A theory of structural change that can fit the data

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Abstract

This paper proposes a theory of structural change that is consistent with the long-run data. We first document the reallocation of final consumption expenditures across the three broad sectors agriculture, manufacturing, and services in the United States, the United Kingdom, Canada and Australia. We find three robust features of the sectoral consumption expenditure shares since the beginning of the last century: (i) a monotonic decrease in agriculture, (ii) a hump shape in manufacturing, and (iii) an accelerated rise of services. Given historical panel data on sectoral prices and nominal per-capita expenditure from 1900 to 2014, we then ask what demand side theory can quantitatively explain the observed structural change. Our analysis shows that the preference specification commonly used in the structural change literature - the generalized Stone-Geary specification - struggles to do so. We propose a generalization of the Price Independent Generalized Linearity (PIGL) class of preferences which is flexible enough to allow for a non-monotonic relationship between sectoral expenditure shares and can therefore fit the historical data much better. Under some restrictions, it can also be consistently used in a dynamic general equilibrium model with steady growth.

Keywords: Structural change, Nonhomothetic preferences, Relative price effects, Nonmonotonic expenditure shares, Balanced growth.

JEL classification: O11, O14, L16, E21.

1 Introduction

Structural transformation is a stylized fact of modern economic development. However, the empirical literature on structural change has come to different conclusions on whether existing demand side theories are consistent with the observed reallocation of economic activity across the three broad sectors agriculture, manufacturing, and services. For example, Herrendorf et al. (2013) find that the sectoral demands derived from the generalized Stone-Geary preference specification are consistent with the United States' structural change in the postwar era. On the other hand, Buera and Kaboski (2009) show for a historical sample starting in 1870, that the same specification struggles to fit the data for the United States.

In this paper we ask the question what preference specification can fit the long-run data on structural change. Understanding and quantifying the demand side forces driving structural change is crucial. While relative prices and expenditure growth are mostly driven by technological change on the supply side, their impact on the sectoral expenditure shares and aggregate growth as well as their welfare consequences depend on the importance of relative price and income effects on the demand side. For example, if the service sector constitutes a gross complement to the rest of the economy and its relative price increases, over time, more and more resources will be shifted in the service sector. This is a major concern, as there was significantly less technological progress in the service sector compared to manufacturing. The result is the so-called Baumol (1967) cost disease where economic activity is reallocated from more to less productive sectors, which slows down aggregate growth. The analog concern applies to the decline of the expenditure share for manufacturing, which is very prominent in the current public debate.

In this paper we aim to make three contributions to the existing literature: (i) we document the development of sectoral final consumption expenditure shares, relative prices, and per-capita expenditure in the United States (USA), the United Kingdom (GBR), Canada (CAN), and Australia (AUS) since the beginning of the last century. The existing literature has mainly focused on consumption expenditure data from the postwar era. (ii) we investigate whether preference specifications previously used in the literature on structural change can fit the historical data. We find that existing theories struggle to match the hump-shape in manufacturing, the late rise of services, and the continued decline of agriculture observed in the long-run data. (iii) we propose a generalization of the Price Independent Generalized Linearity (PIGL) class of preferences that can fit the long-run data and allows for structural transformation along an exact balanced growth path in a standard multi-sector growth model.[1]

Using final consumption expenditure data for the USA, GBR, CAN, and AUS we confirm the finding of the existing literature that the standard preference specification – the generalized Stone-Geary – explains the observed structural transformation very well in the postwar era. For the United States this has been documented in Herrendorf et al. (2013) and we reach the same conclusion for the remaining three countries as well. However, once we consider long-run samples that also include data from the first half of the past century, the generalized Stone-Geary preferences struggle to fit three strong regularities that are observed in the historical data across all four countries: (i) the continued decline of the expenditure share for agriculture, (ii) the hump-shape of the manufacturing share, (iii) and the accelerated rise of the service sector. This finding confirms the result in Buera and Kaboski (2009) who find that the generalized Stone-Geary specification does not fit well the historical consumption value-added shares of agriculture, manufacturing, and services. This result is even the more striking since (i)-(iii) are a very robust pattern of structural change systematically found in data on consumption expenditure, gross output, value-added, and employment shares (see Herrendorf et al. (2014) for an excellent survey). The reason for the bad fit is that, in the long-run data, the generalized Stone-Geary demands a unreasonably high subsistence level (income effect) of agricultural consumption to match the decline in its share. Moreover, to generate a pronounced hump-shape in the manufacturing sector share, the data asks for a non-monotonic relationship between expenditure shares and nominal expenditure levels. However, the Stone-Geary specification restricts this relationship to be monotonic when prices remain constant.

In contrast, in the microeconomic literature on consumer demand systems the

[1] Note that we use the same equilibrium concept as in Kongsamut et al. (2001) and Herrendorf et al. (2014) who call it exact generalized balanced growth. The word *generalized* refers to the feature that not all sectoral variables grow at constant rates and the word *exact* indicates that balanced growth is reached in finite time. Henceforth, we refer to their equilibrium concept simply as exact balanced growth.

flexible functional form normally used is the Quadratic Almost Ideal Demand System (QAIDS) as proposed in Banks et al. (1997). When we estimate a version of this preference specification on the consumption expenditure data, we find a better fit of the historical data compared to the generalized Stone-Geary. It can generate a more pronounced hump-shape in manufacturing without imposing strong restrictions on the functional form of the other sectors, and it can predict the sharp decline of agriculture and the late rise of services. However, the QAIDS framework is not suitable for environments with sustained growth in per-capita expenditure, as the predicted expenditure shares lie outside the unit interval once per-capita expenditure has grown sufficiently over time. In a microeconomic analysis with cross-sectional data this is less of a concern, but in the macroeconomic time series the steady growth of per-capita expenditure is another stylized fact for advanced economies over the last century.

To overcome the theoretical inconsistency of the QAIDS specification in a growth context, while at the same time preserving the functional flexibility of the demand system, we propose a generalization of the PIGL class of preferences as introduced in Muellbauer (1975, 1976). This specification allows for the estimation of non-monotonic expenditure share Engel curves and provides a better fit of the historical data than the generalized Stone-Geary. We also show that the specification is consistent with structural change along an exact balanced growth path once endogenous labor supply is considered, and we demonstrate how it operates in the benchmark multi-sector growth model proposed in Herrendorf et al. (2014).

2 Related literature

Our paper relates to several recent developments in the macroeconomic literature on structural change and to the microeconomic literature on demand system estimation. Being close in spirit to Herrendorf et al. (2013), we focus on the implications of a given preference specification on structural transformation and take as given the relative prices and nominal expenditure in the empirical analysis. As in Boppart (2014) we are after a preference specification that allows for both income and relative price effects along the exact balanced growth path of a standard multisector growth framework as presented in Herrendorf et al. (2014).[2]

The papers most closely related to ours are Buera and Kaboski (2009), Herrendorf et al. (2013), Boppart (2014), and Comin et al. (2015). Herrendorf et al. (2013) find that the generalized Stone-Geary preference specification fits the postwar data in the USA very well. They take two natural perspectives on structural transformation, categorizing the broad sectors agriculture, manufacturing, and services either according to final consumption expenditures or value-added. The focal point of their paper is to reconcile the differences in the estimated preference parameters that result from the two perspectives. The consumption expenditure perspective yields dominating income effects, whereas the value-added perspective predicts relative price effects to be more important. In our paper, we focus on the consumption expenditure perspective, because reliable input-output tables are not available for any of the considered countries prior to World War II (WWII). Thus, it is impossible to separate consumption from investment and net exports from production if one used instead value-added data. When considering long-run consumption expenditure data from 1900 onwards, our conclusions differ from the ones of Herrendorf et al. (2013) which limited the analysis to the postwar sample: the generalized Stone-Geary specification struggles to fit the historical expenditure shares, and the income effects are no longer the single dominating force of structural transformation.

Our empirical results resemble the findings in Buera and Kaboski (2009). Using decennial value-added data from 1870 onwards, the authors have already emphasized that the generalized Stone-Geary specification cannot fit the most salient pattern of structural change. However, our data allows us to focus exclusively on the final output that is domestically consumed, whereas Buera and Kaboski (2009) run the non-homothetic specification over total output that also includes investment as well as exports.

A theoretical drawback of the Stone-Geary specification is that its consistency with exact balanced growth depends on knife-edge parameterizations that imply mutually exclusive income effects (Kongsamut et al., 2001) or relative price effects (Ngai and Pissarides, 2007), respectively. Boppart (2014) overcomes these limita-

[2]Kongsamut et al. (2001), Ngai and Pissarides (2007), Foellmi and Zweimüller (2008), shut down either the relative price or the income effect in order to be in line with an exact balanced growth path. Comin et al. (2015) consider an asymptototic balanced growth path.

tions and proposes a PIGL preference specification where structural transformation occurs along an exact balanced growth path. While Boppart (2014) considers an economy with two broad sectors for services and goods, we are splitting up the goods sector into agriculture and manufacturing as is common in the structural change literature. Moreover, we provide empirical evidence for relative price and income effects for the entire 20th century and for four different countries, while he focuses on the postwar period in the USA.

Our paper is also related to the microeconomic literature on demand system estimation. The PIGL class of preferences has been introduced by Muellbauer (1975, 1976) and it yields expenditure shares that are a quasi-linear function of the nominal expenditure level to some power (or, in the special case of PIGLOG it is a quasi-linear function in the logarithm of the nominal expenditure level). Banks et al. (1997) established the QAIDS that results from the generalization of the Almost Ideal Demand system (AIDS) which is itself a special case of PIGLOG. Similar to our generalization of the PIGL preferences, the QAIDS specification allows for a non-monotonic relationship between expenditure shares of different sectors and the nominal expenditure level. However, in contrast to our specification, it is not compatible with sustained growth and mostly used for the analysis of cross-sectional data where this is less of a concern.

In the empirical literature Buera and Kaboski (2012a) document similar empirical regularities for the sectoral value-added shares for an even longer time series and a broader set of countries. However, since information on prices is not available for their historical panel data, the estimation of preference specifications is not possible with their data. They also provide a theory where the scale of technologies drives the rise of the service economy and the hump-shape of the manufacturing share. Technological progress in manufacturing leads first to the demarketization of services into home production. Later growth in the scale of services explains the marketization of home production into services. Finally, the handbook chapter of Herrendorf et al. (2014) provides an excellent discussion of the recent empirical and theoretical literature on growth and structural transformation. It also provides detailed references to many valuable data sources for several countries.

The remainder of the paper is organized as follows. Section 3 describes the historical panel data and establishes the empirical regularities. In Section 4 we present the general theoretical framework, and in Section 5 we discuss the properties of specific preference specifications. Section 6 contains the structural estimation of preference parameters and discusses the main empirical results. Section 7 concludes. Additional figures and tables, proofs and derivations, and a detailed description of the historical data that enters the estimations are shown in Appendix A, B, and D, respectively.

3 Historical data on structural change

3.1 Data description

We use nominal consumption expenditure and price data provided by the national statistical offices of the USA, GBR, CAN, and AUS whenever available. These primary sources are complemented with historical data from Carter et al. (2006) for the USA, Feinstein (1972) for GBR, and Haig and Anderssen (2006) for AUS.[3] This leaves us with an unbalanced panel of countries, where the data covers the period 1902 to 2014 (USA), 1900 to 2014 (GBR), 1926 to 2014 (CAN), and 1900 to 2014 (AUS).

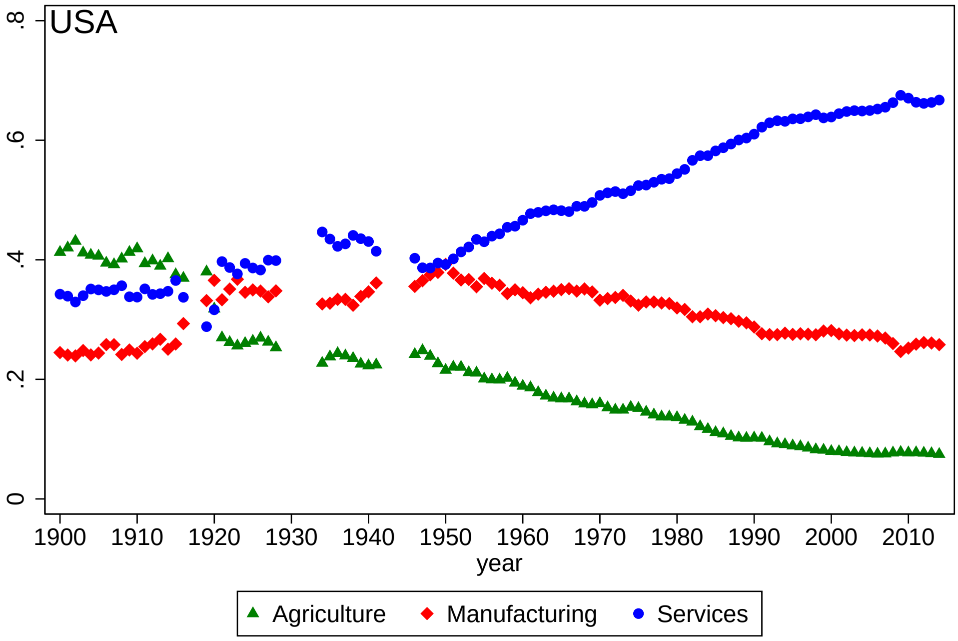
We use the same categorization of the broad sectors as in Herrendorf et al. (2013). Roughly speaking, Agriculture consists of food and beverages purchased for off-premise consumption. Manufacturing captures durable goods, clothing and footwear, gasoline and other energy goods, and other nondurable goods. Services consists of both private services as well as government consumption. The latter categorization is challenging during the periods of World War I (WWI) and WWII, where the expenditure shares in government consumption increased sharply. For this reason - and because we are mainly interested in long-run trends and not short-run fluctuations - we exclude years where each of the countries was involved in WWI and WWII from the analysis. We also drop the years where countries where affected severely by the Great Depression.

Finally, we aggregate up price and quantity indexes to the sectoral level with a Fisher index, as they are mainly obtained for subcategories from the original data

[3] The exact data sources and the detailed categorization of the broad sectors for each country and time period are described in Appendix D.

sources. The resulting sectoral price indexes are then adjusted for local currencies and purchasing power parity (PPP) according to the PPP conversion factors provided in the World Development Indicators (WDI). The details of how both procedures are implemented are explained in Appendix D.

3.2 Final consumption expenditure shares



Notes: The figure plots the final private consumption expenditure share of agriculture, manufacturing and services in the USA. The years affected by WWI, WWII, and the Great Depression are excluded. Source: Bureau of Economic Analysis (BEA) and Carter et al. (2006) for the years pre-1929.

Figure 1: Final private consumption expenditure shares, USA

We start the description of the historical data by presenting the final private consumption expenditure shares for each of the three broad sectors in the USA.[4] Figure 1 illustrates three robust regularities of structural change in the USA since the beginning of the last century: (i) there has been a continuing decline in the

[4] For final private consumption expenditure annual data is available since 1900 for the USA. When government consumption is included, prior to 1929 data for the USA is available in 1902, 1913, 1922, and 1927.

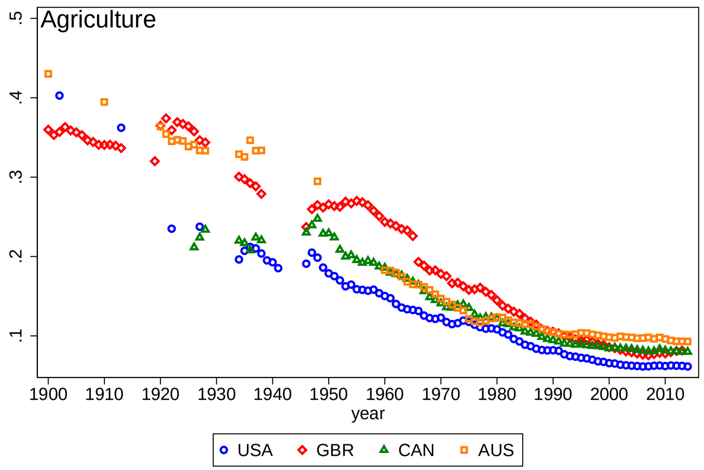
expenditure share for agricultural consumption. Historically, agriculture used to be the largest sector starting with a share of 41% in private consumption. Over time this share has fallen substantially to only 7% in the final year 2014. (ii) the expenditure share for manufacturing consumption is hump-shaped over time. In 1900 the share of manufacturing was 24%, then reaches its peak of 39% in 1950, and finally declines gradually to 26% until the end of the sample. (iii) there is an accelerated rise of the service sector. The share of services increased moderately between 1900 (34%) and 1950 (39%), before it increases strongly to 67% in the second half of the sample.

Qualitatively, the same regularities hold up in GBR, CAN and AUS and they have been documented for other countries and measures of structural changes as well (see Buera and Kaboski (2012b), Herrendorf et al. (2014), and Comin et al. (2015) for recent contributions). The regularities are also robust to the inclusion of government consumption in the service sector.[5] This is illustrated in Figure 2 where we plot the final total expenditure shares (including government consumption) of the USA, GBR, CAN, and AUS by each sector. The three panels show that the pattern of structural change in the consumption expenditure shares is remarkably similar over time in the four countries: there is a gradual decline of the agricultural share over the whole period, manufacturing peaks around 1950, and the service sector starts to rise sharply around the same date. The four countries experienced similar living standards and real per-capita income growth over the considered period such that the regularities also hold up if the expenditure shares are plotted against logarithmic real per-capita GDP.[6] The fact that the expenditure share for manufacturing is

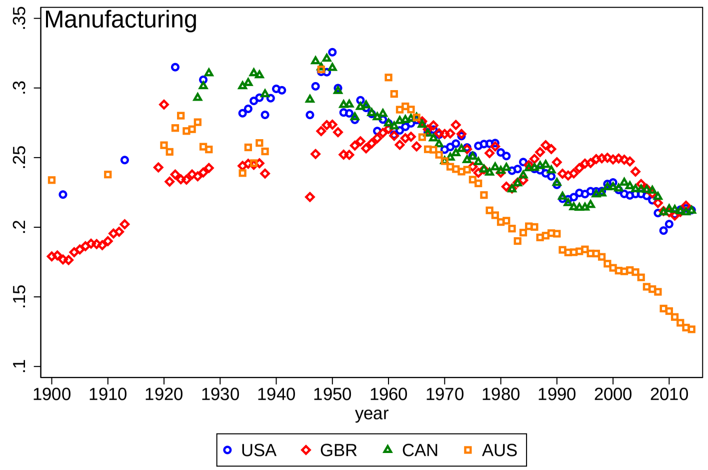
[5] In the benchmark categorization of Herrendorf et al. (2013) government consumption belongs to services.

[6] This is illustrated in Figure 7 of Appendix A where we plot the expenditure shares over the logarithmic real per-capita income taken from the Maddison Project (2013). In order to observe the patterns more formally, we also run regressions of the sector shares on log GDP per capita. Following Buera and Kaboski (2012b), we split the sample at the GDP per capita level that corresponds to the peak in manufacturing, which is $7,035 (international dollars, PPP). The regression of the manufacturing share on log GDP per-capita for the sample below $7,035 yields a coefficient of 0.059 (robust standard error 0.031). In the sample above $7,035, the coefficient is -0.048 (0.006), suggesting a hump-shape in the share of the manufacturing sector. Using the same sample definitions for the share of services yields coefficients of 0.100 (0.038) and 0.163 (0.008), suggesting an acceleration in the rise of the service sector. In the agricultural sector, the same samples lead to estimates of -0.159 (0.030) and -0.115 (0.003), suggesting a continued fall in both samples.

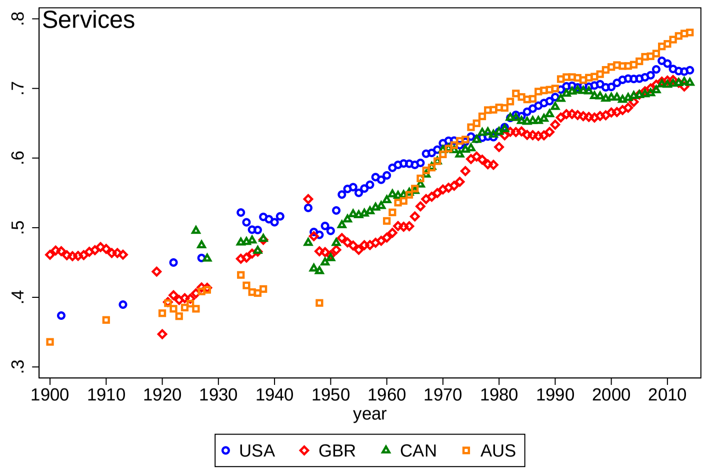
(a) Agriculture



(b) Manufacturing



(c) Services

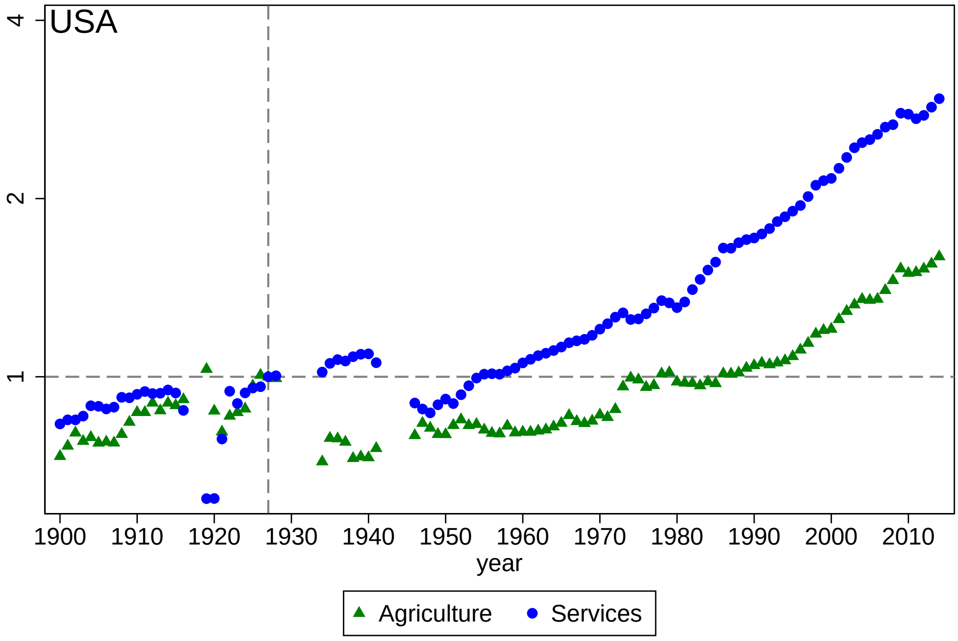


Notes: The figure plots the final total consumption expenditure share (incl. government consumption) for the USA, GBR, CAN, and AUS by sector. The years affected by WWI, WWII, and the Great Depression are excluded. Source: See Appendix D.

Figure 2: Final total consumption expenditure shares, by sector

hump-shaped in real per-capita income is related to the well-established results in the microeconomic literature on demand system estimation that allows explicitly for non-monotonic expenditure share Engel curves.[7]

3.3 Relative prices and real per-capita expenditure



Notes: The figure plots the prices of agriculture and services relative to manufacturing in the USA. The prices are based on final private consumption expenditure and normalized to unity in 1927. The years affected by WWI, WWII, and the Great Depression are excluded. Source: BEA and Carter et al. (2006) for years pre-1929.

Figure 3: Prices relative to manufacturing, USA

The expenditure share of each sector is determined by both the price and the real quantities demanded relative to the other sectors. At the outset, the observed pattern of structural change could be completely driven by movements in relative prices. However, in this section we document the development of the three sector's relative prices over the last century and show that relative price effects alone cannot

[7] See Banks et al. (1997) for the foundations of the established estimation of quadratic almost ideal demand systems.

explain the structural transformation observed in the USA, GBR, CAN, and AUS over the last century.

Figure 3 plots the price of the agricultural and the private service sector relative to manufacturing for the USA. The sectoral prices relative to manufacturing have remained relatively stable in the first half of the century and then started to increase around 1950. The price increase is more pronounced for the service sector than for agriculture, and - if substitution effects are strong enough - the relative price alone could explain the late rise of the service sector. However, for the agricultural sector both the price and the real consumption relative to services are falling over time, in particular since 1950.[8] Such a positive relationship cannot be explained with a well-behaved substitution elasticity and shows that next to relative price effects also income effects are necessary to explaining the pattern of structural change observed in the historical data.

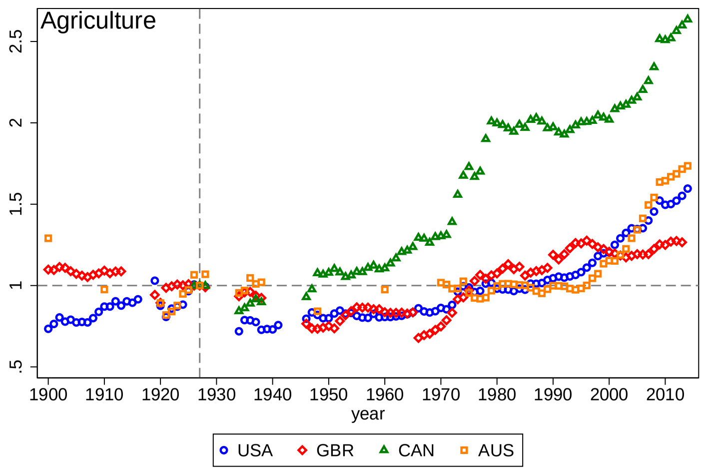
As is the case for the expenditure shares, also the qualitative pattern of relative prices is remarkably similar across the four considered countries. The two upper panels in Figure 4 show the relative prices of agriculture and services for the USA, GBR, CAN, and AUS. Prices are expressed in PPP-adjusted 1990 international $. Panel (a) illustrates that there are some quantitative differences across countries in the price of the agricultural sector. While relative prices remained more or less stable until around 1950 in all countries, the increase in the relative price was more pronounced in CAN compared to the other three economies. Starting from the base year in 1927, the agricultural price in CAN rose by a factor of around 2.5 by the year 2014, while the same increase for GBR was less than a factor of 1.5. However, qualitatively all agricultural prices started to increase from around 1950. Panel (b) shows the same qualitative pattern for the relative price of services, where the price increase between 1950 and 2014 is generally more pronounced than in the agricultural sector. In CAN for example, the price increased by a factor of around 4 compared to the base year in 1927.

Finally, panel (c) of Figure 4 illustrates the real per-capita expenditure growth over the last century in the USA, GBR, CAN, and AUS.[9] It shows that there has

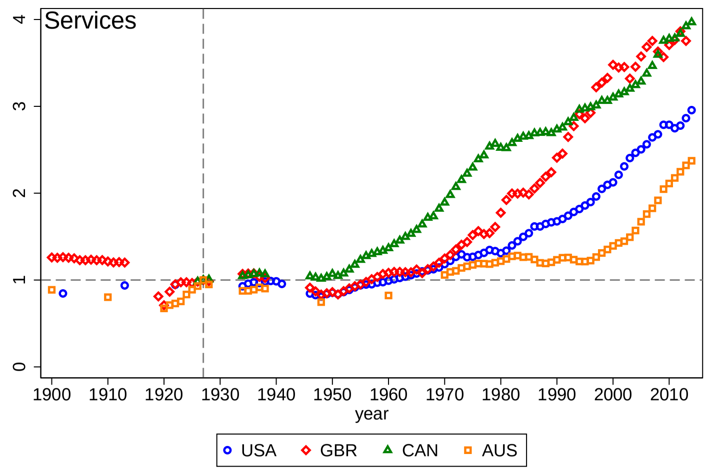
[8] This is illustrated in Figure 10 of Appendix A which plots prices and quantities of agriculture relative to the service sector.

[9] Note that total real expenditure is not observed in the data. Given the sectoral prices, the model-consistent aggregate price index depends on the considered preference specification and

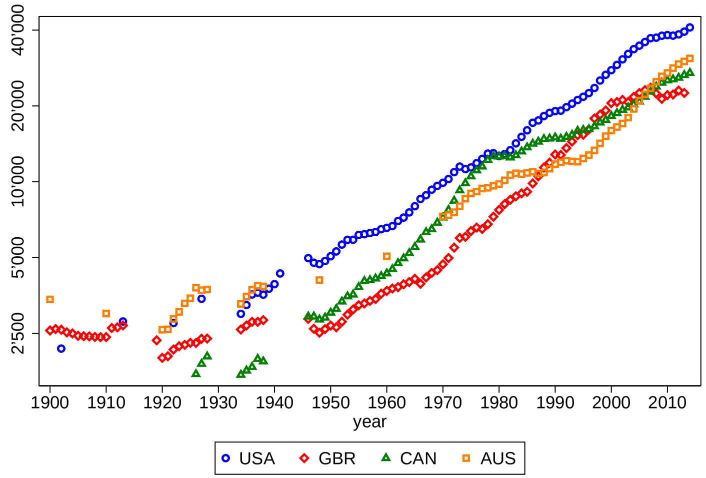
(a) Relative prices, Agriculture



(b) Relative prices, Services



(c) Relative per-capita expenditure



Notes: The figure plots in panel (a) and (b) the prices of agriculture and services, and in panel (c) the nominal per-capita expenditure relative to the manufacturing price in the USA, GBR, CAN, and AUS. All nominal variables are based on final total consumption expenditure (incl. government consumption) and expressed in PPP-adjusted 1990 international \$. In panel (a) and (b) prices are normalized to unity in 1927, and in panel (c) real per-capita expenditure is plotted on a ratio scale. The years affected by WWI, WWII, and the Great Depression are excluded. Source: See Appendix D.

Figure 4: Relative prices and real per-capita consumption expenditure

been sustained growth in all four countries (with the exception of the GBR and AUS between 1900 and 1920 where per-capita expenditure is more or less stagnating). Note that expenditure is plotted on a ratio scale, thus the slope indicated by the data points can be interpreted as its approximate yearly growth rate. For the USA, for example, real per-capita expenditure has increased by more than a factor of 18 between the first observation in 1902 and the last in 2014. Thus, if income effects are at work, they must have an important role in explaining the pattern of structural change over the last century.

3.4 Taking stock

The analysis in this section illustrates the importance of taking into account historical data on consumption expenditure shares, prices and nominal per-capita expenditure prior to 1950. An analysis limited to the postwar period would miss two important regularities of structural change that we find in the long-run data: the hump-shape in the expenditure share of manufacturing and the late rise of the service sector. Moreover, expenditure shares and relative prices developed remarkably monotone in the second half of the last century. Thus, the income and relative price effects inferred from the very smooth and monotonic structural transformation in the postwar periods are likely inconsistent with the dynamics prior to 1950, where expenditure shares were non-monotonic and relative prices more or less stable.

Moreover, we overcome the limited data availability for the USA in the first half of the century by adding historical data for GBR, CAN, and AUS, which experienced a remarkably similar pattern of structural transformation over the last century. At the same time, this approach also increases the external validity of the parameters' empirical estimates that we infer from the pooled historical data for all countries.

its parameter values which are unknown prior to any estimation. Thus, in the figure, we proxy real expenditure by expressing nominal expenditure relative to the price of manufacturing. The qualitative conclusions from the figure remained unchanged if we used, for example, a Fisher-index over the sectoral prices to deflate the nominal expenditure.

4 Theoretical framework

4.1 Economic environment

We consider an infinite horizon, closed economy framework in discrete time with four production sectors. Our main focus will be on three sectors that produce the consumption goods called agriculture A, manufacturing M, and services S, but we also explicitly model a fourth sector that produces an investment good X. In each sector $j = A, M, S, X$ output y_j is competitively produced according to the following Cobb-Douglas technologies

$$y_{j,t} = k_{j,t}^{\alpha} \left(\gamma_j^t n_{j,t}\right)^{1-\alpha}. \tag{1}$$

Here, $k_{j,t}$ and $n_{j,t}$ denotes capital and labor used in sector j and γ_j^t is a time-varying Harrod neutral technology term (where t is a time index). The labor-augmenting technology term is normalized to one in all sectors in period $t = 0$. We have $\alpha \in (0, 1)$, and $\gamma_j \geq 1, \forall j$. The firms in every sector j take the rental rate, $R_t = r_t + \delta$, the wage rate, w_t, and the output price $p_{j,t}$ as given and then choose their capital and labor input to maximize profits. The capital and labor market clearing conditions are

$$\sum_{j=A,M,S,X} k_{j,t} = k_t, \text{ and } \sum_{j=A,M,S,X} n_{j,t} = n, \tag{2}$$

where k_t and n denotes total capital and labor in the economy.[10]

The output of agriculture, manufacturing and services is all consumed whereas the output of sector X is invested. There is a unit interval of infinitely lived households indexed by $i \in [0, 1]$ with the following preferences

$$\mathcal{U}_{i,0} = \sum_{t=0}^{\infty} \beta^t v(e_{i,t}, P_t), \quad P_t \equiv (p_{A,t}, p_{M,t}, p_{S,t}). \tag{3}$$

The instantaneous utility function $v(\cdot)$ is given in *indirect form*, i.e., it is defined over nominal expenditure $e_{i,t}$ and prices $p_{j,t}$ for each of the consumption goods

[10]Here we focus on the case of inelastic labor supply, so total labor endowment in the economy is constant. We relax this assumption by explicitly modeling the choice of hours worked in Section C.

$j \in J \equiv \{A, M, S\}$. The parameter $\beta \in (0, 1)$ denotes the discount factor. We allow for household heterogeneity in factor endowments. Household i supplies inelastically $n_i \geq 0$ hours to the labor market and her initial wealth $a_{i,0}$ is exogenously given. Since preferences are additively separable in time the household's problem can be split up into an inter- and an intratemporal problem. The intertemporal problem deals with the optimal saving/spending decision where household i chooses a sequence $\{e_{i,t}, a_{i,t+1}\}_{t=0}^{\infty}$ to maximize (3) subject to a period budget constraint

$$a_{i,t+1} = a_{i,t}(1 + r_t) + w_t n_{i,t} - e_{i,t}, \tag{4}$$

and a standard no Ponzi game condition.[11] Regarding the intratemporal problem we can simply apply Roy's identity to find how nominal expenditure $e_{i,t}$ is spent on the three different sectors and consequently to find the individual Marshallian demand $c_{i,j,t}$, $j \in J$ for each household i.

In the following we chose the price of the investment as a numéraire. Consequently, we can write the asset market clearing condition as

$$\int_0^1 a_{i,t} di = k_t, \tag{5}$$

and the law of motion of the aggregate capital stock becomes

$$k_{t+1} = k_t(1 - \delta) + y_{X,t}. \tag{6}$$

Furthermore we have

$$\int_0^1 n_i di = n \tag{7}$$

and market clearing in the three consumption sectors imply

$$\int_0^1 c_{i,j,t} di = y_{j,t}, \ j \in J. \tag{8}$$

In macroeconomic theory it is more common to work with direct preference specifications defined over real consumption commodities instead of the indirect formulation used here. However, as we will see below, the indirect formulation

[11] The no Ponzi game condition can be expressed as $\lim_{T \to \infty} a_{i,T+1} \prod_{s=1}^{T} (1 + r_s)^{-1} \geq 0$.

allows us to characterize the optimal saving decision as simple as in a one-sector economy. This enables us to highlight the additional restrictions that the existence of an exact balanced growth path imposes on preferences. Furthermore, for some of the preferences specifications that we will evaluate below, a closed form utility function only exists in the indirect formulation. For these reasons, we prefer the indirect formulation here.

4.2 Equilibrium definition and discussion

An equilibrium in this economy is a sequence of prices and quantities that is jointly consistent with utility maximization of all households, profit maximization (and perfect competition) of all firms as well as all the market clearing conditions (5)-(8).

To analyze the historical consumption expenditure data presented in Section 3.2 we will in the following focus on this dynamic general equilibrium framework as presented in Section 4.1. As we will argue below this is a useful benchmark model to guide our data analysis: The framework is flexible enough to allow relative prices between sectors to change. Furthermore, by allowing for capital accumulation, the model includes the intertemporal margin, which is essential to discuss consistency with sustained growth of income. Although the framework is in some sense very standard it seems nevertheless relevant to comment here on its generality.[12] First, note that we focus here on the decentralized market equilibrium. However, the welfare theorems apply and the decentralized market outcome is Pareto efficient (and could also be characterized as the solution to a planner's problem). Second, the restrictions on the preference side like additive time separability and standard discounting are relatively mild and standard and we keep full flexibility with respect to the instantaneous utility function. And in the remainder of the paper we will analyze the prediction of this framework under different functional form assumption of the instantaneous utility function $v(e_{i,t}, P_t)$. So far we abstract from endogenous labor supply but this assumption is relaxed in Section C. On the production side, however, the framework puts some simplifying structure, most importantly an identical output elasticity of capital α across the three consumption good sectors. This

[12]For instance, it coincides (except for the generality kept in terms of instantaneous utility function) with the "benchmark model" proposed in the Handbook of Economic Growth chapter by Herrendorf et al. (2014).

assumption implies that relative price changes are completely driven by differences in the productivity growth across sectors. It however precludes factor intensity differences as a source of relative price changes (à la Acemoglu and Guerrieri (2008)) and that shifts in the demand structure due to income effects have an impact on relative prices. The Cobb-Douglas functional form of the production function could be relaxed and the output elasticity of capital in the investment good sector could be allowed to be different from the consumption sectors. These generalizations would not affect the model's main predictions.

4.3 Equilibrium implications

In equilibrium, the production side of the economy can be characterized by the following proposition.

Proposition 1. *The capital-labor ratio is equalized across sectors, i.e.,*

$$\frac{k_{j,t}}{n_{j,t}} = \frac{k_t}{n}, \ \forall t, j = A, M, S, X. \tag{9}$$

Furthermore, the prices are given by

$$p_{j,t} = \gamma_j^{(1-\alpha)t} \left(\frac{w_t}{1-\alpha} \right)^{1-\alpha} \left(\frac{r_t + \delta}{\alpha} \right)^{\alpha} = \left(\frac{\gamma_X}{\gamma_j} \right)^{(1-\alpha)t}, \ j = A, M, S, \tag{10}$$

where the choice of numéraire that implies $1 = \gamma_X^{(1-\alpha)t} \left(\frac{w_t}{1-\alpha} \right)^{1-\alpha} \left(\frac{r_t+\delta}{\alpha} \right)^{\alpha}$ *has been used for the second equality. The equilibrium rental rate is given by* $r_t + \delta = \alpha \left(\frac{n}{k_t} \right)^{1-\alpha}$. *Finally, under optimal production, output can be expressed as*

$$y_j = \gamma_j^{(1-\alpha)t} \left(\frac{k_t}{n} \right)^{\alpha} n_{j,t}, \ j = A, M, S, X. \tag{11}$$

This proposition is a direct consequence of the assumption that the output elasticity of capital is identical across sectors. This leads to equalized capital intensities across sectors reported in Equation (9). Furthermore, since the production functions then only differ in the labor-augmenting technology terms the marginal rate of transformation is constant in any given point in time and solely pinned down by the technology side as shown in Equation (10). Hence, shifts in the demand structure will not affect relative prices. Finally, since the capital intensity is identical across sectors, as shown by (11), output in each sector can be written as a linear function of labor used in this sector. Note again, that we could allow the capital intensity in the investment good sectors to differ from the consumption good sectors (since along the balanced growth path the saving and investment rate will be constant. However, for the consumption sectors for which the expenditure shares will vary over time, the assumption of identical capital intensities is crucial, since otherwise already the technology side of the economy would imply that whenever there is structural change there cannot be balanced growth.[13] Consequently the assumption of identical factor shares is a restriction that we impose for this theoretical reason, but what does the data say on this question? Here it is important to first note that the specified production functions are written in terms of gross final output and data on factor intensities is only readily available at the industry value-add level. Hence, in order to measure the capital share α of a sector the entire input-output structure needs to be taken into account. Valentinyi and Herrendorf (2008) do provide such estimates for some broadly defined sectors at the gross final output level. The results show that the shares of capital and labor varies surprisingly little and the assumption of identical factor shares across consumption sectors does not seem to be such a bad approximation. At the same time it is important to emphasize that this is only true with respect to the capital-labor split. If other production factors like land or the division into skilled and unskilled labor were considered we expect factor intensity differences to be more relevant. Also the assumption of Harrod-neutral technical change is made for theoretical reasons. A non-constant rate of technical change would ex ante rule out the existence of a balanced growth path. Importantly, however, we allow the rate of technical change to be sector specific but constant over time. This assumption implies that relative prices will change over time but do so at a constant growth rate. As our data on relative prices in Section 3.3 shows this seems to be a good first-pass approximation of the data, where we see systematic changes in relative prices in the long-run. However, the data also highlights that sometimes

[13]Note that the issue here arises from the intensity differences in the factor that can be accumulated, i.e., here physical capital. In a formulation with human capital that can be accumulated as well the relevant assumption would be that the intensity of human plus physical capital is identical across sectors with changing nominal output shares.

there seems to be a structural break in the relative price growth around WWII. To generate such a structural break by our theoretical framework an exogenous switch of the γ_j parameters is required.

The optimal saving behavior of a household i is characterized by the following Euler equation.

Proposition 2. *Solving the intertemporal household problem gives rise to the following Euler equation*

$$\frac{v_e(e_{i,t}, P_t)}{v_e(e_{i,t+1}, P_{t+1})} = \beta(1 + r_{t+1}), \tag{12}$$

where $v_e(\cdot)$ is the marginal (momentary) utility of nominal consumption expenditure in a given period.

Jointly with the household budget constraint, (4), the transversality condition, as well as with the initial wealth $a_{i,0}$ this fully characterizes the household's spending and saving behavior. Aggregating all the household budget constraints and combining it with (6) gives

$$k_{t+1} = k_t(1 - \delta) + \gamma_X^t k_t^\alpha n^{1-\alpha} - \int_0^1 e_{i,t} di. \tag{13}$$

This allows us to characterize the dynamic of the capital stock and finally solve the model.

In the following we will ask the question whether a given preference specification is in line with exact balanced growth, which requires that the Euler equation supports jointly a constant interest rate and a constant nominal expenditure growth rate. In a framework without endogenous labor supply, as it can directly be seen from (12) this is fulfilled if the indirect utility function is a power function of $e_{i,t}$, i.e. can be written as

$$v(e_{i,t}, P_t) = \frac{[e_{i,t}/\mathcal{B}(P_t)]^\epsilon - 1}{\epsilon} + \mathcal{C}(P_t), \tag{14}$$

where $\epsilon \neq 0$, and $\mathcal{B}(\cdot)$ and $\mathcal{C}(\cdot)$ are arbitrary function of the prices (that of course have to fulfill additional regularity conditions). This is the PIGL class of preferences (see Muellbauer (1975, 1976)) and it is a fact that this is not only a sufficient but also a necessary condition for exact balanced growth without endogenous labor supply.[14]

In addition to the intertemporal problem, applying Roy's identity gives the Marshallian demands, i.e., how a given expenditure level is optimally spent on the different sectoral output. So the focus of the rest of the paper is on the demand side, where we consider different preference specifications and analyze how they perform in terms of fitting the historical expenditure data. Note that for this step no dynamic general equilibrium framework is required, since we just look at the predicted expenditure structure for given preferences $v(e_{i,t}, P_t)$. We then ask what preference parameters give rise to a good fit of the historical expenditure data. For this part of the analysis a static partial equilibrium framework would suffice. However, we also want to discuss the theoretical properties of the different instantaneous utility functions in an infinite horizon general equilibrium model. More specifically we will analyze the aggregation properties of the economy, the existence of a balanced growth path as well as asymptotic dynamics under different preference specifications and we do so in the economic environment specified in Section 4.1.

5 Specific preference specifications

In this section we first discuss the theoretical properties of standard preference specifications that have been used in the existing empirical literature. In the second part, we then propose an alternative preference specification with important theoretical advantages over the standard ones.

An important attribute of preference specifications considered in the structural change literature is that both relative price effects and income effects are demand side drivers of structural transformation. Moreover, it is a stylized fact that advanced economies have experienced steady per-capita expenditure growth over the last century. Thus, one challenge is to incorporate structural transformation into growth models with otherwise standard long-run properties in the aggregate.[15] On the other hand, the microeconomic literature on demand system estimation has

[14] This result is well documented in the literature, see for instance Deaton and Muellbauer (1980) or Crossley and Low (2011). However, as is less well known and shown in Section C below, this necessary class of balanced growth preferences can be generalized if the labor supply is considered as an endogenous choice.

[15] See Herrendorf et al. (2014) for a recent discussion on growth and structural transformation.

been less concerned with the theoretical properties in steady growth environments. Instead, this literature has established demand systems (like the QAIDS of Banks et al. (1997)) that allow for quadratic expenditure share Engel curves, a fact that is already established for microeconomic consumer data. Thus, the QAIDS specification is also suitable to capture the non-monotonic pattern of structural change that we document over the last century for the manufacturing expenditure share.

Motivated by the above observations, we then propose a preference specification which is an extension of the PIGL class of preferences defined in Muellbauer (1975, 1976). This class of preferences has a similar flexibility as the QAIDS considered in the microeconomic literature, but is at the same time consistent with steady growth environments. In a framework with structural change between two sectors - goods and services - Boppart (2014) has already shown that PIGL preferences are consistent with an exact balanced growth path in the aggregate.

5.1 Standard preference specifications

In what follows, we abstract for simplicity from heterogeneity in factor endowments, $a_{i,0} = a_0$ and $n_i = n$. This allows us to work with a representative average household and the individual index i becomes redundant. Moreover, we also omit the time index on prices, p_j, per capita quantities, c_j, and the per-capita expenditure level, $e = \sum_{j \in J} p_j c_j$ when this is no source of confusion. The exogenous parameters of the preference specifications are constant over time unless we make specific statements about time-dependence.

5.1.1 Generalized Stone-Geary

Herrendorf et al. (2013) (henceforth referred to as HRV 2013) demonstrate that the generalized Stone-Geary preference specification predicts a very accurate fit of the USA's pattern of structural change in the postwar period. The specification yields the following expenditure shares as a function of sectoral prices, p_j and nominal expenditure per capita, e,

$$\eta_j \equiv \frac{p_j c_j}{e} = \frac{\omega_j p_j^{1-\sigma} \left[1 - \frac{\sum_{k \in J} p_k \bar{c}_k}{e}\right]}{\sum_{k \in J} \omega_k p_k^{1-\sigma}} + \frac{p_j \bar{c}_j}{e}, \tag{15}$$

where ω_j are positive weights that add up to one, $\sum_{j \in J} \omega_j = 1$, and $\bar{c}_j$ denotes the subsistence consumption level for each good. These preferences are well-behaved if, $\omega_j > 0$ and $\sigma > 0$. Moreover, the subsistence level $\bar{c}_j$ has to be smaller than the minimum real consumption per capita of good j observed in the data.[16] Following the previous literature, HRV 2013 restrict the subsistence level of manufacturing consumption to zero, $\bar{c}_M = 0$.[17] The functional form of the expenditure share in Equation (15) shows that the parameter σ is an important determinant of the relative price effects, i.e., when $\sigma \to 1$ prices do not effect the expenditure shares other than through the terms that contain the subsistence consumption. Moreover, in the long-run - when relative per-capita expenditure continues to grow without bound, i.e. $e/p_j \to +\infty$, all the terms involving the subsistence levels $\bar{c}_j$ vanish. Therefore, when $\sigma < 1$, the Stone-Geary preference specification implies that structural change is driven more and more by relative price effects as real per-capita expenditure grows.

A direct consequence of choosing the Stone-Geary preference specification is that the resulting estimates for the parameters that govern relative price and income effects must depend on the time period covered by the sample (or, the dispersion of income in cross-sectional data). In particular, generating significant income effects towards the end of a long sample requires very high subsistence levels in the first place. These income effects will be even stronger at earlier stages of the sample and may lead to a bad fit of the overall data. For the generalized Stone-Geary specification this problem has already been emphasized by Buera and Kaboski (2009) for historical sectoral value-added shares in the USA. We will show in Section 6 that this finding also holds up in historical final consumption expenditure data not only for the USA, but also for GBR, CAN and AUS.

The existing literature has emphasized that generalized Stone-Geary preferences are only consistent with exact balanced growth for a narrow set of parameterizations: Kongsamut et al. (2001) consider the special case without relative price effects where

[16] For example, suppose that the subsistence level of agricultural consumption $\bar{c}_A$ cannot be covered by real consumption c_A measured in the data. The Stone-Geary preferences are then no longer well-defined. Such a high subsistence level would imply that the consumer starved in that period.

[17] We find that this is an important restriction in the estimation procedure. Without setting $\bar{c}_M$ to an exogenous level the model has a hard time identifying all three subsistence levels simultaneously. However, there is no major information loss (or in other words, the model fit does not worsen substantially) when the restriction $\bar{c}_M = 0$ is imposed.

$\sigma \to 1$ and $\sum_{j \in J} \bar{c}_j p_j = 0$. Ngai and Pissarides (2007) on the other hand assume that there are no income effects, $\bar{c}_j = 0$. We will show in Section 6 that the parameters estimated from the historical data suggest that both relative price and income effects are needed to fit the historical data. Thus, the corresponding parameterizations of the Stone-Geary preferences will be generally inconsistent with exact balanced growth in the aggregate.

5.1.2 Generalized PIGLOG (QAIDS)

In the microeconomic literature on consumer demand systems, Banks et al. (1997) (henceforth BBL 1997) have established the estimation of non-monotonic expenditure share Engel curves with the QAIDS. This demand system results from extending the PIGLOG preferences. The resulting expenditure shares are quadratic in logarithmic real per-capita expenditures and read (see BBL 1997, Equation (10))

$$\eta_j = \pi_j + \sum_{k \in J} \varphi_{jk} \log(p_k) + \theta_j \log(e/\Pi(P)) + \lambda_j/\Theta(P) \left[\log(e/\Pi(P))\right]^2 , \qquad (16)$$

where $\Theta(P) = \prod_{j \in J} p_j^{\theta_j}$ and nominal per-capita expenditure, e, is deflated with the aggregate price index

$$\log(\Pi(P)) = \pi_0 + \sum_{j \in J} \pi_j \log(p_j) + 1/2 \sum_{j \in J} \sum_{k \in J} \varphi_{jk} \log(p_j) \log(p_k).$$

The key parameters of this specification are the λ_js, which regulate the impact of the quadratic terms in the expenditure system. In the special case where $\lambda_j = 0$ for all sectors, the preferences specification reduces to the standard PIGLOG class. Preferences are well-behaved if $\sum_{j \in J} \varphi_{jk} = \sum_{k \in J} \varphi_{jk} = \sum_{j \in J} \theta_j = \sum_{j \in J} \lambda_j = 0$ and $\sum_{j \in J} \pi_j = 1$. It is also common to impose symmetry of price effects, $\varphi_{jk} = \varphi_{kj}$ which allows to further reduce the number of parameters. Finally, it is standard to set π_0 to a fixed value because it is hard to identify empirically. We choose this value according to the procedure suggested in BBL 1997, which makes sure that the real expenditure implied by the model parameters always remains positive.

BBL 1997 show that the QAIDS demand system has rank 3, which corresponds to the highest flexibility that a rational exactly aggregable demand system can achieve according to the Gorman (1981) aggregation theorem (see also Lewbel (2003) for a related discussion). Thus, it doesn't come as a complete surprise that in Section 6 we find that the QAIDS specification provides the best fit of the data among the considered preference specifications in the pooled cross-country sample. However, generalized PIGLOG preferences violate regularity conditions when per-capita expenditure is growing steadily. Intuitively, because the expenditure share is a quadratic function of logarithmic expenditure, in the long-run the expenditure system will violated the restriction that the shares have to remain in the unit interval.

5.2 Generalized PIGL preferences

In this section we propose a preference specification that allows for a similar flexibility of income effects as the QAIDS specification, but is at the same time consistent with steady growth environments.

Suppose preferences of the household sector can be represented by the following indirect utility function

$$v(e,P) = \frac{1}{\epsilon}\left[\frac{e-\mathcal{A}(P)}{\mathcal{B}(P)}\right]^{\epsilon} - \frac{1}{\epsilon} + \mathcal{C}(P), \tag{17}$$

where $\epsilon \neq 0$. The price functions $\mathcal{A}(P)$ and $\mathcal{B}(P)$ are linear homogenous and $\mathcal{C}(P)$ is homogenous of degree zero in the price vector P. In the special case when $\mathcal{A}(P) = 0$, this specification nests the standard PIGL preferences stated in Equation (14). Using Roy's identity, the expenditure share for good $j \in J$ is then given by

$$\begin{aligned} \eta_j &= -\frac{\partial v(e,P)/\partial p_j}{\partial v(e,P)/\partial e}\frac{p_j}{e} \\ &= \frac{\partial \mathcal{A}(P)}{\partial p_j}\frac{p_j}{e} + \frac{\partial \mathcal{B}(P)}{\partial p_j}\frac{p_j}{\mathcal{B}(P)}\frac{1}{e}\left[e-\mathcal{A}(P)\right] - \frac{\partial \mathcal{C}(P)}{\partial p_j}\frac{p_j}{e}\mathcal{B}(P)^{\epsilon}\left[e-\mathcal{A}(P)\right]^{1-\epsilon}. \end{aligned} \tag{18}$$

Equation (18) shows that the expenditure shares are a relatively flexible function of nominal per-capita expenditure, e. We then propose the following parameterization for the price functions

$$\begin{aligned}\mathcal{A}(P) &= \tau p_A^{1-\rho} p_S^{\rho} \\ \mathcal{B}(P) &= p_M^{1-\phi} p_S^{\phi} \\ \mathcal{C}(P) &= -\left(\frac{\nu_1}{\psi_1}\left[\frac{p_A}{p_S}\right]^{\psi_1} + \frac{\nu_2}{\psi_2}\left[\frac{p_M}{p_S}\right]^{\psi_2}\right),\end{aligned}$$

which is a natural extension of the two-sector specification considered in Boppart (2014). We choose the functions $\mathcal{A}(P)$ and $\mathcal{B}(P)$ to be simple Cobb-Douglas aggregators of the sectoral price levels with a parsimonious parameterization, while $\mathcal{C}(P)$ is a flexible function of all relative prices. Given this parameterization, the expenditure shares associated with the preference specification in Equation (17) are given by

$$\eta_A = (1-\rho)\frac{\mathcal{A}(P)}{e} + \nu_1\left[\frac{p_A}{p_S}\right]^{\psi_1}\left[\frac{e-\mathcal{A}(P)}{\mathcal{B}(P)}\right]^{1-\epsilon}\frac{\mathcal{B}(P)}{e} \tag{19}$$

$$\eta_M = -(1-\phi)\frac{\mathcal{A}(P)}{e} + (1-\phi) + \nu_2\left[\frac{p_M}{p_S}\right]^{\psi_2}\left[\frac{e-\mathcal{A}(P)}{\mathcal{B}(P)}\right]^{1-\epsilon}\frac{\mathcal{B}(P)}{e} \tag{20}$$

$$\eta_S = (\rho-\phi)\frac{\mathcal{A}(P)}{e} + \phi - \left(\nu_1\left[\frac{p_A}{p_S}\right]^{\psi_1} + \nu_2\left[\frac{p_M}{p_S}\right]^{\psi_2}\right)\left[\frac{e-\mathcal{A}(P)}{\mathcal{B}(P)}\right]^{1-\epsilon}\frac{\mathcal{B}(P)}{e}. \tag{21}$$

For the sake of illustration, let $\epsilon = -1$. Then the above expenditure shares take the generic form

$$\eta_j = \mathcal{A}(P)D_j(P)[e/\mathcal{B}(P)]^{-1} + E_j(P) + F_j(P)[e/\mathcal{B}(P)], \tag{22}$$

where the price-dependent coefficients $D_j(P)$, $E_j(P)$, and $F_j(P)$ are chosen appropriately. When the price function $\mathcal{A}(P)$ is nonzero, Equation (22) shows that the expenditure shares are non-linear in the deflated per-capita expenditure, $e/\mathcal{B}(P)$. In the empirical specification, we let the data choose the value of ϵ, which allows for even more flexibility. Without further restrictions, the demand system in Equations (19)–(21) has eight parameters: τ, ρ, ϕ, ϵ, ν_1, ν_2, ψ_1, ψ_2. We will refer to this unrestricted specification as the *generalized PIGL* preferences. The number of parameters reduces to six when we restrict the price function $\mathcal{A}(P)$ to be zero, and we refer to this special case as the *PIGL* preference specification.

6 Empirical results

In this section we estimate the expenditure systems presented in Section 5. To identify the preference parameters, we use the variation in the historical data on sectoral prices and nominal final consumption expenditure per-capita for the USA, GBR, CAN, and AUS over the period 1900 to 2014. Following HRV 2013, we report the feasible generalized nonlinear least squares (FGNLS) estimator with robust standard errors for the parameters of each specification.[18] As the expenditure shares for the three sectors add up to unity, it is sufficient to estimate the parameters of the expenditure shares for the manufacturing and the service sector. The remaining parameters and standard errors can then be derived from the appropriate parameter restrictions.

The main finding of this section is that the generalized Stone-Geary preference specification struggles to fit the historical data, in particular the hump-shape in manufacturing, the pronounced decline of agriculture and the late rise of services. Moreover, the resulting point estimates for the parameters differ significantly from specifications that are consistent with exact balanced growth. On the other hand, the generalized PIGLOG and PIGL specifications provide a better fit to the historical data, and the generalized PIGL yields theoretically reasonable parameter estimates.

6.1 Generalized Stone-Geary

In Table 1 we report the estimation results for the expenditure system that results from the generalized Stone-Geary specification in Equation (15). The table reports the estimation results for six different samples: in columns (1)-(3) we pool the observations from all four countries - the *full sample* - and in columns (4)-(6) we restrict the empirical analysis to the USA. In both cases we also report the estimates for shorter sample periods starting in 1929 and 1947, respectively.[19]

[18] This estimator is implemented by Stata's command *nlsur* and can be applied to estimate the parameters of nonlinear systems of equations.

[19] The year 1947 is considered because HRV 2013 estimate the generalized Stone-Geary specification for the USA in the postwar period 1947 to 2010. Moreover, structural change in the postwar

	Full Sample			USA		
	1900-2014	1929-2014	1947-2014	1902-2014	1929-2014	1947-2014
	(1)	(2)	(3)	(4)	(5)	(6)
σ	.569***	.588***	.588***	.498***	.678***	.849***
	(19.31)	(18.99)	(11.72)	(17.31)	(25.59)	(16.10)
$\bar{c}_A$	721.182	848.751	947.227	786.821	854.099	991.665***
	(.)	(.)	(.)	(.)	(.)	(44.98)
$\bar{c}_S$	-773.773***	-1128.777***	-1210.453**	-1059.534***	-2028.498***	-6618.773***
	(-4.27)	(-5.73)	(-2.48)	(-6.39)	(-9.92)	(-4.25)
ω_A	.066***	.047***	.037***	.046***	.036***	.022***
	(38.60)	(49.53)	(28.22)	(23.01)	(37.58)	(19.38)
ω_M	.226***	.224***	.224***	.235***	.226***	.181***
	(66.15)	(66.41)	(29.48)	(85.76)	(82.55)	(14.54)
ω_S	.709***	.730***	.738***	.720***	.738***	.797***
	(161.18)	(197.88)	(84.58)	(218.99)	(243.06)	(60.16)
N	318	276	250	81	77	68
AIC	-2813.8	-2743.2	-2646.1	-923.0	-986.7	-1008.6
$\min\{c_A\}$	721.2	848.8	947.2	786.8	854.1	1171.1
RMS_A	0.027	0.018	0.013	0.017	0.010	0.004
RMS_M	0.026	0.023	0.023	0.014	0.010	0.008
RMS_S	0.027	0.018	0.013	0.017	0.010	0.004

Table 1: Estimation generalized Stone-Geary

Note: Years where the USA was involved in WWI (1917-1918), WWII (1942-1945), or affected by the Great Depression (1929-1933) are excluded from all estimations. In columns (1)-(3), years where AUS, CAN, and GBR where involved in WWI (1914-1918), WWII (1939-1945), or affected by the Great Depression (1929-1933) are excluded.

The point estimate for the price elasticity parameter σ reported in columns (1) to (4) varies between 0.50 and 0.59. This shows that the generalized Stone-Geary specification attributes a substantial fraction of the variation in the expenditure shares to relative price effects, once the sample covers a longer time period or a broader sample of countries. On the other hand, if the sample is restricted to the postwar period of the USA in column (6), price effects become less important ($\hat{\sigma} = 0.85$) which is consistent with the estimates reported in Table 1 of HRV 2013. This confirms the earlier conjecture that the relative importance of price and income effects predicted by the generalized Stone-Geary specification will be sensitive to the considered sample. The more dispersed the per-capita expenditure levels in the sample, the more important are the relative price effects in comparison to the income effects.[20]

The second row in Table 1 shows in columns (1) to (5) that the estimated subsistence level of agricultural consumption hits a corner, $\hat{\bar{c}}_A = \min\{c_A\}$. In other words, the model fit would improve if the subsistence level of food were allowed to be higher than the minimum consumption measured in the data. The reason is that the wider the dispersion of real per-capita expenditure in the data, the higher subsistence levels are required to generate strong enough income effects at the high expenditure levels towards the end of the sample. For the agricultural sector, this is of particular importance, because a strong income effect is needed to explain the parallel decline of prices and quantities relative to services in the second half of the sample.

As a consequence of the importance of both relative price effects and income effects in the historical data, the estimated parameters and standard errors clearly reject specifications that are consistent with exact balanced growth. However, in

period has been remarkably monotone in the considered countries. The other threshold year in 1929 is chosen because the BEA reports harmonized consumption expenditure and price data for the United States from 1929 onwards. Observations from earlier periods are based on historical data from Carter et al. (2006). The details of the data construction are documented in Appendix D.

[20] For an even longer sample with decennial value-added data of the United States (1870-2000), Buera and Kaboski (2009) conclude that the best fit of the generalized Stone-Geary specification is achieved when the relative price effects correspond to a Leontief specification, $\sigma \to 0$, i.e., relative real quantities are inelastic to changes in relative prices such that the effect on the nominal per-capita expenditure is maximal. However, even for this extreme case, Buera and Kaboski (2009) found the overall fit of the generalized Stone-Geary specification to be questionable.

all samples the estimates for the subsistence consumption levels are consistent with the common perception in the literature, that the agricultural good is predicted to be a necessity ($\bar{c}_A > 0$), while the service good is a luxury ($\bar{c}_S < 0$). The remaining parameter estimates for the weights ω_i are also uncontroversial.

6.2 Generalized PIGLOG (QAIDS)

In this section we present the estimation results from the QAIDS. This specification will allow us to explore the potential for improvements in the model fit when allowing for non-monotonic expenditure share Engel curves. We are focusing on a specification with 10 structural parameters.[21] The estimation results are reported in Table 2. Given the relatively large number of parameters, it is not entirely surprising that the statistical significance of different parameters varies across the different samples. If one were to concentrate on a particular sample, it is possible to reduce further parameters without information loss. However, since we report results for different samples we decided to keep the full set of parameters in each of them.

The first two rows of Table 2 report the coefficients of the quadratic term for logarithmic real expenditure in each of the expenditure shares. In all samples at least one of the coefficients is statistically significant. This suggests that indeed the Engel curves are not monotone in real per-capita expenditure. Over the long samples reported in columns (1) and (4), both for the full sample and the USA in isolation, the θ_M coefficient of the linear real expenditure term is positive and significant and the λ_M coefficient of the quadratic real expenditure term negative and significant. Thus, the QAIDS specification is able to generate a hump-shape for the expenditure share of manufacturing. This is illsutrated in Figure 8 of Appendix A which plots the predicted expenditure share for manufacturing in each country. The prediction is based on the sample and point estimates reported in column (1).

[21] Among the cross-price effects, we are estimating the parameters φ_{AA}, φ_{MA}, φ_{MM}, and φ_{SS}. Joint with the symmetry restriction $\varphi_{jk} = \varphi_{kj}$ and $\sum_{k \in J} \varphi_{jk} = 0$ all other parameters φ_{jk} are determined.

	Full Sample			USA		
	1900-2014	1929-2014	1947-2014	1902-2014	1929-2014	1947-2014
	(1)	(2)	(3)	(4)	(5)	(6)
λ_M	-.011***	.038***	-.028***	-.030***	-.015**	-.005
	(-3.79)	(19.56)	(-5.75)	(-5.43)	(-2.13)	(-.76)
λ_S	.000	-.022***	-.011*	-.038***	-.018	-.060***
	(.01)	(-5.10)	(-1.81)	(-3.30)	(-1.13)	(-3.24)
π_M	-.122	.868***	-.314***	.004	.222***	.360***
	(-1.61)	(18.73)	(-4.53)	(.05)	(6.48)	(6.76)
π_S	.308**	.060	.379***	-.116	.202	.103
	(2.11)	(.60)	(4.36)	(-.76)	(1.51)	(.96)
θ_M	.127***	-.315***	.250***	.185***	.058*	-.033
	(4.31)	(-17.20)	(7.01)	(4.62)	(1.75)	(-1.04)
θ_S	.066	.234***	.117***	.349***	.196**	.378***
	(1.26)	(5.69)	(2.59)	(4.16)	(2.09)	(4.40)
φ_{AA}	.003	.059***	-.205***	-.351*	-.011	-.039
	(.05)	(3.19)	(-6.94)	(-1.91)	(-.16)	(-.80)
φ_{MM}	.068***	-.090***	.002	-.073	.014	.001
	(3.21)	(-3.32)	(.07)	(-1.53)	(.44)	(.03)
φ_{SS}	.071***	-.014	.123***	-.023	.070**	-.045
	(3.16)	(-.34)	(4.17)	(-.25)	(2.16)	(-.56)
φ_{MA}	-.014	-.009	.158***	.192**	.030	-.006
	(-.44)	(-.27)	(4.88)	(2.53)	(.85)	(-.24)
N	318	276	250	81	77	68
AIC	-3046.0	-2842.2	-2748.3	-939.5	-1102.7	-1041.8
$\min\{\log(e)\}$	4.10	4.83	5.75	5.55	6.16	7.22
RMS_A	0.019	0.016	0.010	0.017	0.005	0.003
RMS_M	0.025	0.021	0.022	0.013	0.009	0.008
RMS_S	0.032	0.025	0.025	0.012	0.011	0.009

Table 2: Estimation QAIDS

Note: Years where the USA was involved in WWI (1917-1918), WWII (1942-1945), or affected by the Great Depression (1929-1933) are excluded from all estimations. In columns (1)-(3), years where AUS, CAN, and GBR where involved in WWI (1914-1918), WWII (1939-1945), or affected by the Great Depression (1929-1933) are excluded.

6.3 Generalized PIGL

In Table 3 we report the estimation results for the generalized PIGL preference specification for the full sample. The left panel with columns (1) to (3) shows the estimations results for the standard PIGL specification where we have restricted the price function $\mathcal{A}(P)$ to be zero. On the one hand, this yields a parsimonious parameterization of the expenditure shares with only six parameters. On the other hand, we are loosing some flexibility in the functional form, especially with respect to the non-monotonicity of the expenditure shares. However, already the standard PIGL specification improves in terms of the model fit over the generalized Stone-Geary for the full sample. For instance, over the period 1900 to 2014 the Akaike information criterion (AIC) is -2861 for the PIGL while it is significantly higher -2814 for the generalized Stone-Geary.[22]

The right panel of Table 3 shows the estimation results for the generalized PIGL specification. Columns (4) and (5) show that the price function $\mathcal{A}(P)$ is a valuable generalization of the PIGL specification that improves the fit of the model. In particular, the scale parameter τ and the share parameter ρ are well identified and capture the non-monotonic pattern of structural change observed in the historical data. Especially over the long sample period 1900 to 2014, the AIC improves from -2861 to -3023 when allowing for the additional price term $\mathcal{A}(P)$. This fit is very close the QAIDS specification's information criterion which yields -3046 for the same sample. For the postwar sample which is reported in column (6), the parameters ψ_1 and ϵ are not predicted significantly different from zero. Since we cannot rule out that the restrictions on those parameters are violated (they are required to be nonzero), the preferred specification in the postwar sample is the standard PIGL specification reported in column (3).

As in previous estimations, some of the parameters hit value constraints. While the parameter ϕ is estimated to be interior for the PIGL specification in the left panel, the generalized PIGL specification yields the best fit when ϕ hits the unity upper bound. This means that all variation on the price function $\mathcal{B}(P)$ is attributed to the price of services, and a good fit of the historical data can be achieved us-

[22] While the detailed discussion of model selection is deferred to the next section, a lower AIC can be interpreted as a model's higher relative likelihood of minimizing the information loss. Thus, the PIGL would be the preferred specification over the generalized Stone-Geary.

	PIGL			Generalized PIGL		
	1900-2014	1929-2014	1947-2014	1900-2014	1929-2014	1947-2014
	(1)	(2)	(3)	(4)	(5)	(6)
ν_1	72.615**	43.797***	145.758***	.128***	.093***	.015**
	(2.49)	(2.60)	(3.57)	(3.84)	(4.70)	(2.54)
ν_2	-29.142***	13.119***	41.005*	.842***	.530***	.194***
	(-2.66)	(2.66)	(1.89)	(2.90)	(4.66)	(2.77)
ψ_1	.636***	.779***	.611***	1.050***	.872***	.072
	(9.64)	(14.09)	(17.33)	(4.67)	(5.11)	(.23)
ψ_2	-2.105***	.620***	.661**	.306***	.319***	.446***
	(-7.95)	(3.59)	(2.38)	(12.40)	(12.67)	(12.26)
ϵ	.687***	.633***	.760***	.127***	.081***	-.029
	(16.19)	(15.58)	(25.88)	(3.63)	(3.64)	(-.77)
ϕ	.722***	.805***	.802***	1.000	1.000	1.000
	(112.36)	(108.75)	(80.77)	(.)	(.)	(.)
τ				1217.943***	883.597***	1361.360***
				(6.23)	(16.85)	(9.50)
ρ				.207**	.000	.122**
				(2.36)	(.)	(1.98)
N	318	276	250	318	276	250
AIC	-2860.7	-2714.1	-2698.0	-3023.4	-2802.7	-2743.0
RMS_A	0.022	0.015	0.010	0.019	0.015	0.011
RMS_M	0.029	0.027	0.027	0.026	0.023	0.022
RMS_S	0.036	0.032	0.029	0.033	0.028	0.025

Table 3: Estimation of (generalized) PIGL Specification, Full Sample

Note: years where the USA was involved in WWI (1917-1918), WWII (1942-1945), or affected by the Great Depression (1929-1933) and years where AUS, CAN, and GBR where involved in WWI (1914-1918), WWII (1939-1945), or affected by the Great Depression (1929-1933) are excluded from all estimations ing a generalized PIGL specification with only seven parameters. In column (5) additionally the point estimate for the parameter ρ hits the zero lower bound.

In Table 5 of Appendix A we show the analogous estimation results if we restrict the sample to the USA only. The right panel reports that the estimated parameters of the generalized PIGL specification remain valid for all subsamples (including the postwar sample in column (6)) and the parameters of the price function $\mathcal{A}(P)$ are well identified. We find that the model fit of the generalized PIGL even dominates the QAIDS as measured by the AIC. For example, the model fit over the period 1929 to 2014 reported in column (5) yields an AIC of -1179 while the QAIDS remains at a higher value of -1103.

6.4 Model selection

In Section 4 we have already discussed the theoretical advantages of the generalized PIGL specification over the existing theories. In this section we discuss further advantages that relate to its empirical properties.

We start the discussion by comparing the goodness of fit of the different theories. Table 4 reports the asymptotic AIC for each preference specification on each of the reported subsamples. The table confirms that the generalized PIGL specification improves over the generalized Stone-Geary in all considered samples. For the USA, it even dominates the QAIDS demand system. While there is no meaningful interpretation of the absolute AIC, the differences in the AIC are significant in terms of the relative likelihood interpretation. To see this, consider for example column (1) in Table 4 which says that the generalized Stone-Geary specification is $\exp([-3023-(-2814)]/2) \approx 0$ times as probable as the generalized PIGL specification to minimize the information loss of the estimation procedure. A similar conclusion applies to the differences on the remaining samples.

Another way to select among the considered models is to visually compare the predicted fit of the expenditure shares over the considered time periods. To avoid confusion, we limit the comparison to the generalized Stone-Geary and the generalized PIGL specification estimated on the full sample. We leave out the QAIDS specification which yields very similar fit as the generalized PIGL due to the quadratic Engel curves. To this end, we present in Figure 5 the fit of the expenditure shares

	Full Sample			USA		
	1900-2014	1929-2014	1947-2014	1900-2014	1929-2014	1947-2014
	(1)	(2)	(3)	(4)	(5)	(6)
Generalized Stone-Geary	-2814	- 2743	-2646	-923	-987	-1009
PIGL	-2861	-2714	-2698	-912	-1027	-1058
Generalized PIGL	-3023	-2803	-2743	-971	-1179	-1063
QAIDS	-3046	-2842	-2748	-940	-1103	-1042

Table 4: Goodness of fit: AIC

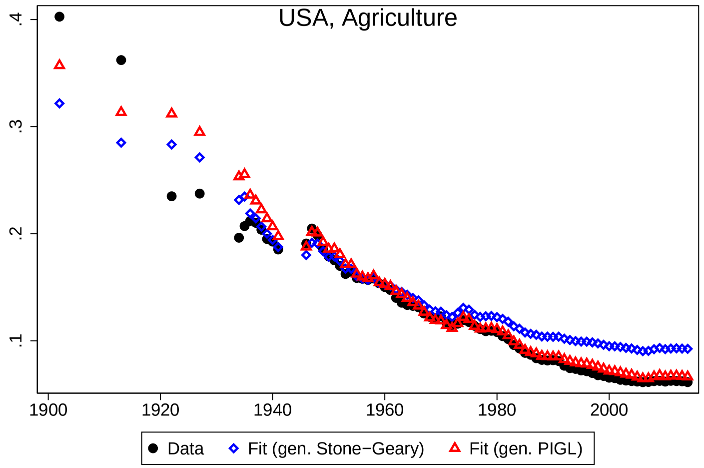
Note: The table reports the asymptotic Akaike information criterion (AIC) for each specification and each sample. The preferred model is the one with the minimum AIC value.

for both specifications along with the actual data points.

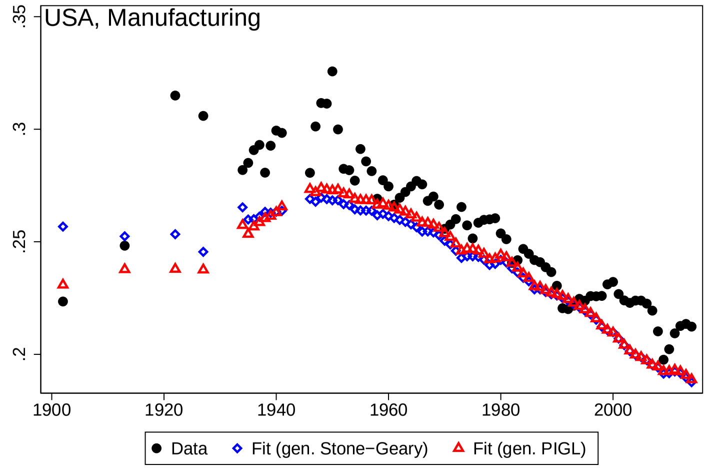
Panel (a) of the figure shows that the generalized Stone-Geary specification underpredicts the decline of the agricultural expenditure share in the USA over the last century. Between 1902 and 2014, the decline of the share is predicted to be only 22.9 percentage points (pp) (from 32.2% to 9.3%), while the actual data shows a decline of 34.2 pp from (40.3% to 6.1%). This shows that the estimated level of the agricultural subsistence consumption in the generalized Stone-Geary preference specification generates too strong income effects in the beginning of the sample, but too weak income effects at the end of the sample. The generalized PIGL specification on the other hand predicts the agricultural share to fall by 29.1 pp (from 35.7% to 6.6%) which is much closer to the pronounced decline observed in the data. A similar pattern occurs for the fit of the late rise of the service expenditure share which is shown in panel (c). The generalized Stone-Geary specification predicts a flatter increase of the service sector compared to the data. Between 1950 and 2014, the increase in the expenditure share for services is predicted to be 16.7 pp (from 55.3% to 72.0%) compared to the actual increase of 23.1 pp (from 49.5% to 72.6%) in the data. On the other hand, the generalized PIGL predicts a late rise of the service sector of 20.3 pp (from 54.1% to 74.4%).

Finally, panel (b) indicates that the generalized PIGL specification is able to generate a more pronounced hump-shape in the expenditure share of the manufacturing sector. Since the data availability for the USA in the earlier periods - where the difference is in the predictions is most pronounced - is limited, Figure 9 of Appendix A shows the same model predictions for GBR. Panel (b) of Figure 9 illustrates that while the generalized Stone-Geary predicts an increase in GBR's manufacturing share between 1900 and 1950 of merely 4.1 pp (from 24.6% to 28.7%) the actual increase was 9.5 pp (from 17.9% to 27.4%). The generalized PIGL yields and increase of 6.1 pp (from 22.6% to 28.7%) which is much closer the the actual number. Also the remaining pattern of the model predictions for GBR are very similar to the USA, i.e., the decline of the agriculture sector and the late rise of the service sector is predicted too flat by the generalized Stone-Geary specification compared to the historical data.

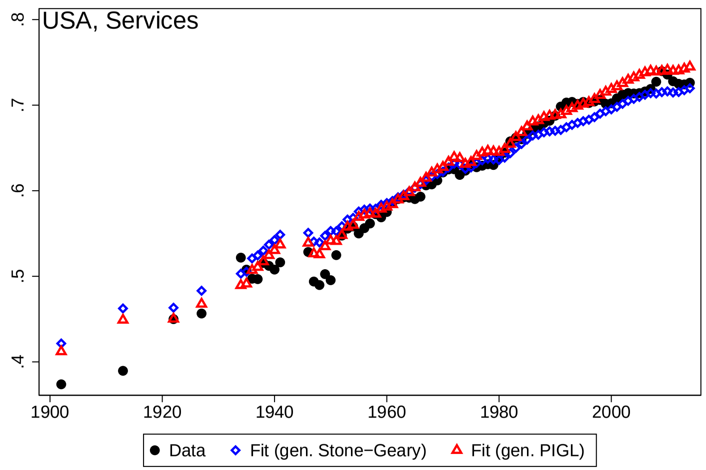
(a) Agriculture



(b) Manufacturing



(c) Services



Notes: The figure plots the predicted and the actual final consumption expenditure shares for the USA by each sector. The blue dots show the fit of the generalized Stone-Geary specification estimated in column (1) of Table 1 and the red dots show the fit of the generalized PIGL specification estimated in column (4) of Table 3.

Figure 5: Predicted final consumption expenditure shares, USA

6.5 Income elasticities

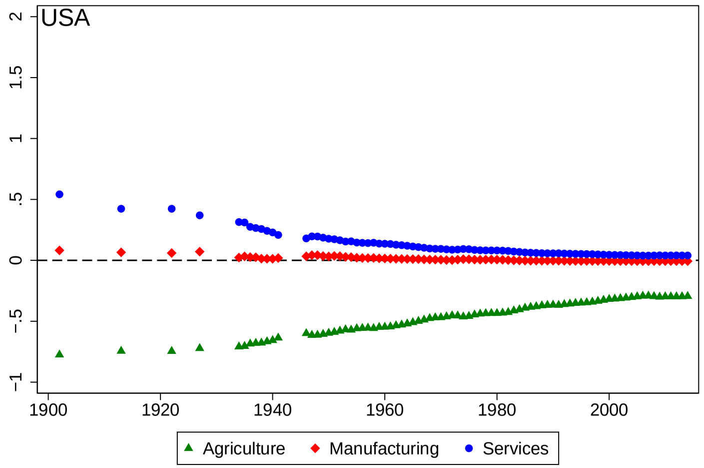
In all of the considered specifications, the income effects on the sectoral expenditure shares depend on the nominal per-capita expenditure and the sectoral prices. Thus, they are changing over time. In this section we predict the corresponding income elasticity of the expenditure shares for the generalized Stone-Geary and the generalized PIGL specification using the point estimates of the model parameters.[23] When the elasticity of the expenditure share is positive, the corresponding sector has a luxury character. Sectors with a negative elasticity have the character of a necessity.

In Figure 6, the upper panels (a) and (b) show the predicted income elasticities of the generalized Stone-Geary specification for the USA and GBR, respectively. The figure shows that while the income effects of manufacturing and services has almost disappeared at the end of the sample, a strong income effect is needed in the agricultural sector to explain the parallel decline of relative prices and relative real quantities in the second half of the sample (see Figure 10). For example, in the year 2000 the income elasticity of demand (which corresponds to 1 plus the expenditure elasticity) is predicted to be 1-0.319 for food and alcoholic beverages, 1+0.005 for durable goods, and 1+0.045 for services in the USA. Thus, agriculture is predicted to be a strong necessity in 2000, while manufacturing and in particular services hardly pass the luxury threshold at unity.

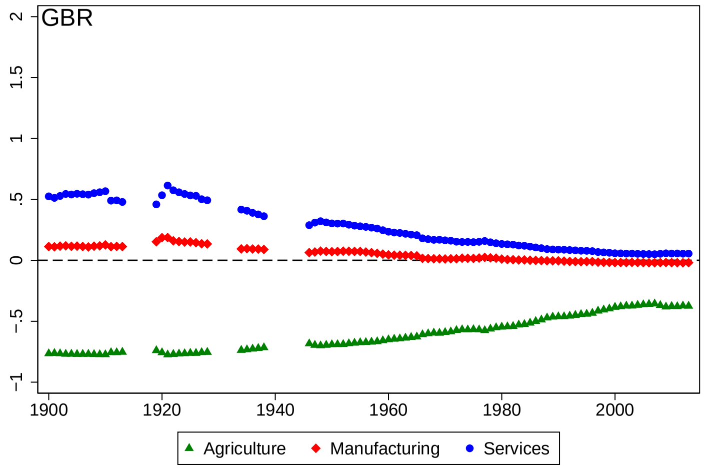
The lower two panels in the figure show the predicted elasticities of the generalized PIGL specification, which classifies both the manufacturing and the service sector as strong luxury goods over the whole period. Thus, the hump-shape of the manufacturing share in final consumption is explained by in initial increase while relative prices where relatively constant and structural change was mostly driven by income effects before 1950. In the postwar period, the pronounced decline of manufacturing prices relative to the service sector takes care of the reallocation of economic activity from manufacturing to services. Throughout, the continued decline of the agricultural sector is also generated by a similar income effect as in the generalized Stone-Geary prediction. Consider again the year 2000 for the USA,

[23] The derivation of the analytical expressions for the income elasticities of the expenditure shares are delegated to Appendix B.1.

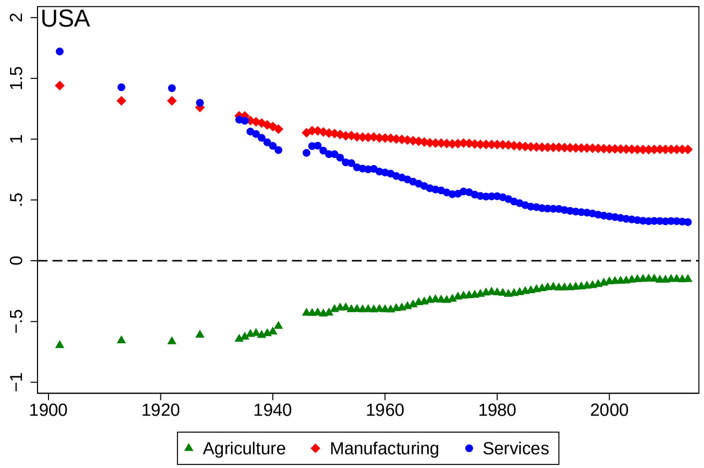
(a) Generalized Stone-Geary, USA



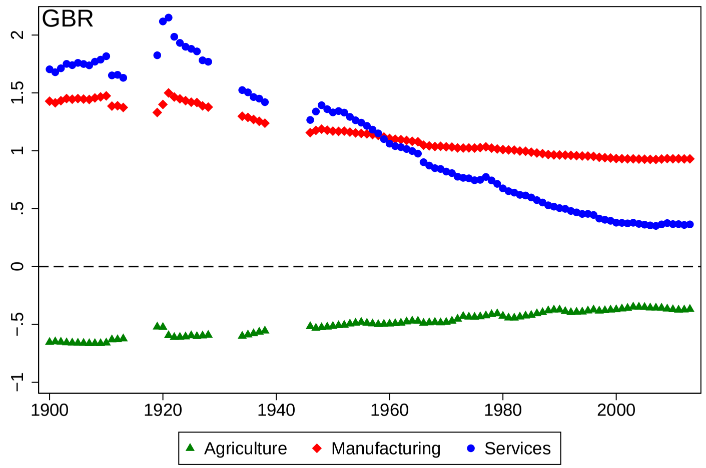
(b) Generalized Stone-Geary, GBR



(c) Generalized PIGL, USA



(d) Generalized PIGL, GBR



Notes: The figure plots the predicted income elasticities of the sectoral expenditure shares for the USA and GBR. Panel (a) and (b) show the elasticities predicted by the generalized Stone-Geary specification estimated in column (1) of Table 1 and panel (c) and (d) show the elasticities predicted by the generalized PIGL specification estimated in column (4) of Table 3.

Figure 6: Predicted income elasticities of the expenditure shares

then the generalized PIGL specification predicts an income elasticity of demand of 1-0.172 for agriculture, 1+0.920 for manufacturing, and 1+0.365 for services.

6.6 Taking stock

In this section we have established that the benchmark preference specification in the existing literature - the generalized Stone-Geary specification - has a hard time generating sustained income effects over long time periods. This is not only problematic when estimating structural parameters on long samples, but it also questions the validity of out of sample predictions. In particular, under the scenario that real per-capita expenditure keeps growing at a steady rate, the Stone-Geary specification predicts that consumption expenditure shares will be driven entirely by relative price effects in the not so distant future. This seems a contradiction to the observation that income effects remain very important in explaining recent microeconomic data on consumer demand at all income levels.

Moreover, the microeconomic literature on the estimation of consumer demand systems is based on preference specifications that allow for non-monotonic Engel curves and have properties similar to our generalized PIGL specification. As a consequence, our specification allows for a direct and straightforward comparison of estimates derived in micro- and macroeconomic data, while the use of the generalized Stone-Geary is mostly restricted to macroeconomic studies of structural transformation.

7 Conclusion

Structural transformation is a stylized fact of modern economic development, but the existing literature has struggled to provide a theory of consumer demand that can explain the observed reallocation across sectors and is also consistent with sustained growth in real expenditures per capita. We contribute to the existing literature in three ways. First, we document the reallocation of consumption shares across the three broad sectors agriculture, manufacturing, and services using historical final consumption expenditure data for more than one century in the United States, the United Kingdom, Canada and Australia. The data allows us to analyze relative prices and consumption shares for a larger sample and a longer time period than existing studies.

Second, we analyze the features of the data that make it difficult for existing demand theories to match the observed patterns. Generalized Stone-Geary preferences, which are often used in the structural change literature, face the challenges that (i) the estimates imply an unreasonably high subsistence level in agriculture, (ii) it is difficult to generate a non-monotonic Engel curve in manufacturing, which the long sample that includes the prewar years asks for, and (iii) the estimated parameter values imply that the preferences are inconsistent with balanced growth. The Quadratic Almost Ideal Demand System, which is often used in the microeconomic literature, can fit the data well, but its functional form is not consistent with the sustained growth of real per-capita expenditure, which is also a stylized fact of modern economic development.

Our third contribution is to propose an alternative preference specification that can fit the data and is also consistent with sustained growth. These preferences are a generalization of the Price Independent Generalized Linear class of preferences that allows for non-monotonic Engel curves and it is possible to make them consistent with balanced growth. We show that these preferences provide a better fit for the historical data on consumption expenditures than existing theories when considering the data from the past century in the United States, the United Kingdom, Canada and Australia.

We believe that our findings are important in a number of ways. The existing literature has come to different conclusions regarding whether the generalized Stone-Geary preferences can fit the observed patterns of structural change. Our analysis of historical consumption expenditure data over more than 100 years and across four countries shows that the sample period is important. All four countries show monotone paths in consumption shares and in relative prices since the Second World War. The generalized Stone-Geary preferences can match these patterns with an income effect alone and it therefore provides a relatively good fit on this shorter sample. When we consider the prewar period, then the manufacturing share is hump-shaped, while agriculture is monotonically falling and services are first relatively constant and then show a late rise in the postwar period. The generalized Stone-Geary preferences cannot match these long-run patterns. Our proposed preference specification is flexible enough to fit the data over this longer period and across all countries.

The findings have important implications for the external validity of the analysis of structural change. The observation that the generalized Stone-Geary preferences imply subsistence levels in agriculture that are binding for (not unreasonably) low income levels limits the ability to apply it to such contexts. Similarly, the Quadratic Almost Ideal Demand Systems can imply consumption shares outside of the unit interval as real expenditures per capita grow. We hope that the alternative preference specification that we propose here will provide a basis for the analysis of structural change in a wide development context. We therefore plan to consider in future work a larger sample of countries.

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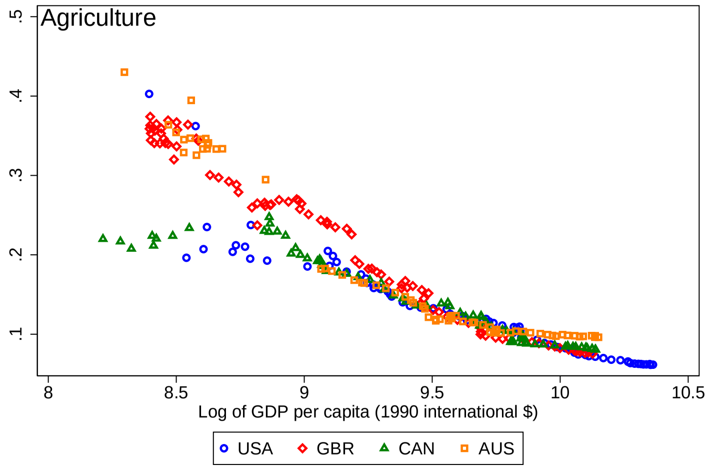
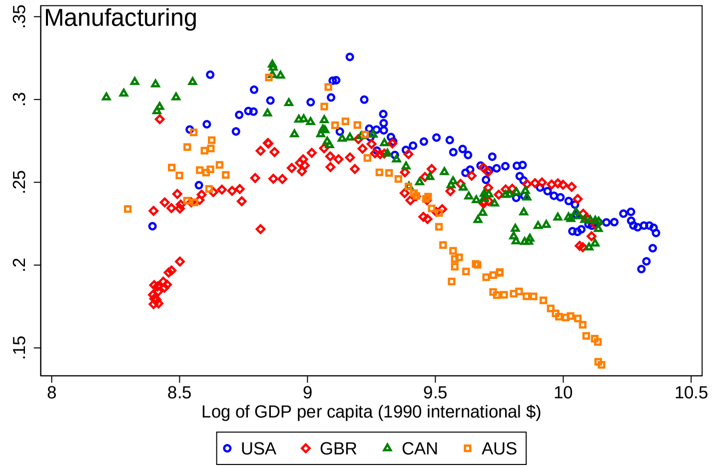
A Additional figures and tables

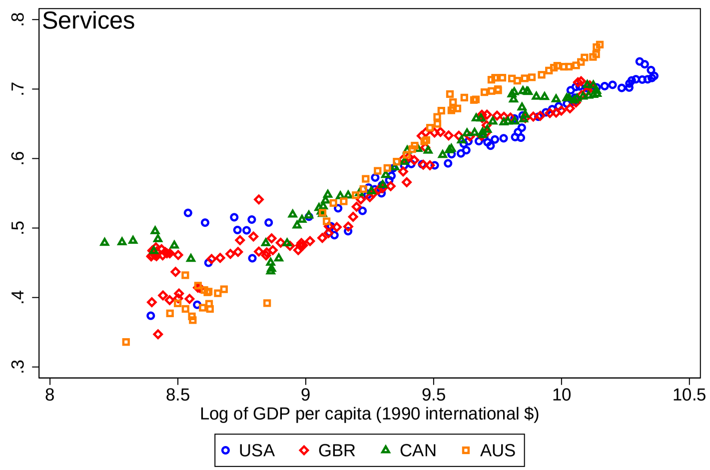
(a) Agriculture



(b) Manufacturing



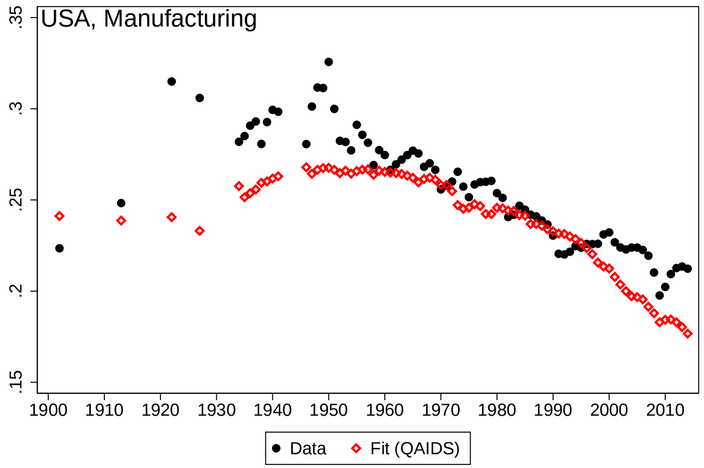
(c) Services



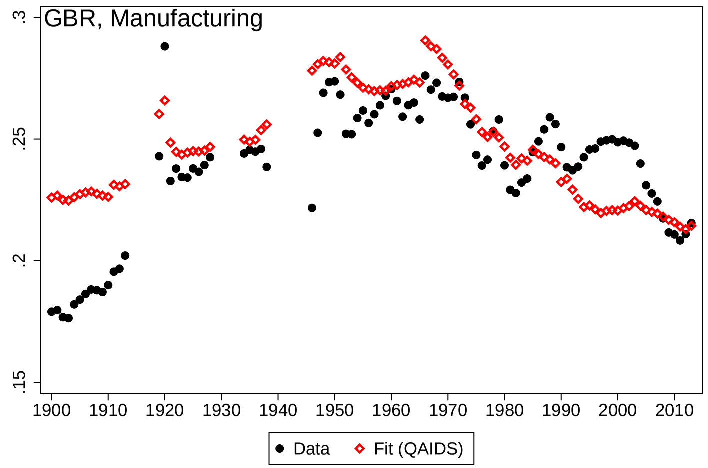
Notes: The figure plots the final total consumption expenditure share over log of GDP per capita (1990 international $) for the USA, GBR, CAN, and AUS by sector. The years affected by WWI, WWII, and the Great Depression are excluded. Source: Expenditure shares (see Appendix D), GDP per capita (Maddison Project, 2013).

Figure 7: Final total consumption expenditure shares

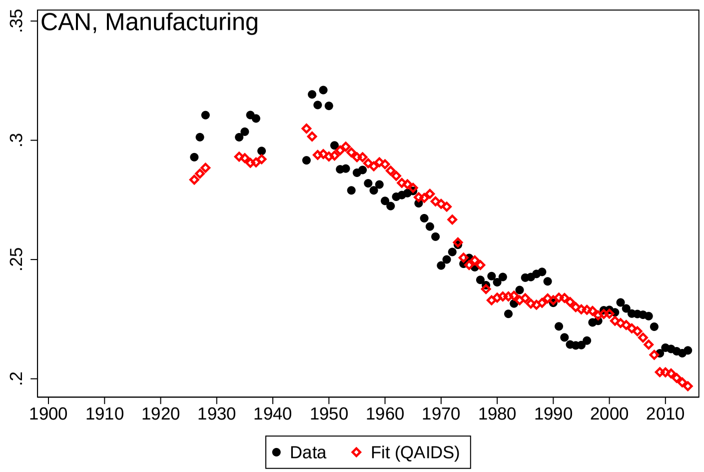
(a) United States



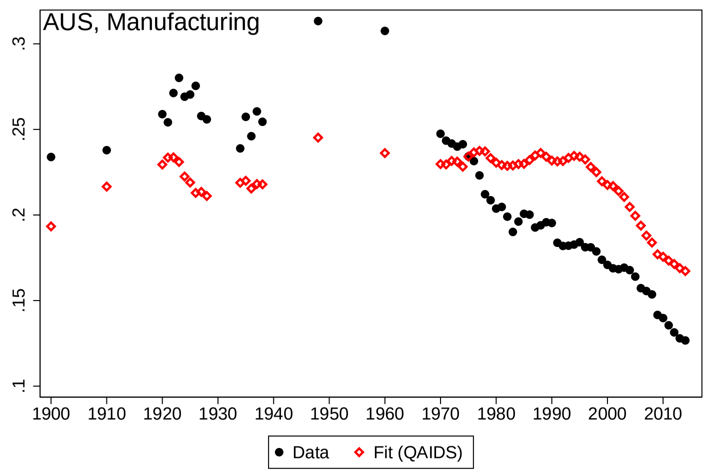
(b) United Kingdom



(c) Canada



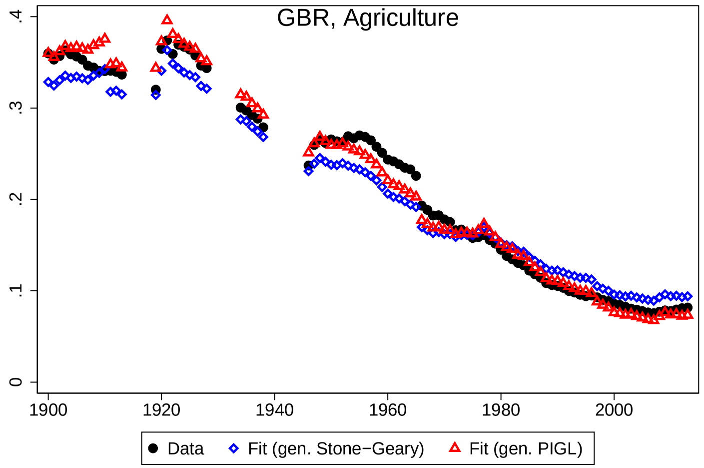
(d) Australia



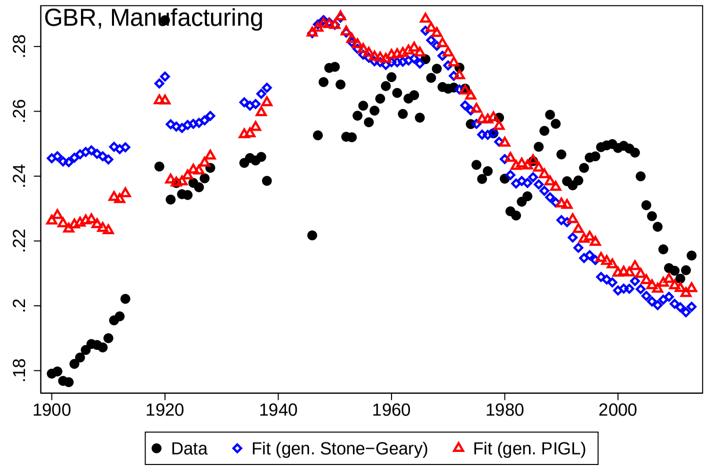
Notes: The figure plots the actual and predicted final consumption expenditure share of manufacturing for each country. The red dots correspond to the prediction of the generalized PIGLOG specification estimated in column (1) of Table 2.

Figure 8: Predicted manufacturing expenditure shares, QAIDS

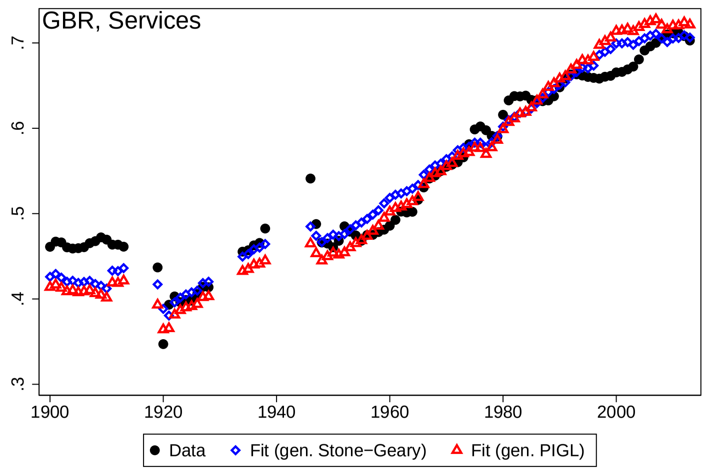
(a) Agriculture



(b) Manufacturing

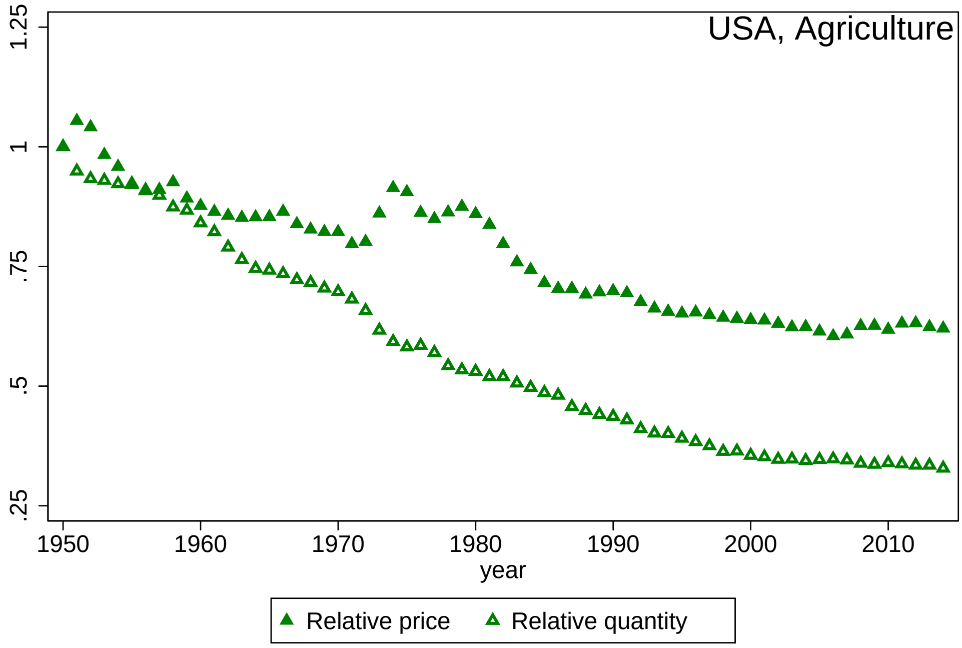


(c) Services



Notes: The figure plots the predicted and the actual final consumption expenditure shares for GBR by each sector. The blue dots show the fit of the generalized Stone-Geary specification estimated in column (1) of Table 1 and the red dots show the fit of the generalized PIGL specification estimated in column (4) of Table 3.

Figure 9: Predicted final consumption expenditure shares, GBR



Notes: The figure plots the price and quantitiy index of agriculture relative to services for the USA. The prices are based on final total consumption expenditure and normalized to unity in 1950. Source: BEA

Figure 10: Prices and quantities of agriculture relative to services, USA

	PIGL			Generalized PIGL		
	1900-2014	1929-2014	1947-2014	1900-2014	1929-2014	1947-2014
	(1)	(2)	(3)	(4)	(5)	(6)
ν_1	10.794***	17.069***	49.429**	.423	281.767***	107.839*
	(2.77)	(4.05)	(2.43)	(1.55)	(12.56)	(1.89)
ν_2	3.794***	-10.609**	28.246*	.753**	365.409***	96.991
	(2.84)	(-2.34)	(1.67)	(2.34)	(10.60)	(1.41)
ψ_1	1.121***	.763***	.719***	1.120***	.589***	.724***
	(8.61)	(13.84)	(8.54)	(6.66)	(16.12)	(8.32)
ψ_2	.946**	-1.761***	.573*	.787***	.176***	.550***
	(2.41)	(-3.71)	(1.81)	(3.68)	(3.14)	(2.68)
ϵ	.494***	.540***	.650***	.230***	.822***	.722***
	(13.22)	(21.46)	(15.54)	(4.78)	(99.63)	(13.78)
ϕ	.795***	.695***	.813***	.832***	.828***	.798***
	(74.48)	(32.05)	(53.52)	(43.25)	(119.64)	(44.50)
τ				716.006***	4825.248***	3832.228**
				(4.79)	(57.30)	(2.40)
ρ				.000	1.000	1.000
				(.)	(.)	(.)
N	81	77	68	81	77	68
AIC	-912.4	-1027.1	-1058.4	-970.9	-1178.7	-1062.7
RMS_A	0.018	0.005	0.003	0.015	0.003	0.003
RMS_M	0.017	0.016	0.008	0.012	0.008	0.008
RMS_S	0.012	0.018	0.009	0.011	0.009	0.009

Table 5: Estimation of Generalized PIGL Specification, USA

Note: Years where the USA was involved in WWI (1917-1918), WWII (1942-1945), or affected by the Great Depression (1929-1933) are excluded from all estimations.

B Proofs and derivations

B.1 Income elasticities

B.1.1 Generalized Stone-Geary

The expenditure share of sector j is given by Equation (15) with associated limit value

$$\lim_{e/p_j \to +\infty} \eta_j = \frac{\omega_j p_j^{1-\sigma}}{\sum_{k \in J} \omega_k p_k^{1-\sigma}}.$$

The elasticity of the expenditure share with respect to nominal per-capita expenditure, e, is given by

$$\frac{\partial \eta_j}{\partial e}\frac{e}{\eta_j} = \frac{\frac{\omega_j p_j^{1-\sigma}\left[\frac{\sum_{k\in J} p_k \bar{c}_k}{e^2}\right]}{\sum_{k\in J}\omega_k p_k^{1-\sigma}} e - \frac{p_j \bar{c}_j}{e^2} e}{\eta_j},$$

and in the limit it approaches zero

$$\lim_{e/p_j \to +\infty} \frac{\partial \eta_j}{\partial e}\frac{e}{\eta_j} = \lim_{p_j/e \to 0} \frac{\frac{\omega_j p_j^{1-\sigma}\left[\frac{\sum_{k\in J} p_k \bar{c}_k}{e}\right]}{\sum_{k\in J}\omega_k p_k^{1-\sigma}} - \frac{p_j \bar{c}_j}{e}}{\eta_j} = 0.$$

B.1.2 Generalized PIGLOG (QAIDS)

The expenditure share of sector i is given by Equation (16). Thus, the elasticity of the expenditure share with respect to nominal per-capita expenditure, e, is given by

$$\frac{\partial \eta_j}{\partial e}\frac{e}{\eta_j} = \frac{1}{\eta_j}\left[\theta_j + \frac{2\lambda_j}{\Theta(P)}\log(e/\Pi(P))\right].$$

B.1.3 Generalized PIGL

The expenditure share of sector i is given by Equation (18). Thus, the elasticity of the expenditure share with respect to nominal per-capita expenditure, e, is given by

$$\begin{aligned}\frac{\partial \eta_j}{\partial e}\frac{e}{\eta_j} &= -\frac{\partial \mathcal{A}(P)}{\partial p_j}\frac{p_j}{e^2}\frac{e}{\eta_j} + \frac{\partial \mathcal{B}(P)}{\partial p_j}\frac{p_j}{\mathcal{B}(P)}\left(-\frac{1}{e^2}\left[e-\mathcal{A}(P)\right]+\frac{1}{e}\right)\frac{e}{\eta_j}\\ &\quad -\frac{\partial \mathcal{C}(P)}{\partial p_j}\frac{p_j}{e}\mathcal{B}(P)^{\epsilon}(1-\epsilon)\left[e-\mathcal{A}(P)\right]^{-\epsilon}\frac{e}{\eta_j}\\ &= -\frac{\partial \mathcal{A}(P)}{\partial p_j}\frac{p_j}{e}\frac{1}{\eta_j} + \frac{\partial \mathcal{B}(P)}{\partial p_j}\frac{p_j}{\mathcal{B}(P)}\frac{\mathcal{A}(P)}{e}\frac{1}{\eta_j} - \frac{\partial \mathcal{C}(P)}{\partial p_j}p_j(1-\epsilon)\left[\frac{e-\mathcal{A}(P)}{\mathcal{B}(P)}\right]^{-\epsilon}\frac{1}{\eta_j}.\end{aligned}$$

Using the parameterization proposed in Section 4 the three sectoral shares can be written as

$$\begin{aligned}\frac{\partial \eta_A}{\partial e}\frac{e}{\eta_A} &= \frac{1}{\eta_A}\left(-(1-\rho)\frac{\mathcal{A}(P)}{e} + (1-\epsilon)\nu_1\left[\frac{p_A}{p_S}\right]^{\psi_1}\left[\frac{e-\mathcal{A}(P)}{\mathcal{B}(P)}\right]^{-\epsilon}\right)\\ \frac{\partial \eta_M}{\partial e}\frac{e}{\eta_M} &= \frac{1}{\eta_M}\left((1-\phi)\frac{\mathcal{A}(P)}{e} + (1-\epsilon)\nu_2\left[\frac{p_M}{p_S}\right]^{\psi_2}\left[\frac{e-\mathcal{A}(P)}{\mathcal{B}(P)}\right]^{-\epsilon}\right)\\ \frac{\partial \eta_S}{\partial e}\frac{e}{\eta_S} &= \frac{1}{\eta_S}\left((\phi-\rho)\frac{\mathcal{A}(P)}{e} + (1-\epsilon)\left(\nu_1\left[\frac{p_A}{p_S}\right]^{\psi_1} + \nu_2\left[\frac{p_M}{p_S}\right]^{\psi_2}\right)\left[\frac{e-\mathcal{A}(P)}{\mathcal{B}(P)}\right]^{-\epsilon}\right).\end{aligned}$$

In the limit this elasticity approaches

$$\lim_{e/\mathcal{A}(P)\to+\infty}\frac{\partial \eta_j}{\partial e}\frac{e}{\eta_j} = -\frac{\partial \mathcal{C}(P)}{\partial p_j}p_j(1-\epsilon)\frac{1}{\eta_j}\times\lim_{e/\mathcal{A}(P)\to+\infty}\left[\frac{e-\mathcal{A}(P)}{\mathcal{B}(P)}\right]^{-\epsilon}$$

Thus, it depends on the parameter value of ϵ and the limit value of $[e-\mathcal{A}(P)]/\mathcal{B}(P)$ how fast the expenditure elasticity approaches zero (or, if it diverges).

C Endogenous labor supply

TBA

D Data description

D.1 Sources

D.1.1 United States

Household and government consumption expenditures, 1929-2014

We construct the broad consumption expenditure categories from the historical National Income and Product Account (NIPA) tables provided by the Bureau of Economic Analysis (BEA). The series on annual real and nominal private consumption expenditures are taken from:

- Table 2.4.3. Real Personal Consumption Expenditures by Type of Product, Quantity Indexes
- Table 2.4.5. Personal Consumption Expenditures by Type of Product

The corresponding government consumption expenditures are taken from:

- Table 3.10.3. Real Government Consumption Expenditures and General Government Gross Output, Quantity Indexes
- Table 3.10.5. Government Consumption Expenditures and General Government Gross Output

We use the same categorization of the broad sectors as in Herrendorf et al. (2013) by aggregating the following subcategories of the NIPA tables (which are themselves classified in even finer categories):

- Agriculture: Food and beverages purchased for off-premise consumption.
- Manufacturing: Durable goods, Clothing and footwear, Gasoline and other energy goods, other nondurable goods.
- Services: Services, Government consumption expenditures.

Household and government consumption expenditures 1900-1929

For periods earlier than 1929, we use the historical consumption expenditure data from Carter et al. (2006). The series on annual real and nominal private consumption expenditures are taken from:

- Tables Cd78-152. Consumption expenditures, by type: 1900-1929 [1987 constant $].
- Tables Cd1-77. Consumption expenditures, by type: 1900-1929.

The corresponding nominal government consumption expenditures are taken from:

- Tables Ea24-51. Total government revenue, by source: 1902-1995.
- Tables Ea52-60. Total government expenditure, by character and object: 1902-1995.

Since the subcategories available for earlier periods from Carter et al. (2006) are not as detailed as the more recent NIPA tables, we list the exact categorization of the broad categories as shown below (column codes from Carter et al. (2006) in brackets):

- Agriculture: Purchased food and meals without alcohol (Cd3), Food to employees (Cd4), Food consumed on farms (Cd5), Alcohol (Cd6)
- Manufacturing: Tobacco (Cd7), Shoes (Cd9), Civilian clothing (Cd10), Military clothing (Cd13), Jewelry (Cd14), Toilet articles (Cd17), Furniture and mattresses (Cd25), Kitchen appliances (Cd26), China (Cd27), Furnishings, other durables (Cd28), Furnishings, semidurables (Cd29), Cleaners and polishes (Cd30), Stationery (Cd31), Wood, gas, and coal (Cd35), Drugs (Cd40), Motor vehicles and wagons (Cd53), Tires and accessories (Cd54), Gasoline and oil (Cd56), Books and maps (Cd61), Magazines and newspapers (Cd62), Nondurable toys (Cd63, Durable toys and wheel goods (Cd64), Music, radio, and television (Cd65), Flowers and plants (Cd66)

- Services: Clothing services (Cd15), Barber and beauty (Cd18), Owner occupied housing (Cd20), Tenant occupied housing (Cd21), Rent of farmhouse (Cd22), Other housing (Cd23), Electricity (Cd32), Gas (Cd33), Water (Cd34), Telephone and telegraph (Cd36)[24], Domestic services (Cd37), Other household operations (Cd38), Ophthalmology (Cd41), Medical, dental, and other professional services (Cd42), Hospitals (Cd43), Health insurance (Cd44), Brokerage (Cd46), Banking and financial services (Cd47), Life insurance (Cd48), Legal services (Cd49), Funeral (Cd50), Other personal business (Cd51), Automobile repair (Cd55), Auto insurance and tolls (Cd57), Local purchased transportation (Cd58), Intercity purchased transportation (Cd59), Recreational services (Cd67), Higher education (Cd69), Elementary education (Cd70), Other education and research (Cd71), Religion (Cd73), Welfare (Cd74), Net foreign travel (Cd75)

The composition of the broad categories is chosen such that in the overlapping year 1929 the sectoral expenditure shares derived from the historical data from Carter et al. (2006) and the NIPA tables are consistent. For private consumption expenditures, we obtain a complete price and nominal expenditure series for agriculture, manufacturing, and services with yearly observations from 1900 to 1929.[25] For total consumption (including government consumption), we obtain four additional observations (1902, 1913, 1922, 1927) before 1929.

To construct government consumption expenditure, we subtract from the current operation series (obtained from the table by character and object) the unemployment benefits and social security expenditures (obtained from the table by source) in order to make it consistent with the definition of government consumption reported in the NIPA tables of the BEA. Nominal government consumption expenditure is only available at roughly ten year intervals (1902, 1913, 1922, 1927) before 1929 and price data is missing over the entire historical period. Thus, we are using the

[24]We classify this as services but this category could be ambiguous. However, it is a small share of total expenditures (less than 1% in both 1900 and 1929).

[25]Whenever possible, we take the finest categories reported in the tables. We then calculate the Fisher aggregates based on these categories. For civilian clothing, the data in constant prices is only available for the total clothing, while the nominal data is reported separately for women and men civilian clothing. We therefore rely on total civilian clothing to calculate prices and Fisher aggregates.

same deflator for government expenditure as for private services to approximate the historical price index for the total service sector including government services.[26]

Population

The population size from 1929 onward is taken from the NIPA Table 7.1: "Selected Per Capita Product and Income Series in Current and Chained Dollars." For earlier years, we obtain the population size from table Aa6-8. "Population: 1790-2000 [Annual estimates]" in Carter et al. (2006).

D.1.2 United Kingdom

Household and government consumption expenditures

We obtain the annual nominal and real household consumption expenditure data from three sources:

1995-2013 We obtain the consumption expenditure series from EuroStat (2015), Series nama_co3_c (Final consumption expenditure of households by consumption purpose - COICOP 3 digit - aggregates at current prices), Series nama_co3_k (Final consumption expenditure of households by consumption purpose - COICOP 3 digit - volumes).

We classify consumption expenditures as follows:

- Agriculture: Food, Non-alcoholic beverages, Alcoholic beverages
- Manufacturing: Tobacco, Clothing, Footwear, Furniture & carpets, Household textiles, Household appliances, Glass & table utensils, Tools & equipment, Goods and services for maintenance[27], Medical products & appliances, Vehicle purchases, Telecommunication equipment, Audio and visual equipment, Durable recreational goods, Newspapers and books, Personal care, Personal effects.

[26] When we consider the same approximation of the price for total services at later points in time where actual price data is available, we find that the difference between the approximation and the correct Fisher price index are very small. This suggests that the approximation works well.

[27] This category is ambiguous and we classify it as manufacturing.

- Services: Actual rent, imputed rent, house maintenance & repair, Water & miscellaneous services, Electricity & gas & fuel, Outpatient services, Hospital services, Transport operation, Transport services, Postal services, Telecommunication services, Recreational services, Holidays, Primary education, Secondary Education, Post secondary education, Tertiary education, Undefined education, Catering services, Accommodation services, Prostitution, Social protection, Insurance, Financial services, Other services.

1963-2011 For this earlier period, we obtain the consumption expenditure series from Office for National Statistics (2015b).[28]

For the period from 1966 to 1995 the Office for National Statistics (2015b) only provides a real consumption index for the broad categories goods, services, and aggregate private household consumption. There is no separate price index for agriculture and manufacturing. However, using a historical food price index from the retail price index for food (series CCYY) in Office for National Statistics (2015a) as the price for agriculture, we can solve for the real quantity sequence of manufacturing that - after aggregating up the three sectoral quantities (agriculture, manufacturing, and services) according to the Fisher procedure stated in Equation (23) of Appendix D - is consistent with the real quantity index of aggregate private consumption in the Office for National Statistics (2015b) data.

1900-1965 For the period going back to 1900, we obtain the consumption expenditure series from Feinstein (1972), Table 24 (current prices, 1900-65) and Table 25 (constant prices, 1900-65).

We classify the broad sectors agriculture (with and without alcohol), manufacturing, and services as follows:[29]

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[28]The Office for national Statistics published this data as "ad hoc data and analysis" on August 21, 2015.

[29]For some of the periods, the categories are further aggregated. In particular for the period 1957 - 1962, the following manufacturing goods are only available as a total for the nominal expenditures: furniture, floor coverings, electrical, household textiles, hardware, matches, cleaning materials, books, miscellaneous recreational goods, chemists' and other goods. For the same period, the following services are only available as a total: domestic service, catering, other services. There are a few further instances that involve fewer categories, but in all cases the classification into the three broad sectors is unambiguous. The real consumption expenditures have a similar feature and in some cases slightly different sub-categories than the nominal expenditures, in which case

- Agriculture: food and alcohol.
- Manufacturing: tobacco, clothing, motor cars & motor cycles, furniture & floor coverings & electrical, household textiles & hardware, matches & cleaning material, books & miscellaneous recreational goods, chemists' & other goods.
- Services: housing, fuel & light, public travel & communication, vehicle running costs, domestic services, catering (meals & accommodation), other services, and government consumption.

Government consumption Annual real and nominal government consumption for the period 1830 to 2009 is available from the Bank of England (2015) and for the more recent period 1948 to 2014 from the Office for National Statistics (2015c).[30]

Population

The population size is obtained from Office for National Statistics (2014) where data is provided from 1851 onwards.

D.1.3 Canada

Household nominal consumption expenditures, 1926-1986

We obtain the detailed subcategories of nominal household consumption expenditures for the years 1926 to 1986 from Table 380-0565. "Personal expenditure on consumer goods and services, 1968 System of National Accounts (SNA), annual (dollars)" provided by Statistics Canada (1988). The categorization is as follows:

- Agriculture: Food & non-alcoholic beverages, Alcoholic beverages
- Manufacturing: Tobacco, Mens & boys clothing, Women & children clothing, Footwear, Furniture & carpets, Household appliances, Semi-durable household furnishings, Non-durable household furnishings, Drugs, Other health goods, Vehicle purchases, Motor vehicle repair parts, Motor vehicle fuel, Reading &

we aggregated the nominal expenditures to match the categories in the real expenditures.

[30] The relevant ONS Series are NMRP (nominal values) and NMRY (real quantities).

entertainment supplies, Jewelry & watch, Toilet articles & cosmetics, Personal care

- Services: Rent by tenant, Rent imputed, Other occupant charges, Electricity, Other fuels, Gas, Laundry & dry cleaning, Domestic child care, Other health services, Physician services, Hospital care, Other automobile services, Purchase of transportation, Communication, Recreational equipment & services[31], Education & cultural services, Restaurants & hotels, Financial & legal services.

Household real consumption expenditures, 1926-1986

We obtain the nominal and real consumption expenditures of durable goods, semi-durable goods, non-durable goods, and services for the period 1926-1986 from Statistics Canada (2016c). We can calculate the prices of services directly from this series for the entire period. Agricultural goods are not separately listed and are part of non-durable goods. Similar to the case of the United Kingdom, we compute real quantities based on the nominal expenditures and the consumer price index (CPI) for food that we obtain from Statistics Canada (2014, 2016a). We then separate real quantities of manufacturing goods from the non-durable goods with a root finding procedure to find the missing sectoral quantities and prices that make the aggregate real consumption consistent with the index implied by the Fisher aggregation.

Household consumption expenditures, 1981-2014

We obtain the series for annual nominal and real household consumption expenditures for the years 1981-2014 from Statistics Canada (2016f). The classification in the three broad categories is as follows:

- Agriculture: Food & non-alcoholic beverages, Alcohol
- Manufacturing: Tobacco, Clothing, Garment, Footwear, Maintenance & repair goods, Furniture, Carpets, Textiles, Major household appliances, Small household appliances, Major tools & equipment, Small tools & miscellaneous accessories, Other semi-durable household goods, Other non-durable household

[31] This category is ambiguous and we classify it as services.

goods, Pharmaceutical & medical products, Medical products & equipment, Car purchases, Truck & van purchases, Telecommunication equipment, Audio and visual equipment, Information processing equipment, Recording & media, Major recreational goods, Indoor recreational goods, Games & toys, Sport and camping equipment, Garden products, Pet & pet food products, Books, Newspaper, Miscellaneous print, Personal goods, Other personal goods, Jewelry & clocks & watches, Other personal effects.

- Services: Clothing services, Actual house rental, imputed house rental, Household maintenance & repair services, Water, Electricity, Gas, Fuel[32], Repair & household goods, Rent of household goods, Other property services, Outpatient services, Hospital services, Vehicle maintenance & repair, Parking, Passenger vehicle rent, Transport operation, Bus transport, Taxi & limo transport, Air transport, Rail & water transport, Other transport services, Postal services, Telephone & fax services, Veterinary services, Recreational & sport services, Cable & satellite services, Cinema, Photo services, Other cultural services, Chance & games, University education, Other education, Food & beverages services, Liquor services, Accommodation services, Insurance & financial services, Life insurance, Property insurance, Health insurance, Transport insurance, Personal services, Childcare outside services, Childcare inside services, Other social & funeral services, Legal & other services.

Government consumption

We obtain annual nominal and real government consumption for the years 1926-1986 from Statistics Canada (2016c) and for the years 1981-2015 from Statistics Canada (2016d).

Population data We get the population data until 1977 from Statistics Canada (2016e) and the more recent series are obtained from Statistics Canada (2016b).

[32] Fuel could include vehicle fuels which are in the other series classified as manufacturing good, but other series combine fuels with electricity and gas which we classify as services.

D.1.4 Australia

D.1.5 Household consumption expenditures, 1900-1948

The nominal household consumption expenditures for the period 1900-1948 (with some gaps) is obtained from Haig and Anderssen (2006). For some subcategories we have missing observations in 1900 and 1910 that we need to approximate based on more aggregated series. In particular, we assume that car purchases in 1900 and 1910 were the same proportion of total expenditures on travel as in 1920. We apply the same strategy for private transport services. Furthermore, we calculate public transport services prior to 1920 by subtracting private transport services and vehicle purchases from total transport expenditures. The real household consumption expenditures are available from the same source.[33]

We calculate prices for each category that is available in the real and nominal series. For some categories such as private transport services we needed to calculate the nominal expenditures by subtracting subcategories from aggregates. In order to find the real quantities and prices for these subcategories, we apply a root finding procedure that inverses the Fisher aggregation as describe on earlier occasions for GBR and CAN.

We then construct aggregate quantities and prices for the three broad sectors using Fisher aggregation with the following classification:

- Agriculture: Food and non-alcoholic beverages, Alcoholic beverages
- Manufacturing: tobacco, clothing & footwear, durable goods, toys & sports goods, newspapers & books, other goods
- Services: Rent, electricity & gas & fuel, communication, entertainment, education, health, other services.

Since some of the subcategories like private transport had to be constructed for the early years, we need to make some assumptions in order to link the series for prices and quantities over time. In particular, we use the growth rates in prices and quantities in manufacturing and services without transport in order to link the

[33] We corrected some obvious typos in the real data. For example, the columns for health and education were incorrectly labeled and some decimal places were shifted.

series before and after 1920.

In order to link the series prior to 1948 to the new series starting in 1970 (discussed below), we exploit the fact that the earlier series reported both nominal and real data for most major categories for the year 1948 in 1938 and 1979 prices.[34] We rely on these categories as proxies for the price and quantity growth of each broad category spanning across both time periods. We then use these proxies to link the more detailed time series for prices and quantities with a common base year 1979.

D.1.6 Household consumption expenditures, 1970-2015

We obtain household final consumption expenditure for the period 1970 to 2015 from Table 42 of the Australian System of National Accounts (Australian Bureau of Statistics (2015)).[35] The table includes expenditures in current and constant prices for 27 expenditure categories and we calculate prices for each category. The quantities for recreational goods, recreational services, and books are missing for the years prior to 1986, but we have the total expenditures for recreation. We therefore assume that price growth in each of the missing subcategories is the same as in total recreation.[36]

We then use Fisher aggregation in order to compute quantity and price growth for the broad sectors agriculture (with and without alcohol), manufacturing, and services. The subcategories are classified as follows:

- Agriculture: food and alcohol.
- Manufacturing: tobacco, clothing, furnishings and household equipment, vehicle purchases, goods for recreation and culture, books, papers, stationery and artists goods.

[34]The real quantities of the following subcategories are observed in 1948 in both 1938 and 1979 prices: food, clothing, rent, tobacco, liquor, durable goods, fuel & light, public transport, private transport, communication. We assign these subcategories to the three broad sectors as defined above and use Fisher aggregation to obtain price and quantity growth rates. It should be noted that the two observations for each real series in 1948 are not only showing different price base years, but also different currencies (Pounds and Australian Dollars). The exchange rate is obtained from the nominal series which show the value in 1948 in each currency.

[35]The table goes back to 1960, but a number of sub-categories are missing.

[36]This appears the best available approximation, but it should be noted that some sub categories combine services and other goods.

- Services: rent, electricity& gas & fuel, health, vehicle operation, transport services, communication, recreational services, education services, hotel & restaurant services, insurance & financial services, and government consumption.

Quantities for insurance and financial services are not available for the years prior to 1980 and we therefore approximate their growth for the early years based on the remaining services. The series from 1900 - 1948 and 1970 - 2015 are linked together as described above, with a common base year 1979.

Government consumption

The nominal and real series for government consumption for the years 1960 - 2014 are obtained from the World Bank Development Indicators (World Bank (2016)). The nominal and real series for government consumption for the years 1900 - 1970 are obtained from tables 22 and 23 of the Source Papers in Economic History Australian National University (1985). We use Fisher aggregation in order to combine government consumption with private household consumption.

Population

The population statistics from 1900 to 2010 are obtained from the Australian Historical Population Statistics (Australian Bureau of Statistics (2014)). The population statistics for the years 1981 to 2015 are available from the Australian Demographic Statistics (Australian Bureau of Statistics (2016)). We use these population series to obtain our per capita measures.

D.2 Price aggregation

We collect data on prices (or, real quantities) and nominal expenditure for the finest subcategories available in each country and time period. By dividing the the nominal expenditure for each subcategory by the price (quantity) index we obtain the associated quantity (price) index. The real quantities are aggregated from the subcategories to the sectoral level according to a chained Fisher index. Fisher aggregation is also the standard procedure for the most recent NIPA tables provided by the BEA) in the USA (see Whelan (2002)). More formally, let the total real consumption index at the sectoral level (for example, manufacturing) be denoted by $c_{j,t}$. The real growth rate of the index satisfies the equation

$$\frac{c_{j,t}}{c_{j,t-1}} = \sqrt{\frac{\sum_{s=1}^{S} p_{s,t} c_{s,t}}{\sum_{s=1}^{S} p_{s,t} x_{s,t-1}} \times \frac{\sum_{s=1}^{S} p_{s,t-1} x_{s,t}}{\sum_{s=1}^{S} p_{s,t-1} x_{s,t-1}}}, \tag{23}$$

where $p_{s,t}$ is the price of subcategory $s = 1, \ldots, S$ (for example, clothing and footwear) and $c_{s,t}$ denotes the associated quantity index such that nominal expenditure on subcategory s corresponds to the product, $p_{s,t}c_{s,t}$. After choosing a base year for the sectoral quantity index $c_{j,t}$ we use the the growth rate implied by Equation (23) to chain the index backward and forward. The sectoral Fisher price index is then simply given by the $p_{j,t}$ such that the product $p_{j,t}c_{j,t}$ corresponds to the total nominal expenditure for sector j in period t.

The aggregation procedure in Equation (23) can also be applied to a more aggregate level. In particular, subcategories s can be substituted by sectors i and the left-hand side by aggregate real consumption growth. This is useful whenever we cannot directly aggregate the price indexes of subcategories to the sectoral level because of missing data. In these cases, however, when we have available an aggregate consumption price index and the other two sectoral price indexes, we are using a root-finding procedure in combination with a more aggregate version of Equation (23 to solve for the unknown sectoral price index. Or, in other words, we are solving for the unknown sectoral price index which makes the aggregate consumption price index consistent with the Fisher index that results from aggregating up the sectoral prices. This is the case for GBR in the period from 1966 to 1995, and for CAN between 1926 and 1986. The data availability of nominal expenditures for the subcategories on the other hand is always complete for the considered time periods and countries.

D.3 Purchasing power parity adjustment

We adjust the sectoral price and quantity indexes measured in local currency units for the power purchasing parity (PPP) relative to the USA for each of the other countries. We follow the Maddison Project (2013) and choose 1990 as the base year. Formally, we set the PPP-adjusted price index in 1990 for the USA to unity and for the remaining countries the price in the same period corresponds to the PPP-adjusted exchange rate reported in the World Development Indicators (World Bank (2016), series PA.NUS.PRVT.PP) in 1990. Then, we chain the PPP-adjusted prices in the base year forward and backward with the inflation rate of the non-adjusted sectoral prices. Thus, all prices can be interpreted in terms of 1990 international $. The same procedure is applied to the sectoral real consumption indexes, except that in the base year real consumption corresponds to nominal consumption expressed in 1990 international $. The PPP-adjusted nominal sectoral expenditure is then derived by simply multiplying the PPP-adjusted price and quantity indexes for each sector.