup is a weighted harmonic mean of the sectoral markups:

$$\frac{1}{\mu} = \frac{\Phi_g \alpha_{K_g}}{\alpha_K} \frac{1}{\mu_g} + \frac{\Phi_s \alpha_{K_s}}{\alpha_K} \frac{1}{\mu_s}.$$

Second, (38) determines α_K/μ but not α_K and μ individually. We will solve out for α_K below. It is important to realize that $\alpha_K \neq \sum_{j=g,s} \Phi_j \alpha_{K_j}$ and the weights don't add up to one. The reason for this, of course, is that the sectoral markups are amplified by the input-output linkages.

3.4 Trend growth

To calculate the trend growth rates for output, capital, and intermediate inputs, it is helpful to first establish that the sectoral Cobb-Douglas production functions aggregate along the RBGP:

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

$$Y_t = \Omega Z_t K_t^{\alpha_K} A_t^{\alpha_L}. \tag{40}$$

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

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

$$Z_t \equiv \left[Z_{gt}^{\left(1-\alpha_{M_{ss}}\right)\phi_g+\alpha_{M_{gs}}\phi_s} Z_{st}^{\left(1-\alpha_{M_{gg}}\right)\phi_s+\alpha_{M_{sg}}\phi_g}\right]^{\frac{1}{\left(1-\alpha_{M_{gg}}\right)\left(1-\alpha_{M_{ss}}\right)-\alpha_{M_{gs}}\alpha_{M_{sg}}}},$$

$$A_t \equiv \left[A_{gt}^{\alpha_{L_g}\left(1-\alpha_{M_{ss}}+\alpha_{M_{gs}}\right)} A_{st}^{\alpha_{L_s}\left(1-\alpha_{M_{gg}}+\alpha_{M_{sg}}\right)}\right]^{\frac{1}{\left[\left(1-\alpha_{M_{gg}}\right)\left(1-\alpha_{M_{ss}}\right)-\alpha_{M_{gs}}\alpha_{M_{sg}}\right]\alpha_L}}.$$

Proof. See Appendix A.3.

The aggregate Cobb-Douglas production function (40) implies that there is an aggregate first-order condition for labor of the usual Cobb-Douglas form:

$$\frac{w_t L_t}{Y_t} = \frac{\alpha_L}{\mu}. \tag{41}$$

Turning now to the growth rates along the RBGP, the aggregate Euler equation (35) implies that $Y_{t+1}/(p_{K_{t+1}}K_{t+1})$ is constant. Using (40), 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:

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

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

$$p_{K_{t+1}}K_{t+1} = T_{t+1}A_{t+1}k^* \qquad \text{where} \qquad T_{t+1} \equiv Z_{t+1}^{\frac{1}{\alpha_L}}Q_{t+1}^{\frac{\alpha_K}{\alpha_L}}, \tag{42}$$

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, γ_T, is constant along the RBGP. Note too that (33) 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 (35) 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 γ_T and:

$$Y_t = T_t A_t y^*, \tag{43}$$

$$y^* \equiv (k^*)^{\alpha_K}. \tag{44}$$

We finish with the remaining growth rates. (15) and (21) imply that

$$\gamma_{p_{G_j}} + \gamma_{G_j} = \gamma_{p_{G_j}} + \gamma_{Y_j} = \gamma_T.$$

Thus, $\gamma_{Y_j} = \gamma_{G_j}$. Moreover, (19) and (20) imply that:

$$M_{jjt} = \frac{\alpha_{M_{jj}}}{\mu_j} G_{jt} \qquad \Longrightarrow \qquad \gamma_{M_{jj}} = \gamma_{G_j}, \tag{45}$$

$$M_{j'jt} = \frac{\alpha_{M_{j'j}}}{\mu_j} \frac{p_{G_{jt}} G_{jt}}{p_{G_{j't}} G_{j't}} G_{j't} = \frac{\alpha_{M_{j'j}}}{\mu_j} \frac{\phi_j}{\phi_{j'}} G_{j't} \qquad \Longrightarrow \qquad \gamma_{M_{j'j}} = \gamma_{G_{j'}}. \tag{46}$$

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

$$\gamma_{G_g} = \gamma_{Z_g} + \alpha_{K_g}\gamma_K + \alpha_{M_{gg}}\gamma_{G_g} + \alpha_{M_{sg}}\gamma_{G_s}. \tag{47}$$

$$\gamma_{G_s} = \gamma_{Z_s} + \alpha_{K_s}\gamma_K + \alpha_{M_{ss}}\gamma_{G_s} + \alpha_{M_{gs}}\gamma_{G_g}. \tag{48}$$

These two equations have a unique solution for $\{\gamma_{G_j}\}_{j\in\{g,s\}}$ in terms of exogenous variables and γ_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:

$$\frac{X_{jt}}{p_{K_t} K_{jt}} = \gamma_T + \delta_j + \gamma_Q. \tag{49}$$

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

Equation (49) aggregates:

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

Thus, in current prices the aggregate-investment-to-capital ratio is given by the aggregate version of (49):

$$\frac{X_t}{p_{K_t} K_t} = \gamma_T + \delta + \gamma_Q. \tag{50}$$

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 Π_{jt+1}, the standard recursion implies:

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

Along the RBGP, the first-order conditions (17)–(20) imply that dividends are given as:

$$\Pi_{jt} = \frac{\mu_j - 1}{\mu_j} p_{G_{jt}} G_{jt}.$$

Moreover, expected dividends are given as:

$$\begin{aligned}
E_t\Pi_{jt+i} &= \frac{\mu_j - 1}{\mu_j} E_t\left(p_{G_{jt+i}} G_{jt+i}\right) \\
&= E_t\left(\frac{\mu_j - 1}{\mu_j}(1 + \gamma_{P_{G_{t+i}}G_{t+i}}) \cdot \ldots \cdot (1 + \gamma_{P_{G_{t+1}}G_{t+1}}) p_{G_{jt}} G_{jt}\right) \\
&= (1 + \gamma_T)^i \Pi_{jt}.
\end{aligned}$$

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

$$p_{F_{jt}} = \Pi_{jt} \sum_{i=1}^{\infty} \left(\frac{1 + \gamma_T}{1 + \rho_j}\right)^i \qquad \Longrightarrow \qquad \frac{p_{F_{jt}}}{\Pi_{jt}} = \frac{1 + \gamma_T}{\rho_j - \gamma_T}. \tag{51}$$

We will use that relationship to calibrate the expected sectoral discount rate ρ_j.

The previous relationships aggregate:

$$\Pi_t \equiv \sum_{j=g,s} \omega_{K_j} \Pi_{jt}, \tag{52}$$

$$\frac{1}{p_{F_t}} \equiv \sum_{j=g,s} \frac{\omega_{K_j}\Pi_{jt}}{\Pi_t} \frac{1}{p_{F_{jt}}}, \tag{53}$$

$$\frac{p_{F_t}}{\Pi_t} = \frac{1 + \gamma_T}{\rho - \gamma_T}. \tag{54}$$

4 Quantitative Analysis

We follow Farhi and Gourio (2018) and assume that in different subperiods the economy is on different RBGPs. We consider their periods 1984–2000 and 2001–2016, which will capture that around 2000 several trends changed. We also consider 1957–1973 as the initial period. The choices of 1957 and 1973 as the initial and final year avoids the postwar boom and the decade after the first oil price shock. The advantage of focusing on different RBGPs is that it allows us to solve analytically for the parameter values including markups. The resulting formulas will be straightforward to connect to the data. The disadvantage is that we will only capture the effects of structural change and outsourcing *across* the subperiods, but not *within* the subperiods. Their effect would be stronger if one could solve the model annually. Thus, our findings will be a lower bound for the effects of structural change and outsourcing.

4.1 Calibration strategy

There are four main calibration steps. First, we calibrate γ_T as the expected trend growth of aggregate final output.

We continue with the next three steps for the calibration at the sectoral level. Second, given γ_T, we calculate $\delta_j + \gamma_Q$ from the investment-capital ratio (49):

$$\delta_j + \gamma_Q = \frac{X_j}{p_K K_j} - \gamma_T.$$

Third, given γ_T, we calculate ρ_j from the Gordon growth formula (51):

$$\rho_j = \gamma_T + \frac{(1+\gamma_T)\Pi_j}{p_{F_j}}. \tag{55}$$

Fourth, given $\rho_j + \delta_j + \gamma_Q$, we calculate μ_j and α_j for each of the two sectors from the first-order conditions (18)–(20) and the capital-gross-output ratio (31):

$$\frac{(\rho_j + \delta_j + \gamma_Q) p_K K_j}{p_{G_j} G_j} = \frac{\alpha_{K_j}}{\mu_j}, \tag{56}$$

$$\frac{w L_j}{p_{G_j} G_j} = \frac{\alpha_{L_j}}{\mu_j}, \tag{57}$$

$$\frac{p_{G_j} M_{jj}}{p_{G_j} G_j} = \frac{\alpha_{M_{jj}}}{\mu_j}, \tag{58}$$

$$\frac{p_{G_{j'}} M_{j'j}}{p_{G_j} G_j} = \frac{\alpha_{M_{j'j}}}{\mu_j}. \tag{59}$$

Imposing that $\alpha_{K_j} + \alpha_{L_j} + \alpha_{M_{jj}} + \alpha_{M_{j'j}} = 1$, we can solve for μ_j:

$$\mu_j = \frac{p_{G_j} G_j}{(\rho_j + \delta_j + \gamma_Q) p_K K_j + w L_j + p_{G_j} M_{jj} + p_{G_{j'}} M_{j'j}}.$$

The markup in sector j equals the value of output in the sector 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 (60) can be restated as:

$$\mu_j = \frac{1}{\frac{(\rho_j+\delta_j+\gamma_Q)p_K K_j}{p_{G_j}G_j} + \frac{wL_j}{p_{G_j}G_j} + \frac{p_{G_j}M_{jj}}{p_{G_j}G_j} + \frac{p_{G_{j'}}M_{j'j}}{p_{G_j}G_j}}. \tag{60}$$

To calculate α_{K_j}, α_{L_j}, $\alpha_{M_{jj}}$, and $\alpha_{M_{j'j}}$, we substitute μ_j into (56)–(59).

$$\alpha_{K_j} = \frac{(\rho_j + \delta_j + \gamma_Q)p_K K_j}{(\rho_j + \delta_j + \gamma_Q)p_K K_j + wL_j + p_{G_j}M_{jj} + p_{G_{j'}}M_{j'j}}, \tag{61}$$

$$\alpha_{L_j} = \frac{wL_j}{(\rho_j + \delta_j + \gamma_Q)p_K K_j + wL_j + p_{G_j}M_{jj} + p_{G_{j'}}M_{j'j}}, \tag{62}$$

$$\alpha_{M_{jj}} = \frac{p_{G_j}M_{jj}}{(\rho_j + \delta_j + \gamma_Q)p_K K_j + wL_j + p_{G_j}M_{jj} + p_{G_{j'}}M_{j'j}}, \tag{63}$$

$$\alpha_{M_{j'j}} = \frac{p_{G_{j'}}M_{j'j}}{(\rho_j + \delta_j + \gamma_Q)p_K K_j + wL_j + p_{G_j}M_{jj} + p_{G_{j'}}M_{j'j}}. \tag{64}$$

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

It is worth stressing 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, δ_j, and what part is economic, γ_Q. Instead, just the sum matters. It is also worth stressing that the sum equals:

$$\rho_j + \delta_j + \gamma_Q = \frac{(1 + \gamma_T)\Pi_j}{p_{F_j}} + \frac{X_j}{p_K K_j}. \tag{65}$$

The values of Π_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 γ_T is small, its exact value is not of first-order importance.

The aggregate calibration proceeds along the same lines as the sectoral calibration. In the second step, given γ_T, we calculate the aggregate depreciation rate $\delta + \gamma_Q$ from the aggregate investment-capital ratio (50):

$$\delta + \gamma_Q = \frac{X}{p_K K} - \gamma_T.$$

Third, given γ_T, we calculate aggregate ρ from the aggregate Gordon growth formula (54):

$$\rho = \gamma_T + \frac{(1+\gamma_T)\Pi}{p_F},$$

where p_F and Π are calculated according to (52)–(53). Fourth, given $\rho + \delta + \gamma_Q$, solving (39) and (41) for the aggregate markup and output elasticities while using that $\alpha_K + \alpha_L = 1$ gives:

$$\mu = \frac{Y}{(\rho+\delta+\gamma_Q)p_K K + wL}, \tag{66}$$

$$\alpha_K = \frac{(\rho+\delta+\gamma_Q)p_K K}{(\rho+\delta+\gamma_Q)p_K K + wL}, \tag{67}$$

$$\alpha_L = \frac{wL}{(\rho+\delta+\gamma_Q)p_K K + wL}. \tag{68}$$

Recalling that the price of final output was normalized to one, the aggregate markup equals the value of final output divided by the aggregate factor payments. The aggregate output elasticities of capital and labor equal the cost shares of aggregate capital and labor. The aggregate results have are close relatives of the sectoral results.

4.2 Data

We focus on the private sector without real estate, which is as in Karabarbounis and Neiman (2018), Barkai (2020), and De Loecker et al. (2020). The rationale for excluding real estate from the analysis is that it looks unusual [Rognlie (2015) and Gutierrez and Philippon (2017)]. A first reason for this is that it is a largely imputed sector, given that owner-occupied housing is not part of market activity. In addition, the NIPA do not include land as part of the capital stock. Land is an important input into producing real estate services, and its scarcity has importantly contributed to price increases of real estate [Rognlie (2015)]. Therefore, omitting land from the capital stock tends to artificially inflate markups in real estate.

If not mentioned otherwise, the data for the calibration are taken from the U.S. NIPA and the input-output tables. Appendix B contains a detailed data documentation. 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 our calibration will capture how sectoral markups aggregate.

Table 1 summarizes the key observations for the four calibration steps. 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 $p_K K_j/(p_{G_j} G_j)$ has gone down considerably in the goods sector and has increased sufficiently in the services sector so as to offset the decrease in the good sectors and to increase the capital-output ratio at the aggregate level. Note that the capital-output ratios are smaller than conventionally found because we have excluded a sizeable part of the capital stock

Table 1: Calibration targets

Statistic	1957–1973	1984–2000	2001–2016
$X/(p_K K)$	0.10	0.11	0.11
$X_g/(p_K K_g)$	0.12	0.11	0.11
$X_s/(p_K K_s)$	0.09	0.11	0.10
p_F/Π	28.06	35.46	55.51
p_{F_g}/Π_g	32.35	39.75	54.45
p_{F_s}/Π_s	27.22	34.68	55.71
$p_K K/Y$	1.37	1.48	1.53
$p_K K_g/Y_g$	1.11	1.55	1.88
$p_K K_s/Y_s$	1.59	1.45	1.41
wL/Y	0.74	0.71	0.69
$wL_g/(p_{G_g} G_g)$	0.29	0.26	0.23
$wL_s/(p_{G_s} G_s)$	0.48	0.46	0.44
$p_{M_g} M_{gg}/(p_{G_g} G_g)$	0.48	0.49	0.48
$p_{M_s} M_{sg}/(p_{G_g} G_g)$	0.12	0.12	0.12
$p_{M_s} M_{ss}/(p_{G_s} G_s)$	0.29	0.30	0.32
$p_{M_g} M_{gs}/(p_{G_s} G_s)$	0.07	0.08	0.08

– real estate capital. We calculate the labor shares, $w_j L_j/(P_{G_j} G_j)$, with 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. The labor share at the aggregate level shows the usual decline.[7] The labor share in the goods sector shows a much larger decline than at the aggregate level. When aggregated, the decline in the goods sector is mitigated by what happens in the services sector, which has an almost constant labor share, and by the increase in the final-output share of services. The intermediate-good shares, $p_{M_j} M_{jj'}/(p_{G_{j'}} G_{j'})$, are stable in the goods sector and increased in the services sector. In other words, outsourcing happened exclusively in the services sector.

We are left with obtaining data on the price-dividend ratio, p_{Fj}/Π_j. Since it is not in NIPA, we follow Farhi and Gourio and use the price-dividend ratio from the Center for Research in Security Prices ("CRSP"), which is available starting in the late 1950s. Dividends are the difference between reported returns with and without dividends. The main finding is that the price-dividend ratio has increased considerably, which the calibration will translate into a decrease in the expected discount rate. 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 rep-

[7]There are different explanations for the fall in the labor share. Elsby et al. (2013) argued that it reflects an increase in competition from international trade. Karabarbounis and Neiman (2014) argued that it reflects changes in the relative price of capital. Koh et al. (2021) showed that it reflects the inclusion of intellectual property product in the U.S. NIPA.

resented in CRSP data. Perhaps surprisingly, that is not much of a concern because they are well represented: During the first calibration period 1957–1973, one third of all listed firms are in the services sector; 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 a serious issue for our calibration because as in-house services are likely to be a small part of total services.

Although our aggregate model is similar to that of Farhi and Gourio (2018), there 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 is included in the measurement are also different. As mentioned above, we use the total private sector except for real estate whereas they use the non-financial corporate sector. Both measures exclude owner-occupied housing, because it is part of real estate and is non-corporate. Our measure excludes corporate leasing of property, which their measure includes, and our measure includes non-corporate businesses and the financial industries (finance and insurance and bank holding companies), which their measure excludes. Including such entities makes our calibration more comparable with international sectorization based on the System of National Accounts [Gutiérrez and Piton (2020)]. A last difference concerns what types of capital are included in the capital stock. We aim to employ a notion of capital that is consistent with the portion of the economy that we focus on. Therefore, we use all non-residential capital to accord with our exclusion of real estate. In contrast, Farhi and Gourio (2018) include residential capital in their measure of capital although much of residential capital is held outside the corporate sector.

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

Parameters	1957–1973	1984–2000	2001–2016
γ_T	0.03	0.03	0.02 (2001–2006)
γ_Q	-0.01	-0.02	-0.01
δ	0.09	0.10	0.10
δ_g	0.11	0.11	0.11
δ_s	0.07	0.10	0.10
ρ	0.06	0.05	0.03
ρ_g	0.06	0.05	0.05
ρ_s	0.06	0.06	0.03

4.3 Results

Table 2 reports the parameter values that are pinned down by the first three steps of the calibration. We obtain γ_T from NIPA as the average growth rate of real output per capita. Note that we estimate γ_T only for the first part of the last period, 2001–2006, which is consistent with the view that the Great Recession constituted a rare disaster shock χ_t that changed the level of trend output growth. Given that (65) implies that the value of γ_T is not of first-order importance for the results, this interpretation is not crucial for what we find.

We obtain γ_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 γ_Q is strongest in the 1980s and 1990s; see for example Duernecker et al. (2020). In our context, this manifests itself by γ_Q being twice as large in the middle period than in the other two periods.

The depreciation rates are 9–10%, which is reasonable without real estate. Note that the depreciation rate increased over time, which is consistent with the observation of Bridgman (2018) that the increasingly important capital stock of intellectual property product tends to have relatively high depreciation rates.

The expected discount rate ρ_j fell from 7–8% to 5%. This is broadly in line with what Farhi and Gourio (2018) found for the aggregate. They argued that the inclusion of a risk premium in ρ implies that its recent values are somewhat higher than those used by Barkai (2020). Note that in the model ρ_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 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 and our calibrated μ_j is upward biased; compare expression (60). 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, ρ_j and ρ would have fallen less, and our estimates of μ and μ_j would have increased less. Since our calibrated values of μ_j and μ will come out to be fairly small compared to the micro estimates, they provide a useful upper bound to the actual values despite these concerns.

As a first step, we report the *aggregate* findings for the two later periods that Farhi–Gourio considered: 1984–2000 and 2001–2016. While our main focus is on the private sector without real estate, we also report results for other portions of the economy. Table 3 shows that for the private sector without real estate aggregate markups increased by 40% from 1.10 to 1.14. These numbers are broadly in line with those of Farhi and Gourio even though the findings are not strictly comparable because of the differences in measurement pointed out above. Table 3 also shows that the increase and the level of aggregate markups are sensitive to the details of the calibration. If instead of using the calibrated ρ_j, we followed Barkai (2020) and used the Aaa interest rate from Moody's, the increase in aggregate markups would be almost twice

Table 3: Markups for different parts of the private sector

Part of the economy covered	Gross markups μ 1984–2000	Gross markups μ 2001–2016	$\frac{\Delta\mu - 1}{\mu - 1}$
Private sector	1.12	1.19	58%
Private sector without real estate	**1.10**	**1.14**	**40%**
Private sector without real estate and with Barkai user costs	1.08	1.14	75%
Private sector without FIRE	1.09	1.13	44%
Corporate sector without FIRE	1.09	1.14	56%
Private sector with corporate labor share	1.08	1.15	88%

as large, that is, 75% from 1.08 to 1.14. This reflects that the Aaa rate was initially higher than the calibrated ρ_j. Lastly, if we followed Farhi and Gourio (2018) in using the *corporate* labor share, then markups would nearly double from 1.08 to 1.15. We interpret our results as saying that, depending on the details of the calibration, aggregate markups have gone up by anywhere between 40% and 88%. While that is a wide range, we emphasize that its upper limit is considerably smaller than what most micro studies find. We share this conclusion with other macro studies like Farhi and Gourio (2018) and Barkai (2020).

Table 3 also shows that markups are larger for the private sectors with real estate than without real estate (lines one versus two). Including real estate has three effects: it lowers overall depreciation because real estate depreciates less than other capital; it increases the capital-to-final-output ratio; it decreases the share of the payments to labor in final output.

$$\mu \uparrow = \frac{1}{(\rho + \delta \downarrow + \gamma_Q)\frac{p_K K}{Y} \uparrow + \frac{wL}{Y} \downarrow}$$

Quantitatively, the decreases in δ and wL/Y dominate the increase in $p_K K/Y$ and so aggregate markups increase. A different way of putting is that markups in real estate are larger than in the rest of the economy. We are suspicious of the relatively large markups in real estate. While land income is included in Y, land is not included in NIPA K, which artificially inflates markups in real estate.

We now turn to the *sectoral* findings, which are new compared to the existing literature. Table 4 shows that between 1957–1973 and 2001–2016, markups doubled in both sectors. While that is the same as we find for the aggregate, we also find that the levels of markups in both sectors are only around half of what they are at the aggregate. The reason for this is that 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 when they are produced and sold and when they are bought and used. This double marginalization amplifies

Table 4: Calibrated parameters for the private sector without real estate – continued

Parameters		1957–73	1984–2000	2001–16
ϕ_g		0.46	0.28	0.19
α_K		0.21	0.22	0.21
α_L		0.79	0.78	0.79
α_{K_g}		0.07	0.09	0.10
α_{K_s}		0.13	0.13	0.11
α_{L_g}		0.30	0.27	0.25
α_{L_s}		0.49	0.48	0.46
$\alpha_{M_{gg}}$		0.50	0.51	0.52
$\alpha_{M_{sg}}$		0.13	0.13	0.13
$\alpha_{M_{ss}}$		0.30	0.32	0.34
$\alpha_{M_{gs}}$		0.07	0.07	0.09
$\boldsymbol{\mu}$		**1.07**	**1.10**	**1.14**
$\boldsymbol{\mu_g}$		**1.04**	**1.05**	**1.08**
$\boldsymbol{\mu_s}$		**1.03**	**1.05**	**1.07**
	$\{\boldsymbol{\phi_j}\}$	**1.07**	**1.10**	**1.16**
$\boldsymbol{\mu}$ **with 57–73**	$\{\boldsymbol{\alpha_i}\}$	**1.07**	**1.09**	**1.13**
	$\{\boldsymbol{\phi_j}, \boldsymbol{\alpha_i}\}$	**1.07**	**1.10**	**1.15**

the sectoral markups to larger aggregate markups.

Table 4 also contains the two counterfactual exercise that quantify the effects on aggregate markups of changes in the sectoral composition and of changes in the input-output linkages. To measure them, we "freeze" the sectoral composition, $\{\phi_j\}_{j\in\{g,s\}}$, or the output elasticities, $\{\alpha_i\}_{i\in\{K_g,L_g,M_{gg},M_{sg},K_s,L_s,M_{gs},M_{ss}\}}$, at their 1957–1973 average values and let all other variables change as before. We begin with the first counterfactual of fixing $\{\phi_j\}_{j\in\{g,s\}}$. It establishes that structural change reduced aggregate markups by reallocating economic activity from the goods-producing sector, which has higher markups, to the services-producing sector, which has lower markups. The reallocation mitigates the increase in aggregate markups by counteracting the increases in both sectoral markups. The table shows that the effect of structural change is quantitatively sizeable: had $\{\phi_i\}$ been frozen at the 1957–1973 values, aggregate markups would have gone up to 1.16, instead of 1.14.

The second counterfactual establishes that changes in the input-output linkages have had the opposite effect of structural change, that is, they amplified aggregate markups. Table 1 showed that, while the cost shares of intermediate inputs have stayed constant in the goods sector, they have increased in the services sector, implying that more output from goods and services is marked up again in the services sector instead of delivered to final uses. This increase in double marginalization increased aggregate markups. The table shows that this effect is quantitatively sizeable: had $\{\alpha_i\}$ been frozen at the 1957–1973 values, aggregate markups would have gone up to only 1.13 instead of 1.14. This finding is consistent with the thesis of Giannoni and Mertens (2019) that outsourcing of services increased aggregate markups. However, somewhat unexpectedly, we find that outsourcing happened exclusively in the services sector. In the goods sector, in contrast, the share of intermediate inputs remained conspicuously stable at 0.60, so outsourcing did not play a role there.

We conclude this section by mentioning that the calibrated increase in α_{K_g} and the calibrated reduction in $\{\rho, \rho_g, \rho_s\}$ are broadly consistent with the implications of China joining the World Trade Organization. In particular, China specializing in exports of labor-intensive manufactured goods to the U.S. should have increased the capital intensity of U.S. manufacturing. China running large current account surpluses should have lowered the user costs of capital in the U.S. The advantage of our method is that it measures the implied reduction in the user costs of capital. That is challenging to do because it is unclear what happened to the risk premium and to inflation expectations, in particular during the 1980s. Nonetheless, our method produces credible reference interest rates that don't swing widely.

5 Discussion

In this section, we put our results into perspective by exploring how three modifications of our model affect our estimates of markups: abstracting from input-output linkages; taking into account unmeasured capital; leaving out a potentially fixed factor.

5.1 Value-added versus gross-output markups

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 section, we shall establish that using a value-added model severely biases the sectoral markup estimates upwards.

The value-added version of our model can be obtained as a special case of the gross-output version by setting $\alpha_{M_{jj}} = \alpha_{M_{j'j}} = 0,\ j, j' \in \{g, s\}$. To see the implications, we rewrite the first-order conditions (19)–(20) as:

$$p_{G_{jt}} M_{jjt} = \frac{\alpha_{M_{jj}}}{\mu_j} p_{G_{jt}} G_{jt}, \tag{69}$$

$$p_{G_{j't}} M_{j'jt} = \frac{\alpha_{M_{j'j}}}{\mu_j} p_{G_{jt}} G_{jt}. \tag{70}$$

Thus, $\alpha_{M_{jj}} = \alpha_{M_{j'j}} = 0$ implies that, in equilibrium, $M_{jjt} = M_{j'jt} = 0$. Imposing symmetric equilibrium, equations (6)–(7) then simplify to:

$$G_{jt} = Y_{jt} = V_{jt}.$$

That is, if $\alpha_{M_{jj}} = \alpha_{M_{j'j}} = 0$, 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.

Calibration steps 1–3 are the same in the value-added model as in the gross-output model. In contrast, the calibration in step 4 changes. Denoting value-added parameters by a tilde, we have at the sectoral level:

$$\tilde{\mu}_j = \frac{p_{V_j} V_j}{(\rho_j + \delta_j + \gamma_Q) p_K K_j + w L_j}. \tag{71}$$

$$\tilde{\alpha}_{K_j} = \frac{(\rho_j + \delta_j + \gamma_Q) p_K K_j}{(\rho_j + \delta_j + \gamma_Q) p_K K_j + w L_j}, \tag{72}$$

$$\tilde{\alpha}_{L_j} = \frac{w L_j}{(\rho_j + \delta_j + \gamma_Q) p_K K_j + w L_j}. \tag{73}$$

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

$$\tilde{\mu} = \frac{V}{(\rho + \delta + \gamma_Q) p_K K + w L}. \tag{74}$$

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 there are positive markups, then the sectoral markups are larger in the value-added model than in the gross-output model: $\tilde{\mu}_j > \mu_j$.*

Proof of the second statement. See Appendix A.4.

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 capita 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 5: Calibrated parameters for value-added model of private economy without real estate

Parameters	1957–1973	1984–2000	2001–1916
$\tilde{\phi}_g$	0.46	0.32	0.26
$\tilde{\alpha}_K$	0.21	0.22	0.21
$\tilde{\alpha}_{K_g}$	0.19	0.25	0.30
$\tilde{\alpha}_{K_s}$	0.21	0.21	0.19
$\boldsymbol{\tilde{\mu}}$	**1.07**	**1.10**	**1.14**
$\boldsymbol{\tilde{\mu}_g}$	**1.11**	**1.14**	**1.22**
$\boldsymbol{\tilde{\mu}_s}$	**1.05**	**1.07**	**1.11**
$\boldsymbol{\tilde{\mu}}$ **with 57–73** $\boldsymbol{\{\tilde{\phi}_j\}}$	**1.07**	**1.10**	**1.17**

Table 5 contains the quantitative results for the value-added calibration. Reassuringly, the result 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%. Moreover, the effect of structural change is much stronger now. Without structural change, aggregate markups would have gone up by 10 percentage points to 1.17, which is 3 percentage points more than they did with structural change.

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. Interestingly, however, the estimates of aggregate markups are the same irrespective of whether we take the input-output linkages into account. 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).

5.2 Unmeasured versus measured capital

On obvious concern with our analysis is that some of the profits that our model interprets as markups may be payments to unmeasured capital. In this subsection, we explore whether, in what direction, and by how much unmeasured capital biases our measurement of markups.

Examples of unmeasured capital include brand names, intellectual property, and organizational capital. An important subset of unmeasured capital is Intellectual Property Product ("IPP"), which comprises software, research and development, and entertainment, literary, and artistic originals. IPP capital is of particular interest because it is now included in the U.S. NIPA, and so one can study the effect on macro statistics of including or excluding it.[8]

Table 6: Aggregate calibration without IPP capital and real estate

Targets	1957–1973	1984–2000	2001–2016
$X^*/(p_K K^*)$	0.09	0.09	0.08
$p_K K^*/Y^*$	1.31	1.38	1.40
wL/Y^*	0.74	0.73	0.73
Parameters			
δ^*	0.08	0.08	0.08
α_K^*	0.19	0.19	0.16
$\boldsymbol{\mu^*}$	**1.10**	**1.11**	**1.15**

Including additional unmeasured capital in the measurement of markups requires two modifications to equation (66): first, one must count the user costs paid to the stock of unmeasured capital, $r_t^* K_t^*$, as an additional factor payment; second, one must capitalize the expensed investment in unmeasured capital, X_t^*, and count it as additional output and additional capital stock. Given that the income and product approaches to measuring GDP must give the same answer, the two modifications must conceptually be equal in value: $r_t^* K_t^* = X_t^*$. Given that $Y_t > r_t K_t + w_t L_t$, including unmeasured capital therefore *decreases* aggregate markups:[9]

$$\mu^* = \frac{Y_t + X_t^*}{r_t K_t + r_t^* K_t^* + w_t L_t} < \frac{Y_t}{r_t K_t + w_t L_t} = \mu.$$

Since including additional unmeasured capital would lower markups which are already low compared to the micro estimates, it would not overturn our results.[10]

To get a sense of the quantitative effect of unmeasured capital, we remove IPP capital from the accounts (along with real estate as before). Table 6 reports the results. As expected given the discussion in the previous paragraph, the aggregate markups, μ, are larger without than with IPP capital. The effect on aggregate markups of excluding IPP capital from the capital stock

[8]Koh et al. (2021) provided a detailed analysis of the effects on the labor share of including IPP capital. They found that it is responsible for almost all of the recent decrease in the U.S. labor share. Atkeson (2020) extended their analysis and discussed the effects on markups of including of IPP capital.

[9]Atkeson (2020) arrived at a similar conclusion regarding the effect of unmeasured capital on markups.

[10]We study the effects of unmeasured capital only on aggregate markups. The formula for sectoral markups is similar. But we cannot implement it on the data because we have no information about the sectoral allocation of unmeasured capital.

is limited, however. Overall, aggregate markups increased from 1.10 in 1957–1973 to 1.15 in 2001–2016. In comparison, markups for the private sector *without* real estate but *with* IPP capital increased from 1.07 to 1.14; see Table 4. This result suggests that including additional unmeasured capital of similar size as the existing IPP capital is unlikely to move our results massively.

Two additional effects of excluding IPP capital are worth mentioning. First, the labor share falls less than with IPP capital, that is, from 0.74 to 0.73 instead of from 0.74 to 0.69; compare Table 1. This is a version of the finding of Koh et al. (2021). Second, the depreciation rate is lower than with IPP capital, that is, it stays at 0.08 instead increases from 0.09 to 0.10; compare Table 2. The difference reflects that IPP capital both depreciates relatively fast and increased in importance.

5.3 Fixed versus variable inputs

One explanation for the discrepancy between different estimates of markups is that it is not always clear what a fixed and what a variable input is. The distinction matters when markups are measured as price over marginal costs, where marginal costs are defined as the costs of variable inputs. In micro studies with short horizons, several inputs might temporarily look fixed although they are flexible over longer horizons like a year. An example is the faculty of an economics department, which tends to be fixed during the academic year but is not fixed from year to year. If part of the inputs are fixed over short horizons, then that reduces marginal costs and inflates markups.

We emphasize that the issue of fixed versus a variable inputs does not affect our approach of calculating markups as long as total labor is flexible and optimally chosen at the annual frequency. The reason for this is that our model is built around a production function of the Cobb-Douglas form. To see what that entails, we rewrite the implied aggregate first-order condition for labor, (23), as follows:[11]

$$\mu = \frac{\alpha_L Y}{wL}. \tag{75}$$

Clearly, the aggregate markup does not depend on wether or not the other factor, here capital, is fixed or flexible. If capital was fixed and chosen in advance, then we could interpret it as a suppressed production factor and the aggregate production function (40) would take the form:

$$Y_t = \Omega Z_t (A_t L_t)^{\alpha_L}. \tag{76}$$

The payments to capital would then come from the profits that would accrue because the modi-

[11] While we focus on the aggregate markup here, we note that a similar argument applies to the sectoral level.

fied production function has decreasing returns. Importantly, nothing in the calibration formula (75) would change. Raval (2019) was the first to observe this point. He then went on to measure markups for different variable inputs and explored under what conditions the estimates are the same also in practice.

6 Related literature

As discussed above, Farhi and Gourio (2018) and Barkai (2020) took the macro perspective and used a similar methodology as we did. Several other paper have also used macro data to examine the behavior of markups. Hall (2018) used industry level data from NIPA to examine Lerner indices. Barkai and Benzell (2018) use the sectoral macro accounts to examine profit rates. They tend to find relatively moderate increases in profit shares, which is consistent with our findings. Our work extends their analysis by decomposing the sources of markup growth into different margins, and by quantifying how structural change and outsourcing interact to shape aggregate markups. 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, 2000–2018. Therefore, they cannot speak to our main question of how the extensive margin has affected aggregate markups over longer time horizons.

A large literature takes a micro perspective and examines individual industries, including De Loecker and Scott (2016), Asker et al. (2019), and Miller et al. (2019). The value added of our work compared to the industry studies is that macroeconomic trends need not be the same for individual industries or firms, and so it is worth to supplement the valuable industry perspective by taking the macro perspective as we do. A related literature examines how markups behave at a business cycle frequency, which is of interest in the context of New Keynesian macro models; see for example Hall (1988), Haskel et al. (1995), and Nekarda and Ramey (2019). Our work complements this literature by studying long-run trends in markups, instead of short-run fluctuations around a trend.

Lastly, there is also 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 Herrendorf et al. (2013). A closely related example is Hang et al. (2020) from the literature on misallocation. Studying a competitive economy, they find that the aggregate effects of misallocation are the same for the gross-output model and the value-added model, but that sectoral misallocation is amplified through input-output linkages in the gross-output model but not in the value-added model.

Thus, the gross-output model implies less misallocation at the sectoral level than the value-added model, which is in line with our findings for sectoral markups in a monopolistically competitive economy with monopoly power.

7 Conclusion

We have examined U.S. markups in a two-sector growth model with monopolistic competition and input-output linkages. Calibrating the model to the NIPA and the input-output tables, we have obtained the following results. Since the 1950s, aggregate and sectoral markups have doubled but they fall short of what many micro studies suggest. Moreover, double marginalization implies that sectoral markups are considerably smaller than aggregate markups. Lastly, structural change reduced aggregate markups whereas outsourcing increased aggregate markups. The net effect of the two is a one percentage point reduction in aggregate markups since the 1950s.

Our results have the implication that taking into account how sectoral markups aggregate does not reconcile the large micro estimates with the much smaller macro estimates. If anything, it worsens the puzzle why many micro estimates are so large. In particular, double marginalization implies that sectoral markups should be considerably *smaller* than aggregate markups. This illustrates that carefully taking into account the effects of aggregation and input-output linkages is of first-order importance for the integration of the micro with the macro results.

Our analysis suggests several directions for future work. First, it would be useful to estimate markups also for finer industry disaggregations and investigate what patterns arise in the aggregation of more disaggregate markups. 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, given that aggregation does not help to reconcile the large micro estimates with the small macro estimates and that the small macro estimates are broadly consistent with the stylized macro facts, it will be fruitful to revisit the micro studies. One possibility for why they find such large markups is that since Compustat covers fewer than 1/3 of all U.S. firms, it is just not representative of the other 2/3 or the entirety of the U.S. economy. More work exploring the related issues is needed. Lastly, 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.

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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 (14) implies:

$$p_{G_{jt}}G_{jt} = p_{G_{jt}}Y_{jt} + p_{G_{jt}}M_{jjt} + p_{G_{jt}}M_{jj't}.$$

Using (15), (19), and (20) gives:

$$p_{G_{jt}}G_{jt} = \phi_j Y_t + \frac{\alpha_{M_{jj}}}{\mu_j} p_{G_{jt}}G_{jt} + \frac{\alpha_{M_{jj'}}}{\mu_{j'}} p_{G_{j't}}G_{j't}.$$

Denoting column vectors and matrices in boldface,

$$\frac{\boldsymbol{p_{G_t}G_t}}{\boldsymbol{Y_t}} \equiv \begin{bmatrix} \frac{p_{G_{gt}}G_{gt}}{Y_t} \\ \frac{p_{G_{st}}G_{st}}{Y_t} \end{bmatrix}, \quad \boldsymbol{\phi} \equiv \begin{bmatrix} \phi_g \\ \phi_s \end{bmatrix}, \quad \boldsymbol{\Omega} \equiv \begin{bmatrix} \frac{\alpha_{M_{gg}}}{\mu_g} & \frac{\alpha_{M_{gs}}}{\mu_s} \\ \frac{\alpha_{M_{sg}}}{\mu_g} & \frac{\alpha_{M_{ss}}}{\mu_s} \end{bmatrix},$$

this implies:

$$\frac{\boldsymbol{p_{G_t}G_t}}{\boldsymbol{Y_t}} = \boldsymbol{\phi} + \boldsymbol{\Omega}\frac{\boldsymbol{p_{G_t}G_t}}{\boldsymbol{Y_t}}.$$

If $\boldsymbol{\Omega}$ is invertible, then:

$$\frac{\boldsymbol{p_{G_t}G_t}}{\boldsymbol{Y_t}} = [\boldsymbol{I} - \boldsymbol{\Omega}]^{-1}\boldsymbol{\phi}, \tag{A.1}$$

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

$$\begin{aligned}
[\boldsymbol{I} - \boldsymbol{\Omega}]^{-1} &= \begin{bmatrix} 1 - \frac{\alpha_{M_{gg}}}{\mu_g} & -\frac{\alpha_{M_{gs}}}{\mu_s} \\ -\frac{\alpha_{M_{sg}}}{\mu_g} & 1 - \frac{\alpha_{M_{ss}}}{\mu_s} \end{bmatrix}^{-1} \\
&= \frac{1}{\left(1 - \frac{\alpha_{M_{gg}}}{\mu_g}\right)\left(1 - \frac{\alpha_{M_{ss}}}{\mu_s}\right) - \frac{\alpha_{M_{gs}}}{\mu_s}\frac{\alpha_{M_{sg}}}{\mu_g}} \begin{bmatrix} 1 - \frac{\alpha_{M_{ss}}}{\mu_s} & \frac{\alpha_{M_{gs}}}{\mu_s} \\ \frac{\alpha_{M_{sg}}}{\mu_g} & 1 - \frac{\alpha_{M_{gg}}}{\mu_g} \end{bmatrix}.
\end{aligned}$$

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

$$p_{G_{jt}}G_{jt} = \Phi_j Y_t \qquad \text{where} \qquad \Phi_j \equiv \frac{\left(1 - \frac{\alpha_{M_{j'j'}}}{\mu_{j'}}\right)\phi_j + \frac{\alpha_{M_{jj'}}}{\mu_{j'}}\phi_{j'}}{\left(1 - \frac{\alpha_{M_{jj}}}{\mu_j}\right)\left(1 - \frac{\alpha_{M_{j'j'}}}{\mu_{j'}}\right) - \frac{\alpha_{M_{jj'}}}{\mu_{j'}}\frac{\alpha_{M_{j'j}}}{\mu_j}}.$$

QED

A.2 Euler Equation

Substituting out X_{jt} in the household problem (25) by using (9), the problem simplifies to:

$$\max_{C_t,\{K_{jt+1}\}_{j\in\{g,s\}}} U_t = \left((1-\beta)C_t^{1-\sigma} + \beta\left[E_t\left(U_{t+1}^{1-\theta}\right)\right]^{\frac{1-\sigma}{1-\theta}}\right)^{\frac{1}{1-\sigma}}$$

$$\text{s.t. } C_t = \sum_{j\in\{g,s\}}\left[\left(\frac{1-\delta_j}{Q_t} + r_{jt}\right)K_{jt} - \frac{K_{jt+1}}{Q_t\exp(\chi_{jt+1})}\right] + w_t.$$

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

$$\max_{K_{t+1}} U_t = \left(1-\beta)N_t^{\sigma}\left[\left(\frac{1-\delta}{Q_t} + r_t\right)K_t + w_tN_t - \frac{K_{t+1}}{Q_t\exp(\chi_{t+1})}\right]^{1-\sigma} + \beta\left[E_t\left(U_{t+1}^{1-\theta}\right)\right]^{\frac{1-\sigma}{1-\theta}}\right)^{\frac{1}{1-\sigma}}$$

The first-order conditions are:

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

$$\frac{\partial U_{t+1}}{\partial K_{t+1}} = U_{t+1}^{\sigma}(1-\beta)C_{t+1}^{-\sigma}\left(\frac{1-\delta}{Q_{t+1}} + r_{t+1}\right)$$

Hence,

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

Rewriting this gives the Euler equation (26) stated in the text:

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

where

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

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

A.3 Proof of Proposition 2

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

$$Y_t \propto G_{gt}^{\phi_g}G_{st}^{\phi_s}. \tag{A.2}$$

(19) implies that $M_{jjt} \propto G_{jt}$ and (20) implies that:

$$M_{j'jt} = \frac{\alpha_{M_{j'j}}}{\mu_j} \frac{p_{G_{jt}} G_{jt}}{p_{G_{j't}} G_{j't}} G_{j't}.$$

Using (21), the previous equation implies that $M_{j'jt} \propto G_{j't}$. (24) and (33) imply that $L_{jt} \propto 1$ and $K_{jt} \propto K_t$. Substituting all these equilibrium relationships into (4) gives:

$$G_{jt} \propto Z_{jt} K_t^{\alpha_{K_j}} A_{jt}^{\alpha_{L_j}} G_{jt}^{\alpha_{M_{jj}}} G_{j't}^{\alpha_{M_{j'j}}} \qquad (j, j' \in \{g, s\}).$$

We can solve this equation for G_{jt}:

$$G_{jt} \propto Z_{jt}^{\frac{1}{1-\alpha_{M_{jj}}}} K_t^{\frac{\alpha_{K_j}}{1-\alpha_{M_{jj}}}} A_{jt}^{\frac{\alpha_{L_j}}{1-\alpha_{M_{jj}}}} G_{j't}^{\frac{\alpha_{M_{j'j}}}{1-\alpha_{M_{jj}}}} \qquad (j, j' \in \{g, s\}).$$

Substituting the same equation for $G_{j't}$ into the previous equation:

$$G_{jt} \propto Z_{jt}^{\frac{1}{1-\alpha_{M_{jj}}}} K_t^{\frac{\alpha_{K_j}}{1-\alpha_{M_{jj}}}} A_{jt}^{\frac{\alpha_{L_j}}{1-\alpha_{M_{jj}}}} \left[Z_{j't}^{\frac{1}{1-\alpha_{M_{j'j'}}}} K_t^{\frac{\alpha_{K_{j'}}}{1-\alpha_{M_{j'j'}}}} A_{j't}^{\frac{\alpha_{L_{j'}}}{1-\alpha_{M_{j'j'}}}} G_{jt}^{\frac{\alpha_{M_{jj'}}}{1-\alpha_{M_{j'j'}}}} \right]^{\frac{\alpha_{M_{j'j}}}{1-\alpha_{M_{jj}}}}.$$

Solving for G_{jt}, we find:

$$G_{jt} \propto \left[Z_{jt}^{1-\alpha_{M_{j'j'}}} Z_{j't}^{\alpha_{M_{j'j}}} K_t^{\alpha_{K_j}\left(1-\alpha_{M_{j'j'}}\right)+\alpha_{K_{j'}}\alpha_{M_{j'j}}} A_{jt}^{\alpha_{L_j}\left(1-\alpha_{M_{j'j'}}\right)} A_{j't}^{\alpha_{L_{j'}}\alpha_{M_{j'j}}} \right]^{\frac{1}{\left(1-\alpha_{M_{jj}}\right)\left(1-\alpha_{M_{j'j'}}\right)-\alpha_{M_{jj'}}\alpha_{M_{j'j}}}}.$$

Substituting the previous equation for G_{gt} and G_{st} into (A.2) gives us the aggregate Cobb-Douglas production function (40). **QED**

A.4 Proof of Proposition 3

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:

$$\begin{aligned} V_t \equiv \sum_{j\in\{g,s\}} p_{V_{jt}} V_{jt} &= \sum_{j\neq j'\in\{g,s\}} \left(p_{G_{jt}} G_{jt} - p_{G_{jt}} M_{jjt} - p_{G_{j't}} M_{j'jt} \right) \\ &= \sum_{j\neq j'\in\{g,s\}} p_{G_{jt}} \left(G_{jt} - M_{jjt} - M_{jj't} \right) = \sum_{j\in\{g,s\}} p_{G_{jt}} Y_{jt} \equiv Y_t. \end{aligned}$$

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 (19)–(20) into (7):

$$p_{V_{jt}} V_{jt} = p_{G_{jt}} G_{jt} \left(1 - \frac{\alpha_{M_{jj}} + \alpha_{M_{j'j}}}{\mu_j}\right). \tag{A.3}$$

Sector j's share of total value added is:

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

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

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

In the value-added model, in contrast, $\tilde{\mu}_j$ is given by (71) from above. Using (A.3), we get:

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

Using the first-order conditions (17)–(18) gives:

$$\tilde{\mu}_j = \frac{\mu_j}{\alpha_{K_{jt}} + \alpha_{L_{jt}}} \left(1 - \frac{\alpha_{M_{jj}} + \alpha_{M_{j'j}}}{\mu_j}\right).$$

Since $1 = \alpha_{K_{jt}} + \alpha_{L_{jt}} + \alpha_{M_{jj}} + \alpha_{M_{j'j}}$, we end up with:

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

Thus, $\tilde{\mu}_j > \mu_j$. **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

1947–2018: Gross Output by Industry and Components of Value Added by Industry, BEA Industry Accounts, October 29, 2019 release.

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

1987–2018: BEA Industry Accounts, October 29, 2019 release.

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 Proprietor's Income

1998–2018: Table 6.12D. Nonfarm Proprietors' Income by Industry, July 30, 2019 release plus Farm Proprietor's income from Table 1.12. National Income by Type of Income July 30, 2020 release. 1987–1997: SIC87 Industry Accounts to calculate Proprietor's Income share of GOS and we multiply these shares by NAICS GOS.

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

1947–1997: Chain–Type Quantity Indexes for Value Added by Industry (2012 base year), BEA Industry Accounts, October 29, 2019 release.

1997–2018: Real Value Added by Industry (2012 dollars), April 6, 2020 release.

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

(See file Fixed Assets by Industry.xlsx)

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.1.7 Non-Financial Corporations

(See files IMAs.xlsx, NFC Data.xlsx) Most NFC moments are calculated using the Integrated Macroeconomic Accounts, Table S.5.a (Nonfinancial Corporate Business), June 19, 2020 release. These data go back to 1960, so early moments are 1960-1973 averages.

Labor share is calculated using Value Added (line 1), Compensation of Employees (line 5), and Taxes on Production and Imports less Subsidies (line 7).

Capital-output ratio uses Value Added and non-financial assets (line 102).

Investment-capital ratio uses Non-financial Assets and Gross Fixed Capital Formation (acquisition of produced nonfinancial assets) (line 29).

Trend growth (γ_T is the growth rate of real NFC value added, NIPA Table 1.14. Gross Value Added of Domestic Corporate Business in Current Dollars and Gross Value Added of Nonfinancial Domestic Corporate Business in Current and Chained Dollars, July 30, 2020 release, line 41.

B.2 Financial Data

(See file Sectoral Dividend Data.xlsx)

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

(See file Final Data.xlsx)

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