Arndt-Corden Department of Economics

Crawford School of Public Policy

College of Law, Governance and Policy

Australian National University

What causes structural change?

Peter Warr
Arndt-Corden Department of Economics
Crawford School of Public Policy
Australian National University
peter.warr@anu.edu.au

Arief Anshory Yusuf
Padjadjaran University
Bandung, Indonesia
arief.yusuf@unpad.ac.id

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Peter Warr and Arief Anshory Yusuf

Abstract

Structural change refers to long-term, systematic changes in the sectoral composition of aggregate economic output. Ordinarily, it means the contraction of agriculture relative to industry and services. We analyse its economic causes, using a small, comparative-static, empirically-based computable general equilibrium model of the economy of Thailand, a country experiencing rapid structural change over recent decades. We test the explanatory power of five potential contributors to structural change, suggested by simple economic theory and relevant literature, using Thai data: (*a*) differential growth rates of aggregate supplies of physical capital, labour, and land (the Rybczynski effect); (*b*) differential growth rates of total factor productivity between sectors; (*c*) changes in relative international prices; (*d*) changes in sectoral rates of trade protection; and (*e*) income growth with differences in expenditure elasticities of demand between final consumer goods (Engel's law). It is concluded that, in Thailand's case, explanation (*b*) dominates the other four.

Keywords: Thailand, structural change, Engel's law, Rybczynski effect

JEL codes: O11, C60, O53

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I. Introduction

Structural change, by which we mean the contraction of agriculture as a share of aggregate economic output and the corresponding expansion of the combined shares of industry and services, is an almost universal feature of long-term economic growth (Clark, 1957; Rostow, 1960; Chenery and Syrquin, 1975; Timmer, 2007, 2014; Monga and Lin, 2019). Seemingly, the faster the growth, the more rapid the structural change. By changing the sectoral composition of output, this process may influence aggregate macroeconomic relationships. There is also empirical evidence that the relocation of resources, especially labour, from low productivity agriculture to higher productivity employment in other sectors, raises the productivity of labour (Gollin *et al*., 2014). If so, structural change may itself be a source of economic growth as well as a consequence of it. Our focus in this paper is on explaining changes in the sectoral composition of aggregate output, not the aggregate rate of economic growth.

Structural change implies that sectors grow at different rates. Because growth in different sectors has been shown to affect poverty incidence differently (Ravallion and Datt, 1996; Warr, 2014; Erumban and de Vries, 2024), structural change presumably influences the degree to which aggregate economic growth contributes to poverty reduction. Our findings below show that the structural change consequences of economic growth are affected by its sources. Different sources may therefore have implications for the impact that a given rate of growth has for poverty reduction. Beyond economics, it is clear that structural change has profound social and cultural consequences. Structural change is really important. What causes it?

Our conceptual starting point is suggested by simple economic theory. Imagine a production possibility frontier (PPF), describing the potential outputs of agriculture, industry and services, at the national level, given available resources, technology, and trading opportunities. Alternative drivers of structural change may operate by changing: (i) the shape of the PPF; and / or (ii) the position on the PPF where production occurs, through changes in relative output prices. Based on this framework, we test the explanatory power of five possible contributors to this process, each considered exogenous:

(*a*) changes in the shape of the aggregate production possibility frontier (PPF), induced by accumulation of the aggregate stocks of physical capital, labour and land at different rates;
(*b*) changes in the shape of the PPF caused by different rates of total factor productivity growth between major sectors;
(*c*) price-induced movements around the PPF induced by changes in the relative international prices of traded goods;
(*d*) price-induced movements around the PPF induced by changes in Thailand's own trade policies, affecting relative domestic prices for these goods, given their international prices;
(*e*) price-induced movements around the PPF induced by differences in expenditure elasticities of demand between final consumer goods, including inelastic demand for food.

The literature on structural change provides a mixed account of the relevance of these five potential drivers of structural change. Anderson (1987) provides an analytical overview that recognizes the potential relevance of most of these explanators. We discuss the contributions of that important study further below. Our objective in this paper is to quantify the respective importance of the above five explanators of structural change outcomes, by disentangling their quantitative impacts. We do this in the empirical context of Thailand, a country undergoing rapid structural change over recent decades.

In brief, our findings are that supply-side changes in the shape of the production possibilities frontier, induced mainly by changes in technology, rather than capital accumulation, were the main source of structural change. The effects of price-induced movements around the frontier—whether caused by changes in international prices, changes in protection policy, or differences between commodities in expenditure elasticities of final household demand—were relatively minor.

Regarding explanator (*a*), it is important that the focus is on *relative* factor supplies, not their absolute levels. Martin and Warr (1993, 1994) provide econometric evidence for Indonesia and Thailand, respectively, that changes in relative factor supplies significantly influence the rate of structural change consistent with the theoretical expectations demonstrated by Rybczynski (1955).

Regarding explanator (*b*), it is again important that the focus is on *relative* rates of productivity growth between sectors, not their absolute levels. Most of the literature, including Anderson (1987), assumes that the rate of productivity growth in agriculture is exogenous and that its rate exceeds that of other sectors. Ngai and Pissarides (2007) present a model of structural change that emphasizes the role of technical change in agriculture as a driver of structural change. Alvarez-Cuadrado and Poschke (2011) challenge this analysis, arguing that higher rates of total factor productivity growth in agriculture ordinarily reduce the rate of industrialization, but that factor bias in the technical change in agriculture can potentially reverse this outcome. If the primary factors are sufficiently complementary in agricultural production, labour-saving technical change in agriculture can promote industrial growth.

The latter finding contrasts with the theoretical findings of Matsuyama (1992) for the polar case of a fully open economy. In that case, exogenous productivity growth in agriculture impedes structural change in the expected direction of a resource movement away from agriculture and towards industry. But Matsuyama claims the opposite in a fully closed economy. The discussion lacks an intuitive explanation, but the underlying mechanism is seemingly as follows. In Matsuyama's model, productivity growth in industry is endogenous, resting on learning by doing in that sector. Productivity growth in agriculture is exogenous. By assumption, learning by doing does not occur in agriculture, though it is not clear why. These assumptions mean that any event that increases industrial employment raises industrial productivity, through learning by doing, thus promoting structural change in the expected direction.

In a fully open economy, the domestic price of the agricultural good relative to the industrial good is exogenously determined by international prices. Exogenously determined labour-saving technical change in agriculture raises the marginal value product of labour in agriculture, attracting labour to that sector. Industrial employment falls, impeding structural change.

In a closed economy, relative commodity prices are endogenously determined. Increased labour productivity in agriculture raises food production. Because the domestic demand for food is assumed to be inelastic, this output expansion depresses the relative price of food sufficiently to lower the value of the marginal product of labour in agriculture, despite the increase in its physical marginal product. Labour exits agriculture, raising industrial employment, thereby promoting structural change.

Matsuyama's model rests on 'special assumptions', as the author acknowledges, but an important insight provided by the above account is the central role played by changes in relative commodity prices, or the absence of such changes, and their role in influencing structural change. This will be important for our later discussion.

On explanator (*c*), the data generally indicate a long-term decline in the international prices of agricultural commodities relative to industrial commodities. But for individual countries this result varies considerably, depending on the composition of their trade, especially regarding agricultural commodities.

Regarding explanator (*d*), a well-known empirical observation is that as the value-added share of agriculture declines, the sectoral impact of trade policy gradually shifts. In most low-income, agricultural commodity exporting countries, agriculture is taxed and industry is subsidized. But as incomes grow, trade policy gradually transforms to the opposite, where agriculture is subsidized at the expense of industry, as in most developed economies, such as the US, Western Europe, Japan, and Korea (Anderson and Hayami, 1986; Swinnen, 2018). One interpretation of this policy transition is that it reflects resistance to the process of structural change.

Regarding explanator (*e*), the expenditure elasticity of demand for food is seemingly less than unity almost everywhere (Lluch *et* al., 1977), an empirical phenomenon often called Engel's law. Consider first a (hypothetical) closed economy. If agricultural, industrial, and services output all expanded at the same rate with economic growth, food would be in excess supply and relative output prices would move against agriculture, inducing movements around the PPF away from agriculture. The effect originates on the demand side of the economy and affects production solely through changes in relative prices. This seems to be the conventional textbook explanation for structural change during economic growth. Perkins *et al*., (2013, p. 587) and Thirlwall and Pacheco-Lopez (2017, p. 62) are important examples.

A variant of this argument is provided by Anderson (1987), who points out that the world as a whole is a closed economy. Therefore, demand effects, consistent with Engel's law, presumably operate globally. But the story for individual countries may be quite different. Consider a hypothetical small country where all goods it produces are traded internationally at given world prices. Domestic relative producer prices are determined by international prices, independently of domestic demand. Engel's law would be irrelevant. Now introduce one or more non-traded goods into this model. Because the expenditure share-weighted sum of expenditure elasticities of demand must be unity, if the elasticity for food is less than unity (inferior good), there must be other goods for which it exceeds unity (luxury goods). If those luxury goods include non-tradables, with prices determined by domestic supply and demand conditions, then as incomes rise their relative prices could be expected to increase, diverting resources into their production, even in (otherwise) open economies.

This narrative would predict relative price changes inducing resource movement away from tradables, such as agriculture and industry, and towards supposed non-tradables such as services. It could not explain structural change among sectors producing traded commodities, such as agriculture and industry, because in this framework their domestic prices are exogenously determined by international prices.

The five theory-based explanators summarized above are not mutually exclusive. All could be operating simultaneously, though not necessarily with similar explanatory power, or even in the same direction. Theory alone cannot predict which will be more or less important in a particular context. Empirically-based analysis is required. Structural change is clearly a general equilibrium phenomenon, involving the interaction between resource supplies, technical change, and price changes in different commodity and factor markets. Accordingly, we construct for this purpose a simple, analytically conventional but empirically-based computable general equilibrium (CGE) model of the Thai economy. Because structural change is a long-term issue, the simulations performed with this comparative-static model employ closure assumptions and shocks that are consistent with long-term, rather than short-term adjustment.

The strategy of our quantitative analysis, using this model, is that each of the five explanatory factors listed above is considered an independent, exogenous driver of long-run structural outcomes. The observed pattern of structural change over time (sectoral value-added shares) is assumed to incorporate their combined impact, but with unknown relative importance. We estimate their respective contributions by constructing a series of counterfactuals, each of which is designed to *remove* the impact on the observed structural change outcomes derived from just one of the above five explanatory factors, holding all other determinants constant. In each case, we then compare the observed sectoral shares of output with those estimated under the corresponding counterfactual. The difference between the observed structural change and that estimated under each counterfactual is then attributed to the explanatory factor concerned.

Thailand is chosen for this exercise because of its experience of rapid structural change and also the availability of an internally consistent data set, especially suitable for quantifying the impact of explanations (*a*) and (*b*), above, assembled by the Thai government's economic planning agency. The analysis combines these data, along with information about each of the other three explanatory factors listed above, with the general equilibrium model constructed by the authors. After briefly summarizing the Thai data on structural change we describe our CGE model and then use it to test the explanatory power of each of the above five explanatory hypotheses, one at a time.

As background, in Figure 1, panels a and b describe sectoral output (value-added) shares from 1960 to 2022. Over this long period, the changes in the percentage shares of GDP were: agriculture, a decline from 34 to 8; industry, a rise from 20 to 46; and services unchanged at 46 per cent. That is, the decline in agriculture's share of output was taken up entirely by an increase in the share of manufacturing.[1] Taking account of the availability of data used in the subsequent analysis, we must concentrate on the sub-period from 1990 to 2014. The changes in the percentage point shares of GDP between those years were: agriculture –2.82, industry 5.78, and services –2.96. That is, the value-added shares of agriculture and services each declined by roughly 3 per cent and industry's share rose by roughly 6 per cent. Thailand's structural change during the quarter-century following 1990 differed somewhat from the preceding three decades. But it should be possible to explain what happened over that

[1] Warr and Suphannachart (2022) show that this broad summary is different when Thailand's structural change is viewed in terms of sectoral employment shares rather than value-added shares. While structural change in output, analysed in this paper, can be described as 'industrialization', this is not similarly true of employment. Relocation of workers from agriculture to services was more important than their relocation to industry.

significant interval, 1990-2014, for which available data permit quantitative analysis. We now turn to that explanation.

II. A three-sector general equilibrium model

(i) Model structure

The analysis draws upon a simple, comparative static, CGE model of the Thai economy called *Thai Lek-3*. Most features are conventional for models of this kind. The mathematical structure, but not the numerical database, draws upon the generic model ORANI-G (Horridge, 2000), which provides the full equation set, aggregated within the present model to three production sectors—agriculture, industry, and services—and three corresponding commodities. Its production structure is summarized schematically in Figure 2. The aggregation to only three production sectors makes it possible to use data available for Thailand on relevant shocks, described in section IV below. Also, by reducing the amount of sectoral detail, this aggregation facilitates bringing out the essential features of the analysis, simplifying both the exposition of the model and its results.

The Thailand component of the 2011 release of the GTAP database, aggregated by the authors, serves as the core database for *Thai Lek-3*. There are three primary factors of production: labour, capital, and land, the last employed only in agriculture. Each sector uses a constant elasticity of substitution (CES) production structure and each also uses intermediate goods, both imported and domestically produced, using a Leontief-type input–output structure based on the Thailand-specific data incorporated in the GTAP database. Firms behave as perfect competitors. The cost shares of the three industries are summarized in Table 1 and the exposure to international trade of the three industries and principal supply-side elasticity assumptions are summarized in Table 2.

There is a single household, maximizing utility subject to an income constraint, treating commodity prices as given. Demand for final commodities follows the linear expenditure (LES) demand system (Pollak and Wales, 1992). The three consumer goods correspond to the commodities produced by the three industries, except that consumer goods are each Armington aggregates of domestically produced and imported goods (Dixon *et al*., 1992), meaning that they are imperfect substitutes. Numerical Armington elasticities of substitution and expenditure elasticities of demand are derived from the GTAP database and are shown in Table 2.

(ii) Model closure

Model closure entails the distinction between endogenous and exogenous variables. Consistent with our intended application to long-term issues, labour and capital are fully mobile between all three industries. In all simulations, the input levels of capital and labour are each endogenously determined at the level of individual industries, so as to minimize costs, treating their prices as given, subject to the exogenously given aggregate supply of that factor, as in the Heckscher–Ohlin–Samuelson and Rybczynski frameworks. The aggregate supply of land is also exogenously given, but it is used only in agriculture. Factor markets clear, maintaining full employment. Returns to capital and labour are therefore each equalized across industries. The endogeneity of both capital and labour employment in each industry distinguishes the long-run model closure employed here from short-run closures in which industry-level capital stocks are exogenously fixed.

Consumer demands, industry outputs, international trade, and all domestic factor and commodity prices, are endogenously determined. Thailand is assumed to face downward-sloping demand functions for its exports of all goods on international markets, meaning that export prices are endogenously determined.[2] Unless otherwise stated, simulations are conducted with balanced trade (exogenous balance on current account). This ensures that the potential economic effects of the shocks being studied do not flow to or from foreigners, through a change in the current account balance. For the same reason, real government spending and investment demand for each good are fixed exogenously. The absence of a link between investment demand (exogenous) and the capital stock (independently exogenous) means that the model is not a true growth model, in which the capital stock could be endogenous. Finally, the government budget deficit is held fixed in nominal terms. This is achieved by endogenous across-the-board adjustments to the sales tax rate to restore the base level of the budget deficit.

(iii) Model solution

A model that is linear in proportional changes can be used to estimate the impact of small shocks, but because large shocks to exogenous variables are used in this analysis, linear solutions would involve unacceptable errors. The modelling software used in this study, GEMPACK, release 12 (Horridge *et al.* 2024),[3] takes account of this point by using a step-wise computation, known as the Gragg method, to estimate the non-linear effects of large shocks (Horridge *et al.* 2012). The method uses multiple piecewise linear simulations with an increasing number of steps and then extrapolates from these results to estimate the solution that would be obtained with an infinite number of steps. The effect is that the model is no longer strictly linear in each individual exogenous variable or that the solution is exactly additive across simulations. It nevertheless remains true that, as in strictly linear models, the solution does not account for any interaction effects between different exogenous variables.

III. Interpreting model simulations

A strength of the analysis is the simplicity made possible by using a comparative-static model to represent the effects of a dynamic economic process. The comparative-static question addressed by the simulations is in three parts.

First, *the shocks*.[4] Suppose, hypothetically, that the values taken by one (or more) of the exogenous variables had been different, in the base year, from its actual, observed level in that year. We shall use upper case Roman letters to indicate levels of variables and lower case Roman letters to indicate proportional changes in them. Thus $x = dX/X$. Writing X_T^* for the

[2] This feature is important for Thailand's key agricultural exports, including rice (Warr and Wollmer, 1997), but the GTAP parameters imply that it is also important for service exports.
[3] Further details are available at: https://www.copsmodels.com/gempack.htm
[4] See also Horridge (2000).

counterfactual level of exogenous variable *X* at time *T* and X_T^0 for its actual level at time *T*, the shock to variable *X* is

$$x_T^* = (X_T^* - X_T^0) \,/\, X_T^0. \quad (1)$$

Second, the *estimated impact of the shock*. Given the shocks, x_T^*, the simulation model generates y_{T+l}^*, the estimated proportional changes in the values of the endogenous variables, after an assumed period of adjustment.[5] Writing Y_{T+l}^* for the estimated counterfactual level of endogenous variable *Y* after a period of adjustment beyond year *T*, denoted *l*, and Y_{T+l}^0 for its actual value after that same lag, y_{T+l}^* is given by

$$y_{T+l}^* = (Y_{T+l}^* - Y_{T+l}^0) \,/\, Y_{T+l}^0, \quad (2)$$

and the estimated counterfactual value of *Y* is therefore

$$Y_{T+l}^* = Y_{T+l}^0(1 + y_{T+l}^*). \quad (3)$$

Third, the *estimated impact of the explanator.* Recall that the strategy of the analysis is to estimate the effect of explanators present in the actual data but absent from the estimated counterfactual. The estimated impact of the explanator excluded from the counterfactual is therefore

$$Y_{T+l}^0 - Y_{T+l}^* = -\, y_{T+l}^* Y_{T+l}^0. \quad (4)$$

The 'period of adjustment' means that the true relationship between exogenous shocks and their endogenous consequences is not instantaneous, but involves lags. Nevertheless, the class of models employed here is comparative-static and time itself is not formally represented. The true lags are unknown. Assumptions about them are judgements on the part of the researcher, external to the model itself. They are based partly on the choice of model closure, but the period of adjustment is not explicit and is always approximate. In our empirical analysis, we take this lag to be 3 years, meaning that we interpret the impacts of the shocks as occurring in 2014, not 2011, and we thus estimate impacts by comparing estimated counterfactual values of endogenous variables with their observed values in 2014. This assumption could be disputed, but the assumed lag is relevant only for the interpretation of the results—the story that we tell describing the findings—and plays no role in estimating the proportional changes in endogenous variables.

IV. The shocks

The shocks are summarized in Table 3. Their construction is separate from, and prior to, the CGE model simulations using these shocks, as described under Results below.

[5] The model actually expresses both the shocks and endogenous responses as percentage changes, rather than proportional changes, but the difference is unimportant for this discussion.

***(a)* Relative factor supply shock**

The first three rows of Table 3 summarize the growth of the aggregate stocks of capital, labour, and land estimated for Thailand over the period 1990 to 20l1. In the Thai government study producing these estimates,[6] land is assumed to be used only in agriculture, as in our model. The stock of land grew only slowly but labour and especially capital stocks grew significantly. The most important issue is the *difference* between the growth rates of capital and labour. Now consider hypothetical growth paths of their aggregate stocks, covering the period 1990 to 2011, in which these two factors each grow at the same annual growth rate *r*, resulting in the same level of real GDP in 2011 as was observed in that year, but where land grew only at the observed rate.[7] We calculate the counterfactual levels in 2011 of the total supplies of capital and labour that are implied by this exercise. The proportional differences between these counterfactual 2011 factor supply levels and the observed levels in 2011 are the shocks represented by equation (1) and shown in Column [4] of Table 3.

We implement this calculation for capital and labour, assuming all other exogenous variables, including the stock of land, remain at their observed levels. The logic is: we take away the observed sectoral *differences* in the growth rates of capital and labour, by requiring them to grow at the same annual rate *r*, where *r* generates the observed level of real GDP in 2011. The difference between (i) the observed sectoral shares in 2014 (not 2011; see the discussion of lags above) and (ii) the counterfactual shares estimated for 2014 through model simulation, as in equation (4) above, is then attributed to the differences in the growth rates of capital and labour.

(*b*) Relative TFP growth shock

Table 3 shows the estimated levels of total factor productivity (TFP) in agriculture, industry, and services, between 1990 and 2011, drawing on the same Thai government study as the factor supply estimates described above. For the purposes of the present study, these data on factor supplies and TFP growth have the important advantage that they are internally consistent between factor supplies and TFP. We conduct a counterfactual simulation, similar to that described above, in which these three TFP growth rates are each constrained to increase at the same constant annual rate *s* in agriculture, industry, and services between 1990 and 2011, again producing the same level of real GDP as was observed in 2011.[8] The counterfactual values of TFP in 2011 are then estimated in the same manner as described above for factor supplies.

Again, the logic is: we take away the observed sectoral *differences* in TFP growth, by requiring their growth rates to be equal, subject to producing the observed level of GDP in 2011. Now consider the levels in 2011 of TFP in agriculture, industry, and services implied by this counterfactual exercise. The proportional differences between these counterfactual values and the observed levels of TFP in 2011 are the shocks represented in equation (1). The difference

[6] These estimates are published in "Capital Stock of Thailand, 2021 Edition", available in English at: https://www.nesdc.go.th/nesdb_en/article_attach/%E0%B8%82%E0%B8%B6%E0%B9%89%E0%B8%99%E0%B9%80%E0%B8%A7%E0%B9%87%E0%B8%9A%E0%B8%A0%E0%B8%B2%E0%B8%A9%E0%B8%B2%E0%B8%AD%E0%B8%B1%E0%B8%87%E0%B8%81%E0%B8%A4%E0%B8%A9.pdf
Thailand's national accounts are available in English at:
https://www.nesdc.go.th/nesdb_en/main.php?filename=national_account

[7] That estimated common annual growth rate of capital and labour was $r = 3.39$ per cent.

[8] That common annual growth rate of sectoral TFP was $s = 1.14$ per cent.

between the observed structural change and that estimated through the simulation, as in equation (4), is then attributed to the *differences* in TFP growth rates.

(*c*) Relative international price shock

Most of Thailand's agricultural products are net exports (soybeans and dairy products are exceptions) and most manufactured goods are net imports (vehicles, vehicle parts, and computer hard drives are important exceptions). Table 3 summarizes data from the Thai government on the average unit values of Thailand's agricultural exports relative to those of manufactured imports. The data show a U-shaped pattern, but decline from an index of 1 in 1990 to 0.979 in 2011.[9] That is, over this period relative international prices moved marginally against agriculture and in favour of industry.

(*d*) Protection shock

Since the late 1980s Thailand has progressively eliminated most agricultural export taxes and reduced average rates of industrial protection. The implied negative protection of agriculture and positive protection of manufacturing has therefore declined over time. Quantifying these changes, Warr (2008) and Warr and Kohpaiboon (2009) assembled data on average rates of trade protection for agricultural and manufactured goods, for the years 1970 to 2005. These estimates were updated to 2011 for the present study. The data, summarized in Table 2, imply a decline in the net rate of taxation (negative protection) of agriculture from 27.2 per cent in 1990 to 4.5 per cent in 2011. Changes in trade policy therefore favoured agriculture and disfavoured manufacturing. The counterfactual removes this decline in manufacturing protection. Implementation of this shock takes account of the fact that imported industrial goods comprise a large share of costs in the industry sector. This is also true, but less so, of agriculture and services, where imported industrial imports are significant. The effective rates of protection summarized in Table 3 are net of protection applied to imported inputs (Corden, 1966). Accordingly, the protection shock is implemented as a change to rates of protection of final industrial goods and not intermediate goods. The model software being used implements a change in protection as a percentage change in the power of the tariff, not in the level of the tariff. The power of the tariff, in percentage terms, is $(100 + t)$ where t is the percentage rate of the tariff.

(*e*) Demand shock: inelastic demand for food (Engel's law)

The Engel's law explanation for structural change has two components: (i) non-unitary expenditure elasticities of demand, subsequently described as non-homothetic demand; and (ii) an increase in final household expenditure accompanying economic growth. The expenditure elasticities assumed in the model are summarized in Table 2. The percentage increase in real consumption from 1990 to 2011 was 61.8 per cent. The counterfactual analysis removes this increase in consumption expenditure by separating the change in household expenditure from changes in GDP and its other components. Consider the familiar demand-side national accounting identity

[9] *Source*: Authors' calculations from Bureau of Trade and Economic Indices, Ministry of Commerce, Government of Thailand, Bangkok:
http://www.indexpr.moc.go.th/PRICE_PRESENT/exi/index_exi.asp?list_year=2567&province_code=00

$$GDP = C + I + G + X - M, \tag{5}$$

where all variables are defined in real terms (GDP deflator), C is household consumption, I is total investment, G is government expenditure and $X - M$ is the trade balance. Rearranging,

$$C = GDP - I - G - (X - M). \tag{6}$$

Given our model closure (see above), real GDP is determined by technology and the aggregate supply of resources, all of which are exogenous. Each of the other terms on the RHS of (4) is also exogenous, including the trade balance, $(X - M)$. In all simulations (*a*) to (*d*) above, the change in the trade balance was exogenously zero. Shock (*e*) was implemented by changing the trade balance exogenously by an amount sufficient to reduce real consumption expenditure in 2011 to its 1990 level.[10] That required change in the trade balance was found through an iterative series of simulations called 'grid search'.

This counterfactual exercise of changing the trade balance can be understood as eliminating the increase in household expenditure that occurred between 1990 and 2011 by exogenously transferring to foreigners enough revenue to keep real household expenditure at its 1990 level, leaving the supply side of the economy unaffected. The large increase in real consumption that actually occurred, combined with non-homothetic expenditure elasticities of demand, induced changes in relative commodity prices that presumably influenced structural change. Simulation (*e*) eliminates those demand-induced relative price changes, by removing the underlying increase of household expenditure, leaving all other determinants of structural change unaffected. The difference between the actual structural change and the counterfactual change estimated by this simulation is then attributed to the observed increase in household expenditure, combined with non-homothetic demand.

IV. Estimated impacts

(i) Expectations based on standard theoretical models

Before presenting the simulation results on the estimated effects that the above shocks have on changes in sectoral shares, and attempting to explain them, it may be intuitively helpful to consider the results that might be expected from familiar but simplified theoretical models. First, consider the standard two-sector Heckscher–Ohlin–Samuelson (HOS) model. Each of the two domestically produced goods is a perfect substitute for a corresponding internationally traded good, the domestic country is a price taker on all international markets, and aggregate factor supplies are exogenously determined. Stolper and Samuelson (1941) showed that in this model factor prices are determined by commodity prices and domestic technology. If the latter are constant, the former are constant as well. Within that model, explanators (*a*) to (*d*) would be potentially relevant for structural change, but not explanator (*e*).

Explanator (*a*) corresponds to the famous Rybczynski (1955) model. Suppose first that capital is accumulated but labour supply remains constant. Output in the more capital-intensive sector must expand to employ the new capital. But to raise output it must also use some additional labour. It can get this labour only from the more labour-intensive sector, so output in the latter

[10] See Table 3. The required percentage change in the 2011 level of real consumption was $100(100 - 161.8)/161.8 = -38.2$.

must contract to release that labour. Now assume that both capital and labour supplies expand but capital grows more rapidly. Output in the capital-intensive sector must expand more rapidly than the growth rate of capital and output in the labour-intensive sector must expand less rapidly than the growth rate of the labour supply. Another way of viewing this analytical result is that the Rybczynski effect changes the shape of the production possibilities frontier (PPF). Growth of capital relative to labour expands the possible outputs of the capital-intensive sector relative to the labour-intensive sector. Rybczynski's analysis predicts that factor growth may be a powerful driver of structural change, because sectoral outputs change in a more magnified form than changes in factor supplies. The size of this magnification depends on the degree of substitutability between factors. It is important to recall that under Rybczynski's assumptions, commodity prices and factor prices cannot change in response to changing factor supplies.

Explanation (*b*) similarly changes the shape of the PPF in favour of the sector(s) experiencing the most rapid productivity growth, but it does so directly, not involving the degree of factor substitutability. Explanations (*c*) and (*d*) leave the shape and position of the production possibilities frontier unchanged but alter relative domestic commodity prices, changing the position on the PPF at which production occurs.

Explanator (*e*)—Engel's law—implies changes in the composition of final demand, but it would be irrelevant in this open economy framework because relative domestic prices would be independent of domestic demand. As incomes grow, the composition of final demand and international trade would be endogenously influenced by the characteristics of domestic demand. But the sectoral composition of output would be unaffected by these demand-side phenomena because neither the shape of the PPF nor relative domestic producer prices are affected by them.

The extension of this framework to three traded goods sectors is straight-forward. Now consider the 'Australian' 3-sector model (Jones, 1965; Anderson, 1987; Devarajan *et al*., 1993; Menzies and Vines, 2008). This can be considered a variant of the 3-sector HOS model in which the exportable good (agriculture) and the import-competing good (industry) each remain perfect substitutes for their internationally traded counterparts, but in which services is non-traded. The introduction of the non-tradable is the essential difference from the HOS model. Domestic income growth would affect the domestic price of the non-tradable relative to each of the two tradable commodities, but would not affect the relative prices of the two tradables. Explanator (*e*) would predict movement of resources towards services, assuming its expenditure elasticity of demand exceeds unity, because income growth would generate an increase in its domestic price. Since the resources required must come from elsewhere, agriculture and industry combined must contract. Which contracts the most will presumably depend on which sector has the more similar resource structure to services – presumably industry.

The *Thai Lek-3* model used in the present paper has some similarities to the HOS and 'Australian' model, as above, but with three important differences. First, *Thai Lek-3* recognizes intermediate inputs in all three sectors, through an input–output structure, based on Thai data. Second, within *Thai Lek-3* all three sectors are exposed to international trade, again reflecting Thai data, both for intermediate inputs and final produced goods, but this exposure to international markets is only partial. In contrast with the HOS model, domestically produced goods are imperfect substitutes for imports, in both final demand and intermediate good demand, reflecting the Armington elasticities of substitution contained in the GTAP database.

None of the commodities is 'non-traded', but none of them is fully traded in the HOS sense, either. This means that all domestic relative prices can change endogenously in response to shocks. Exports and imports co-exist in all three sectors. This is analytically possible because of the Armington assumption described above. Third, export demand functions are downward-sloping, again reflecting the GTAP parameters.

How these empirically-based assumptions will affect the structural change outcomes of the five explanators is difficult to predict *a priori*. An insight derived from the above discussion is the key role played by changes, or the absence of changes, in relative domestic prices. An empirically-based general equilibrium treatment seems essential to keep track of this level of complexity, even in a three-sector context. We now turn to the results of that exercise.

(ii) Quantitative results

Table 4 and Figure 3 summarize the findings, showing observed and counterfactual value-added shares derived from the shocks corresponding to the four explanatory variables (*a*) to (*e*) above. Columns [1] and [2] of Table 4 show the observed sectoral shares in 1990 and 2014, respectively. Of course, they are the same for all counterfactual simulations. All counterfactual simulations assume LES final demand with the elasticities summarized in Table 2.

(*a*) *Factor supply shock*. Column [4] of Table 4 shows the estimated counterfactual sectoral shares, as described above. The difference between Column [2] and Column [4], shown in Column [5], is interpreted as the impact on sectoral shares of capital and labour stocks growing at *different* rates—as they do in the observed data (Column [2]), but not in the counterfactual (Column [4]). This was the essence of Rybczynski's theoretical contribution—the structural effects of aggregate factor supplies growing at different rates (Rybczynski, 1955; Jones, 1965).

The estimated pattern of structural change resulting from the factor supply shock (Column [5]), is qualitatively similar to the observed changes (Column [3]), but only about one-tenth the size. Figure 3 makes this comparison clear. The results confirm the theoretical expectation that differential growth rates of factor supplies (capital growing faster than labour) lead to an expansion of the capital-intensive sector, industry, and a decline in the labour-intensive sectors, agriculture and services. But the magnitude of this effect is not large enough to explain the structural change that actually occurred.

(*b*) *TFP shock.* Again comparing Column [5] with Column [3], the estimated pattern is again qualitatively similar to the observed changes in sectoral shares, but much closer in magnitude. Now imagine these two supply-side shocks simulated together. This simulation of the two supply-side shocks together, depicted in Figure 4, seemingly explains the observed structural change quite well, except that the divergence between the expansion of industry's share and the contraction in services' share is somewhat under-predicted.

(*c*) *International price shock* and (*d*) *Protection shock.* The estimated pattern of effects each again fit the expected pattern, but their magnitudes, especially the protection shock, are much smaller than the two supply-side shocks considered above. In Thailand's case, these impacts apparently supported structural change, in the observed direction, but their magnitude was minor.

(*e*) *Demand shock*. Again we compare Column [5] with Column [3]. The estimated effects differ radically from the observed structural change. The estimated contraction of agriculture is minor, services expands, reflecting its higher expenditure elasticity of demand, but the resources required for this expansion come mainly from industry, which contracts as a share of GDP, roughly matching the expansion of services.

The combination of all five shocks, implemented jointly, explains the actual changes well but somewhat understates the divergence between the shares of industry and services in the actual data. The estimates generated by the demand shock are largely responsible for this difference. Finally, Figure 4 returns to a question raised in the Introduction. Do supply-side induced changes in the shape of the production possibility frontier or price-induced movements around the frontier provide a better explanation for structural change? For Thailand, over this period, the unambiguous answer is the former.

We now return to the comparison between this model and more conventional trade-theoretic models and how the differences in models affect the findings. A crucial difference is that finite Armington elasticities of substitution and finite elasticities of export demand within *Thai Lek-3* confer greater flexibility of domestic relative prices than exists in models that tether domestic prices of at least some commodities ('traded' commodties) to fixed international prices. The role of domestic relative prices in driving the results can be seen from Table 5, which shows percentage changes in the relative prices of final commodities (upper panel) and relative value-added prices (lower panel). The latter allow for changes in intermediate goods prices as well as output prices and are thus more relevant for explaining changes in value-added shares. Since only relative prices matter, both panels normalize on the price of industry. This means that the level of the price of industry (both final commodity price and value-added price) is unity and the change in it is zero, by construction.

It is sufficient to focus on the first two columns – shocks (*a*) and (*b*). The key point is that domestic relative prices move strongly *against* the structural changes that are occurring, an endogenous response to these structural changes, not in support of them. This is particularly clear in the case of value-added prices in shock (*a*). The structural change effects of this shock are small, partly because domestic relative value-added prices move heavily in favour of agriculture and services, *inhibiting* the larger structural changes that would otherwise have occurred if domestic prices did not change as much.

It follows that models incorporating less flexibility of domestic prices than exists in *Thai Lek-3* can be expected to show larger structural changes. This point has been demonstrated by re-running the simulations with all Armington and export demand elasticities arbitrarily increased by a multple of 40, relative to those shown in Table 2.[11] As expected, the results then show smaller relative price changes than those shown in Table 4. The simulated structural changes are in the same direction as the simulations shown in Table 4, but much larger, and greatly exceeding the structural changes actually observed. Shock (*b*) still has a larger impact than shock (*a*), but the difference between the two is smaller than in our estimates. The demand shock then performs even less well in explaining structural change than in Table 4. The methodological implication seems clear. To analyze structural change effectively, it is essential to capture the role of endogenous domestic price movements in response to exogenous shocks. Based on our results, the Armington framework does this well.

[11] For brevity, these quantitative results are not shown.

V. Conclusions

Structural change means changes in the sectoral composition of GDP. We have constructed a simple analytical framework, centred on a small comparative-static general equilibrium model of the Thai economy, that attempts to ascertain its causes. We do this in the context of the large structural changes that occurred in Thailand over the quarter-century between 1990 and 2014. The analysis performs well in explaining these changes. The reason for this happy outcome is *not* that the model was calibrated, by contrivance, to achieve it. The structure of the model is conventional, based on standard neo-classical assumptions, derived from a publicly available generic general equilibrium model; the database and all model parameters are based on the publicly available GTAP model; and the shocks are all calculated from published Thai government data.

The most important explanators for structural change were found to be supply-side forces, especially sectoral differences in rates of TFP growth. According to our findings, this explanator alone accounts for most of the structural change that occurred. The observed difference in the growth rates of aggregate supplies of capital and labour contributed to the explanation of structural change, in the expected direction. But somewhat surprisingly, given the theoretical expectation, the estimated impact was small. Factor supplies actually grew at significantly different rates. The small estimated impact seemingly reveals that this driver of structural change is not as powerful as might reasonably have been expected, based on Rybczynski's famous trade-theoretic analysis. We have attempted to explain this finding in terms of the departures of our model from the strong open economy assumptions of the conventional Heckscher–Ohlin–Samuelson–Rybczynski trade theoretic models and models making similarly rigid assumptions about domestic price determination. Based on our findings, the latter models restrict domestic price flexibility excessively, reducing their capacity to predict or explain structural change.

Exogenous changes in international prices and changes in rates of trade protection also had little estimated impact. Of course, these results reflect the events that actually occurred over this period. If there had been larger changes in international prices or in relative rates of protection, their estimated impact on structural change would of course have been larger. But the observed changes in international prices and rates of protection were both quite significant. It seems from these results that these explanators are simply not particularly powerful as drivers of structural change.

Two well-known empirical observations are that, first, rising incomes are accompanied by structural change. Second, at the same time, the sectoral impact of trade policy gradually shifts. From taxing agriculture and subsidizing industry, as in most low income, agricultural commodity exporting countries, trade policy gradually transforms to the opposite, subsidizing agriculture at the expense of industry, as in most developed economies, such as the US, Western Europe, Japan, and Korea (Anderson and Hayami, 1986; Swinnen, 2018). Thailand's historical experience fits this general pattern. The political economy underlying this policy transition is debated, but one interpretation is that the two empirical observations described above are causally related. That is, the shift in trade policy represents, in part at least, policy resistance to ongoing structural change. Our findings nevertheless suggest that sectoral protection policy is a particularly blunt instrument for resisting structural change.[12]

Our findings also indicate that over the period studied the standard textbook explanation for structural change—Engel's law—is a poor explanator of Thailand's structural change. We have shown this by simulating the effect of removing the observed increase in household expenditures, holding GDP and all other explanators constant. The implied effects of an increase in expenditures differed markedly from the observed structural change. Engel's law seemingly has little empirical salience in explaining structural change.

Overall, our results suggest that the main source of structural change arises from supply side forces: changes in the shape of the production possibilities frontier, induced mainly by changes in technology, rather than by capital accumulation or by price-induced movements around the frontier. This is so whether those price changes are induced by changing international prices, changes in the country's trade policy, or the implications of Engel's law. This does not mean that relative price changes play no role in influencing structural change. We have shown that domestic price flexibility facilitates large endogenous relative price movements that *oppose* structural change driven by supply side forces, limiting the much large structural changes that would otherwise occur.

The CGE modelling approach used in this study has advantages and liabilities. A clear analytical advantage is that, unlike most econometric models, causation is clear. Experiments can be conducted in which changes in the exogenous variables (the shocks) unambiguously *cause* changes in the endogenous outcomes (the impacts). A second advantage is that the quantitative analysis is internally consistent. All relevant accounting identities are satisfied by the simulation results. Everything must 'add up' correctly, eliminating the possibility of internally inconsistent results. A third advantage is that the analysis is based on economic data for the country concerned and explicitly specified assumptions about behavioural relationships and parameters. None of these claims can be made for analyses based on 'back-of-the-envelope' theorizing. A simplifying limitation relates to interaction effects between shocks. Our modelling framework rules them out, but they could be important in some cases.

The above findings may be relevant for other countries experiencing a similar growth path to Thailand, but that could not be guaranteed. Generalisations of that kind could be misleading. The relative importance of the underlying drivers of structural change may differ between countries and may change over time, partly because the changes in the explanatory variables corresponding to our five shocks are different, but also because the economic structures are different and changing. Country-specific empirical research for other countries would be required to support any such conclusions.

We have demonstrated in this paper a method by which such studies can be conducted, using simple comparative-static general equilibrium models. These now exist for many countries. Well-developed, internally consistent generic models also exist and country-specific data can be applied to them, as we have done in this paper. It is important that this research draw on country-specific data for construction of the models themselves. The GTAP database is a useful resource in this respect. The resulting models must then be operated with long-term, not short-term closure assumptions. Equally important, to be empirically relevant the shocks used to

[12] See also Anderson and Ponnusamy (2022) for cross-country econometric evidence supporting this conclusion.

capture the impact of alternative explanators should be based firmly on data for the country concerned and not on arbitrary, illustrative assumptions.

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Table 1: Industry cost shares

(Units: per cent total primary factor cost)

	Capital	Labour	Land	Intermediate inputs		Commodity taxes	Total
				Domestic	Imported		
Agriculture	6.0	22.6	28.2	34.3	8.0	0.9	100
Industry	15.3	6.4	0	42.0	34.5	1.8	100
Services	33.8	20.2	0	38.3	6.3	1.5.	100
Total	21.7	12.7	1.6	40.0	21.9	1.6	100

Note: These data seemingly imply that services is more capital-intensive than industry. That occurs because of the large cost share of imported intermediate goods used in industry. Focusing only on value-added, the percentage cost shares of capital are: agriculture 10.6; industry 70.5; services 62.6. In agriculture, focusing on value-added generated by mobile factors (excluding the fixed factor, land) the cost share of capital becomes 21.0.
Source: Authors' calculations from GTAP 2011 database, Thailand, as described in Hertel (1999).

Table 2: Trade shares and principal elasticity assumptions

Sector / commodity	Trade shares (%)		Elasticity parameters			
	Import	Export	Armington elasticity of substitution	Export demand elasticity	Elasticity of factor substitution	Expenditure elasticity of demand
Agriculture/food	10.6	7.5	2.4	4.9	0.25	0.414
Industry/manufactured goods	46.4	45.3	3.5	7.7	1.03	0.823
Services	7.9	10.0	1.9	3.9	1.37	1.197

Note: Import share means imports/domestic demand. Export share means exports/domestic production.
Source: Authors' calculations from GTAP 2011 database, Thailand, as described in Hertel (1999).

Table 3: Shocks to exogenous variables

Variable	Units	Actual level 1990	Actual level 2011	Counterfactual level 2011	Shock (proportional change)
From equation (1):	(See below)	X^{0}_{1990}	X^{0}_{2011}	X^{*}_{2011}	$(X^{*}_{2011}$ - $X^{0}_{2011})$ / X^{0}_{2011}
***(a)* Relative factor supply shocks**					
Capital	Index: 1990 = 100	100	271.4	205.6	–24.2
Labour	Thousands	29,317	38,465	60,279	56.7
Land	Index: 1990 = 100	100	115.1	115.1	0
***(b)* Relative factor productivity shocks**					
Agriculture	Index: 1990 = 100	100	64.4	98.8	53.4
Industry	Index: 1990 = 100	100	139.6	126.9	-9.1
Services	Index: 1990 = 100	100	71.8	69.4	–3.3
***(c)* Relative international price shock**					
Price of agricultural /industrial goods	Index: 1990 = 100	100	97.9	100	2.1

***(d)* Protection shock**					
Power of the tariff on industrial goods	100 + percentage tariff rate	127.2	104.5	127.2	21.7
(*e*) Demand shock					
Real household expenditure	Index: 1990 = 100	100	161.8	100	–38.2
[Column number]		[1]	[2]	[3]	[4] ={[3] - [2]}/[2]

Notes: See equation (1) in the text.
For shock (*a*), the calculation of Column [4] follows these steps:
(1) Column [1]: Actual levels of capital, labour and land in 1990.
(2) Column [2]: Actual levels of capital, labour and land in 2011.
(3) Using the simulation model, estimate a single, common counterfactual growth rate of both capital and labour, *r*, between 1990 and 2011 that would replicate the observed level of real GDP in 2011. The estimated value of *r* was 3.39 per cent per annum.
(4) Column [3]: Use *r* to calculate counterfactual levels of capital and labour in 2011, beginning with their actual 1990 levels.
Column [4]: Proportional differences between the counterfactual 2011 levels of capital and labour (Column [3]) and their actual levels (Column [2]) –as in equation (1) of the text.
For shock (*b*), the steps are the same. In step (3) the estimated value of the single, common counterfactual growth rate value of TFP growth for all three sectors was s = 1.14 per cent per annum.
For shock (*d*), the model implements a change in protection as a percentage change in the power of the tariff = 100 + t, where t is the percentage tariff rate, not as a percentage change in the level of the tariff.
For shock (*e*), Column [4] shows the percentage change in real household expenditure that was required. That change was implemented through a shock to the trade balance, as described in the text.
Source: Authors' calculations.

Table 4: Results: actual and counterfactual value-added shares (% of GDP)

Variable	Actual level 1990	Actual level 2014	Actual change 1990 to 2014	Counterfactual level 2014	Estimated impact of explanator
From equations (2) to (4):	Y^0_{1990}	Y^0_{2014}	$Y^0_{2014} - Y^0_{1990}$	Y^*_{2014}	$Y^0_{2014} - Y^*_{1`014}$
(*a*) Relative factor supply shocks					
Agriculture	9.91	7.09	–2.82	7.32	–0.23
Industry	28.42	34.20	5.78	33.59	0.61
Services	61.67	58.71	–2.96	59.09	–0.38
Total	100	100	0	100	0
(*b*) Relative factor productivity shocks					
Agriculture	9.91	7.09	–2.82	9.37	–2.28
Industry	28.42	34.20	5.78	27.63	6.57
Services	61.67	58.71	–2.96	63.01	–4.30
Total	100	100	0	100	0
(*c*) Relative international price shocks					
Agriculture	9.91	7.09	–2.82	7.13	–0.04
Industry	28.42	34.20	5.78	34.14	0.06
Services	61.67	58.71	–2.96	58.73	–0.02
Total	100	100	0	100	0
(*d*) Protection shocks					
Agriculture	9.91	7.09	–2.82	7.09	0.00
Industry	28.42	34.20	5.78	34.31	–0.11
Services	61.67	58.71	–2.96	57.18	0.11
Total	100	100	0	100	0
(*e*) Demand shock					

Agriculture	9.91	7.09	–2.82	7.26	–0.17
Industry	28.42	34.20	5.78	38.20	–4.00
Services	61.67	58.71	–2.96	54.54	4.17
Total	100	100	0	100	0
All shocks (*a*) to (*e*) jointly					
Agriculture	9.91	7.09	–2.82	9.78	–2.69
Industry	28.42	34.20	5.78	30.99	3.21
Services	61.67	58.71	–2.96	59.24	–0.53
Total	100	100	0	100	0
[Column number]	[1]	[2]	[3] = [2] – [1]	[4]	[5] = [2] – [4]

Notes: See equation (2) in the text.
Each explanator is assumed to affect the actual (observed) 2014 data on value-added shares, Y^0_{2014} (Column [2]), but with unknown magnitude. The counterfactuals, Y^*_{2014} (Column [4]) are the estimated levels of value-added shares that would have resulted in 2014 from the hypothetical *absence* of the explanator concerned. Our interest is in the estimated impact of the explanator: actual minus the counterfactual = $Y^0_{2014} - Y^*_{2014}$, shown in Column [5] = Column [2] – Column [4], which can be compared with Column [3].
Source: Simulation results described in the text.

Table 5: Simulated changes in commodity and value-added prices (% change)

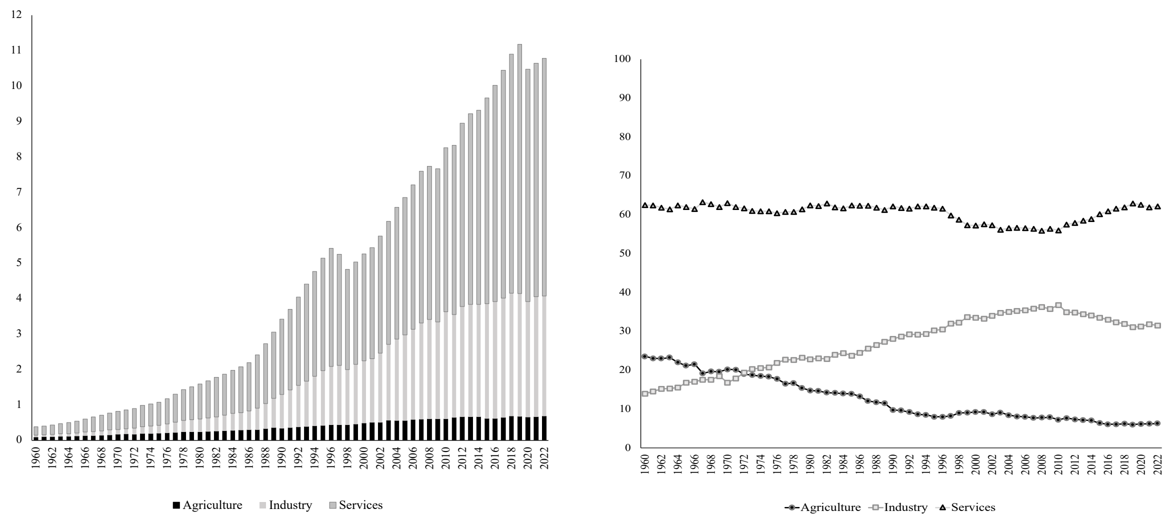
	Relative factor supply shock (*a*)	Relative factor productivity shock (*b*)	Relative international price shock (*c*)	Protection shock (*d*)	Demand shock (*e*)	All shocks (*a*) to (*e*) jointly
Change in relative commodity prices (normalized on industry price)						
Agriculture	5.90	33.49	-1.08	-0.08	-3.44	34.78
Industry	0*	0*	0*	0*	0*	0*
Services	1.85	15.13	0.14	-0.25	2.62	23.15
Change in relative value-added prices (normalized on industry value-added price)						
Agriculture	12.59	17.65	-1.99	0.28	-9.62	18.91
Industry	0*	0*	0*	0*	0*	0*
Services	5.85	0.56	-0.01	0.01	0.35	6.75
[Column number]	[1]	[2]	[3]	[4]	[5]	[6]

Note: The notation 0* for changes in industry prices means that because only relative prices are relevant, the table expresses changes in agricultural and services prices relative to industry prices. The level of the industry price is thus unity and its % change is zero, by construction.
Source: Simulation results described in the text.

Figure 1: Structural change: observed value-added and value-added shares

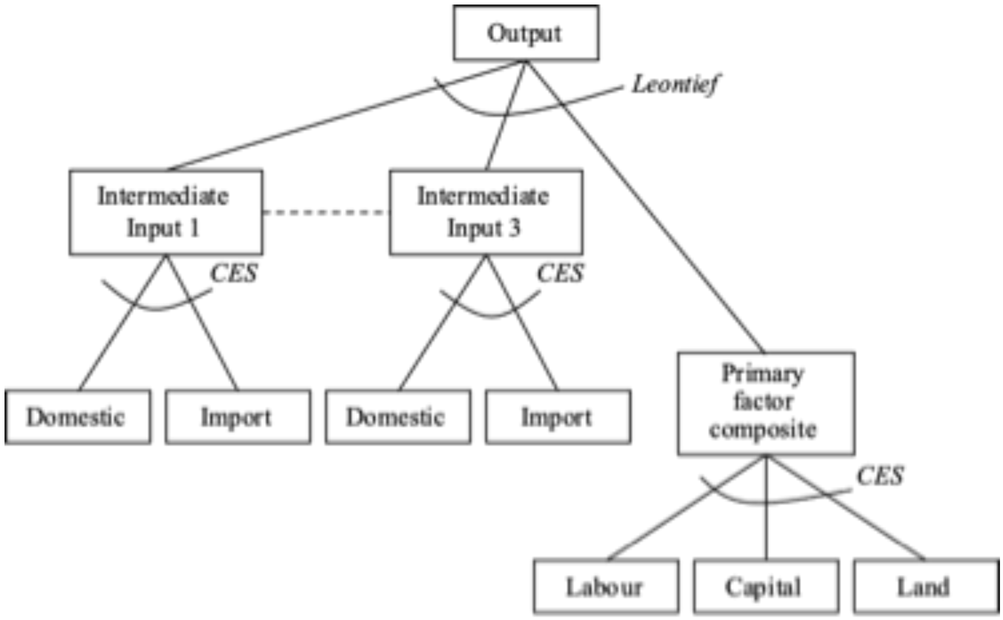
Panel a. Total value-added

Panel b. Value-added shares



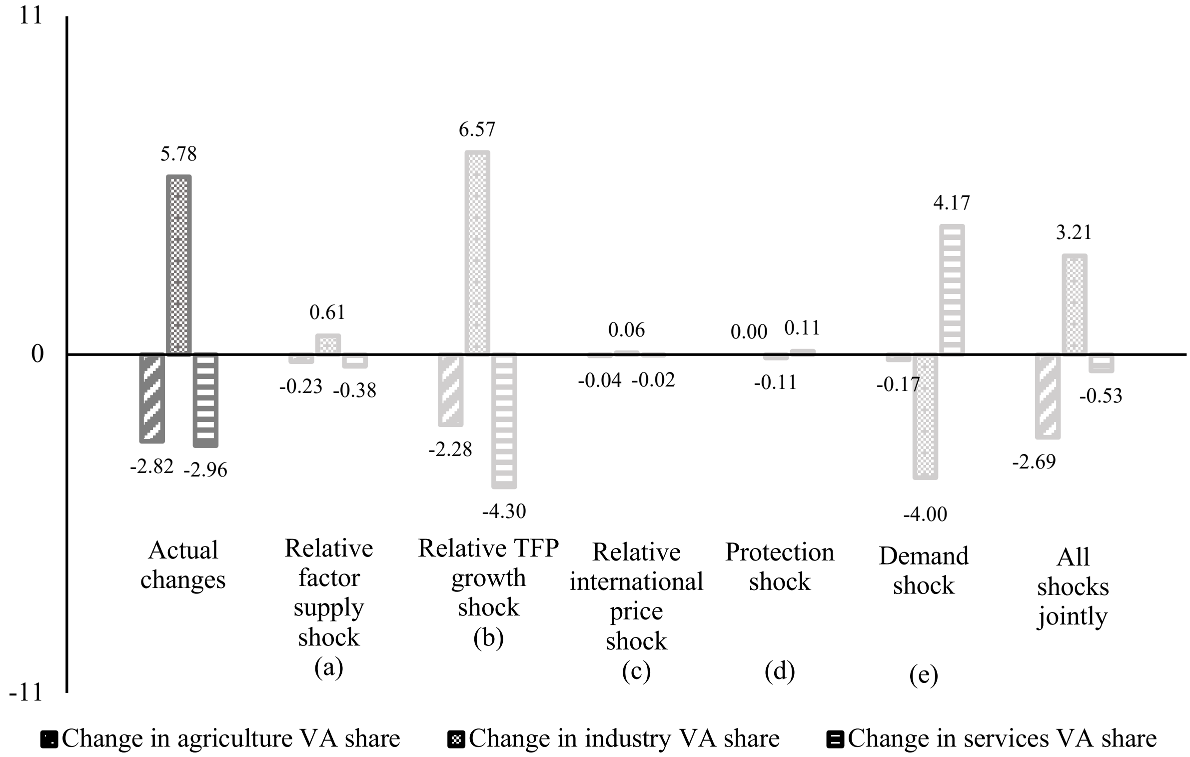
Note: Units: panel a level, constant prices; panel b percentage share.
Source: Authors' calculations, using data from National Economic and Social Development Council, Bangkok.

Figure 2: Model production structure for each sector



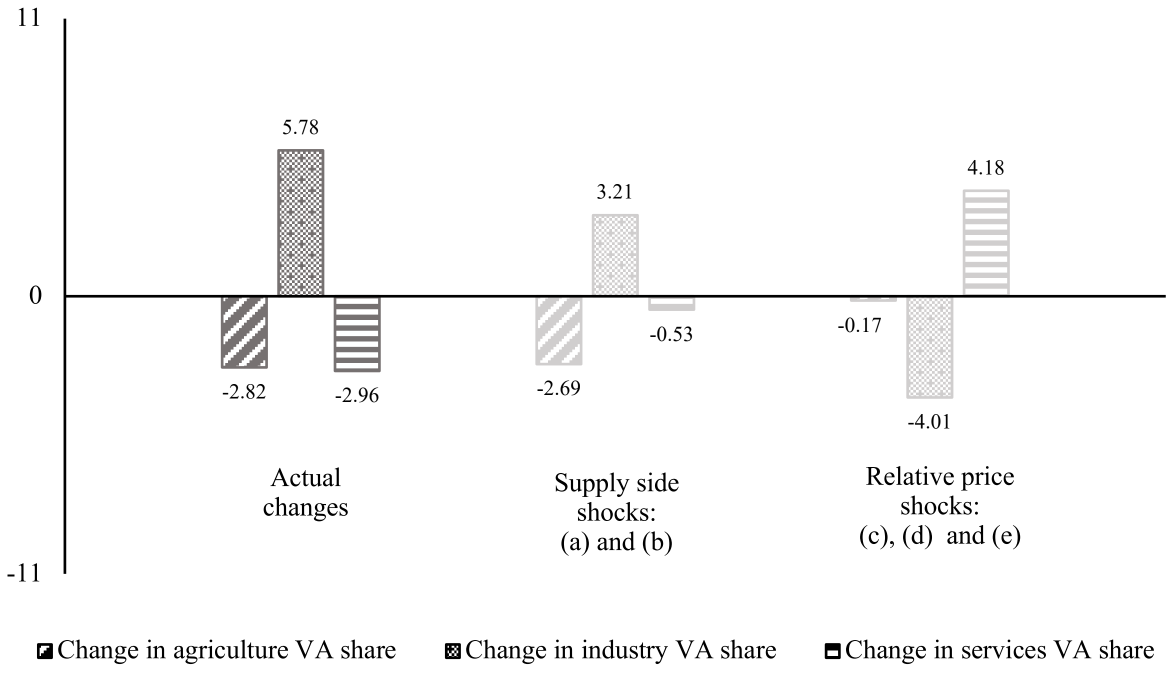
Note: Labour, capital, and land are primary factors in agriculture. In industry and services, labour and capital are the only primary factors. All three sectors (agriculture, industry, and services) also use intermediate goods, which are CES (Armington) aggregates of domestically produced and imported intermediate goods.
Source: Authors' construction.

Figure 3: Actual and estimated changes in sectoral value-added shares (% change)



Note: The diagram corresponds to Table 4: Column [3] - actual changes, in dark grey; and Column [5] - estimated impact of explanator, in light grey.
"All shocks jointly" means shocks (a), (b), (c), (d) and (e) simulated jointly.
Source: Simulation results described in the text.

Figure 4: Supply side shocks vs relative price shocks (% change)



Note: The diagram corresponds to Table 4: Column [3] - actual changes, in dark grey; and Column [6] - estimated impact of explanators, in light grey.
"Supply side shocks: (a) and (b)" means shocks (a) and (b) simulated jointly.
"Relative price shocks: (c), (d) and (e)" means these three shocks simulated jointly.
Source: Simulation results described in the text.