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Abstract

We empirically analyse the response of labour market related variables in the US manufacturing sector to various shocks, notably to trade openness and technology, as well as examining spillovers from industry-specific labour market shocks. The econometric approach involves an application of the recently developed global VAR (GVAR) methodology of Dées, DiMauro, Pesaran, and Smith (2007) to 12 manufacturing industries over the period 1977-2003. The framework allows us to analyse the response of a standard set of labour-market related variables (employment, real compensation, productivity and capital stock) to exogenous factors (a sector-specific measure of trade openness, a common technology and oil price shock), along with industry spillovers using specific measures of manufacturing-wide variables for each sector. Generalised impulse responses indicate that increased trade openness negatively affects real compensation, has negligible employment effects and leads to higher labour productivity. These impacts, however, are relatively weaker than those induced by technology shocks, with the latter positively and significantly affecting both real compensation and employment. There is also evidence of positive spillovers across industries from sector-specific employment and productivity shocks. Impact elasticities suggest strong intra-sectoral linkages for employment and capital stock formation, contrasting with weak linkages for what concerns real compensation and productivity.

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1 Introduction

In recent years, increasing trade integration of emerging markets in an environment of rapid technological change has intensified a long-standing debate on the effects of international trade on employment and wages in industrialised countries. In particular, expanding international trade and accelerating technological progress have tended to constitute two main structural arguments for weakness in industrialised countries' labour market outcomes in the traded goods sector. On the one hand, it has been argued that increasing trade integration has led to an attrition of low-skilled and / or low-wage jobs in certain sectors to developing countries given growing imports of labour-intensive manufactured goods from developing countries, considerable global corporate restructuring involving more intense use of global subsidiaries and outside contractors, and a greater mobility of production factors. On the other hand, it has been argued that skill-biased technological change arising from an autonomous surge in technical progress has generated sectoral reallocation of production biased against primarily low-skilled workers in developed economies.[1] A strict dichotomy between trade and technology, however, is difficult in practice given that the two phenomena have become progressively intertwined, with trade being a channel for technology diffusion and adoption, both *directly* (through imports of capital goods) and *indirectly* (for instance, through pressure on firms exposed to trade to innovate). Research to date has offered no conclusive estimates of the effects of trade liberalisation and technological progress on labour market outcomes.

A focus on the manufacturing sector is natural in providing an assessment of labour market impacts of increased trade openness, given that goods are inherently more internationally tradeable than services despite any increasing tradability of the latter in recent years. In the US, similar to other advanced economies, employment in the manufacturing sector has been relatively weak in recent years, whilst more generally being in a position of relative secular decline when assessed against nonfarm employment for the economy as a whole since the mid-1970s. This relative sluggishness (see Chart 1a) has been correlated with a sizeable expansion in the trade deficit in goods and services since the mid-1990s (Chart 1b) along with strong productivity gains (Chart 1c). These relatively strong productivity gains have only been partly reflected in real compensation per hour in the manufacturing sector (Chart 1d).

[INSERT CHART 1]

This paper aims to provide a quantification of the extent to which relative weakness in US manufacturing labour market outcomes has derived from international trade issues versus a measure of technological progress. The behaviour of wages, employment, productivity and the capital stock for 12 sectors of US manufacturing is analysed both in response to shocks to weakly exogenous factors –such as industry-specific trade openness, R&D spending and oil shocks– and in response to intra-sectoral spillovers of select industry-specific shocks. The methodology involves an application of the GVAR framework of Dées, DiMauro, Pesaran, and Smith (2007) (henceforth DdPS) applied to an industry setting, with manufacturing-wide variables for each sector constructed as weighted average of other sectors.[2]

While several papers have already analysed the role of trade and technology on labour market outcomes, this paper applies a novel empirical approach in analysing the issue in two main ways. First, the adopted methodology analyses labour market to trade openness and technology shocks in

[1]Other structural factors behind weak employment in the manufacturing sector include (1) a general reduction in the share of manufactured goods in consumption through time in favour of services given demographic changes in advanced economies, such as the consumption of more medical care and the outsourcing of household tasks to various service providers (see CongressionalBudgetOffice (2004)); and (2) a statistical effect of a "splintering" or "fragmentation" of services from manufacturing, whereby part of the manufacturing value added is contracted out to a separate firm and re-classified as a service (see Bhagwati, Panagariya, and Srinivasan (2004)).

[2]In this sense, the 'GVAR' nomenclature is retained for this sectoral analysis in contrast to the country analysis of DdPS.

a cohesive empirical framework allowing for the simultaneous interaction of wages, employment and productivity in response to exogenous shocks. Second, the construction of industry-specific weighted manufacturing-wide variables allows for a differentiated analysis of spillovers from idiosyncratic shocks in particular sectors.

The paper is organised as follows. We preface the analysis with a brief overview of the relevant literature in Section 2. Next, we proceed to outline the econometric estimation in Section 3. We then present the results of the econometric analysis, both in the form of generalised impulse responses and impact elasticities, in Section 4. Some concluding remarks are then drawn in Section 5.

2 Trade, technological change and the labour market: a brief review of the literature

Widely cited theories linking trade to labour market outcomes include those of Heckscher-Ohlin-Samuelson and Stolper-Samuelson along with Ricardian models. In the first two theories, comparative advantage is due to different factor intensities, whereby countries export goods that intensively utilise the factors of production with which they are relatively abundantly endowed, and import goods that use intensively factors that are relatively scarce at home. In the third theory, comparative advantage is due to relative technology differences. Despite underlying differences, all theories indicate that, as trade liberalisation facilitates international specialisation in production, it should result in higher real aggregate incomes and welfare (OECD (2005)). That said, higher trade openness may imply distributional and occupational shifts. In this vein, while the Stolper-Samuelson theory posits that when import-competing goods are relatively labor-intensive, protection unambiguously raises real wages (see Neary (2004)), such a prediction depends importantly on whether the trade prices of labour intensive goods rise or fall in response to an openness shock, reflecting the interplay of a "lift all boats" effect versus a "redistributive" effect – see Bhagwati (1998).

Frictions and stickiness may alter the predictions of these theories, which are assumed to operate over a time period that is long enough to allow complete detachment of workers and capital from their original sectors. Indeed, in the *long run* trade (along with associated technological gains) would be expected to benefit the population of both emerging and developed economies through more efficient resource allocation, lower prices, more product choice and pecuniary gains from deepening specialisation and, ultimately, higher living standards. In the *short run*, however, some adjustment costs could result, in particular related to distributional effects associated with sectoral reallocation of labour. Such adjustment costs may arise from, *inter alia*, frictional unemployment associated with sectoral reallocation of displaced workers and any associated need for retraining, and policies that impede the mobility of labour by slowing down the transfer of resources from declining to expanding activities. It could be argued that adjustment frictions are higher in the manufacturing sector than elsewhere as job-specific or industry-specific skills are likely more important in manufacturing firms than in service industries where skills transfer across firms and industries more easily. In this vein, Terfous (2006) contrast a temporary adjustment effect on developed economies' labour markets (given frictions in related adjustment) with lasting effects (through changing skill composition of the demand for labour and trade-induced technical progress).

Various approaches have been followed in the empirical validation of the above theories. A first strand of the literature has involved factor content calculations, whereby trade flows are analysed to compute the labour content of imports relative that of exports to evaluate the net impact of trade on labour markets – such as Baily and Lawrence (2004), Sachs and Shatz (1994), Wood (1995) and Wood (1998). A second strand has involved econometric analysis, such as Abraham and Brock (2003), Revenga (1992), and Grossman (1987), whereby it is empirically tested whether increasing import competition can be a major factor behind declining employment and sluggish real compensation growth in industrialised economies. A third strand has been more eclectic, involving *inter alia* general equilibrium models of trade, analysis of input mixes at the industry level given input mix changes in production as trade is liberalised, and the role of prices (e.g. the evolution of commodity prices over time).

Available empirical evidence has been mixed for what concerns the labour market impacts of increasing trade openness. Three main conclusions can be drawn from the extensive review of available literature within OECD (2005) and Molnar, Pain, and Taglioni (2006). First, enhanced trade between developed and developing countries places some downward pressure on the relative returns to unskilled, low-wage workers in developed countries.[3] Second, the direction of causality between trade and employment is not always easy to establish (though several studies report a negative relationship). Third, domestic factors are typically found to be the principal determinant of employment changes.

Whilst several studies have found evidence that the demand for labour in developed economies – particularly unskilled– may have become more elastic as a result of enhanced international openness, the literature has pointed to only a limited *direct* impact of trade on wages and/or employment in developed economies. Such findings, however, must be tempered by the fact that trade and technological progress may be inextricably linked, thereby introducing an *indirect* effect of trade on labour market outcomes. As pointed out in several papers, notably Wood (1994), Wood (1995), Wood (1998), Anderton and Oscarsson (2002), and Thoenig and Verdier (2003), international competition may lead firms in advanced economies to raise productivity by pursuing "defensive innovation", including pressure to innovate and/or alter the skill-intensity of production in response to a higher degree of trade openness. Moreover, trade may constitute a form of "technology transfer", i.e. convergence in technical efficiency within individual countries over time, particularly for trade among developed economies.[4] Accounting for productivity impacts of increased trade openness, a trade-induced technology shock can either negatively or positively affect labour market outcomes, as trade may induce firms to successfully introduce productivity-enhancing technologies which do not have a definite positive or negative ex-ante labour market impact. On one hand, as noted in Amiti and Wei (2005), a positive technology shock may result in higher demand for labour due to scale effects, whilst higher productivity can lead to lower prices, generating further demand for output and labour given associated competitiveness gains. On the other hand, higher productivity can translate into job losses as the same amount of output can be produced with fewer inputs, whilst lower prices of imported inputs could lead to substitution away from domestic labour. Complicating matters further, trade does not have a clear causal effect on productivity. Whilst frictions associated with the adjustment to trade shocks may imply short-term labour market impacts which correlate with productivity,[5] the causality may go in the other direction due to a composition effect, whereby more productive firms become better exporters.[6]

Ultimately, a lack of clear theoretical or empirical findings showing a definite quantitative impact of trade and technology on labour market outcomes motivates further empirical work on the issue. Considering the interrelations between not only key labour market variables –i.e. compensation and

[3]Further complicating matters, wage adjustment may be more complex in the case of increasingly fragmented production –or "task-trading"– in contrast to the production and exchange of complete goods examined in traditional trade theory. In this context Grossman and Rossi-Hansberg (2006) argue that when considering the real wage impacts of offshoring, productivity effects should be considered along with relative price and labour supply effects.

[4]In terms of recent studies, Badinger (2007) finds that pro-competitive effects of trade account for approximately 30% of trades total productivity effects in a sample of manufacturing industries in 11 OECD economies over the period 1995-00. Cameron, Proudman, and Redding (2005) provide an empirical investigation of such effects between the US and the UK, with the finding that international trade raises rates of UK productivity growth through technology transfer but not innovation, whilst Keller and Yeaple (2005) find for the case of the US that FDI spillovers have a significant role in boosting productivity growth in the manufacturing sector though the case for import-related technology transfers is less clear.

[5]In particular, domestic companies subject to foreign competition may pursue internal restructuring involving lay-offs and firm closures – though if such restructuring does not keep up with the decline in sales, which is plausible given adjustment costs in intensity of employment along with hiring and firing costs, this may imply falling productivity on the aggregate. Bernard, Jensen, and Schott (2006) find that plant survival and growth are negatively associated with industry exposure to low-wage country imports.

[6]Bernard, Jensen, Redding, and Schott (2007) report that exporters in the US have a productivity advantage before they start exporting, thereby suggesting that exporters are more productive not as a result of exporting, but because only the most productive firms are able to overcome the costs of entering export markets.

employment– but also trade and technology, a systems analysis also analysing dynamics induced by shocks is warranted.

3 Empirical setup

In this section present the empirical framework used to generate results in Section 4 in three steps. We first explain the general properties of the empirical framework. Second, we outline the data used in the empirical analysis. Third, we present information on specification issues and integration properties of the data.

3.1 The GVAR application

The GVAR framework of DdPS and Pesaran, Schuermann, and Weiner (2004) –henceforth PSW– is adapted to an analysis of labour market developments in the US manufacturing sector. This model explicitly allows for interdependencies that exist between sectoral and manufacturing-wide factors, allowing for an analysis of the industry effects of exogenous common or sector-specific shocks as well as an assessment of spillovers from industry-specific shocks to endogenous variables within the system.

In line with DdPS, we assume we have $N+1$ states, indexed by $i = 0, 1, 2, ..., N$. For each industry, we thus assume that industry-specific variables x are related to corresponding industry-specific weighted averages of the other industry's variables x^* plus deterministic variables, such as a time trend (t), industry-wide (weakly) exogenous variables and an industry-specific exogenous variable. For simplicity, we confine our exposition here to a first-order dynamic specification as in PSW. In this case we can relate the $k_i \times 1$ industry-specific variables, $x_{it} = (p_{it}, y_{it})$, to $x^*_{it} = (p^*_{it}, y^*_{it})$, the industry-wide (weakly) exogenous variables d_t and an industry-specific exogenous variable m_t and write:

$$x_{it} = a_{io} + a_{i1}t + \Phi_i x_{i,t-1} + \Lambda_{i0}x^*_{i,t} + \Lambda_{i1}x^*_{i,t-1} + \psi_{i0}d_t + \psi_{i1}d_{t-1} + \mu_{i0}m_t + \mu_{i1}m_{t-1} + \varepsilon_{it}$$

where Φ_i is a $k_i \times k_i$ matrix of lagged coefficients, Λ_{i0} and Λ_{i1} are $k_i \times k^*_i$ matrices of coefficients associated with the industry-specific variables, ψ_{i0} and ψ_{i1} are $k_i \times s$ matrices of coefficients associated with the common industry-wide variables, μ_{i0} and μ_{i1} are $k_i x1$ matrices of coefficients associated with the industry-specific exogenous variable and ε_{it} is a $k_i \times 1$ vector of idiosyncratic industry-specific shocks. We assume in this model that the idiosyncratic shocks, ε_{it}, are serially uncorrelated with mean zero and a nonsingular covariance matrix, $\Sigma_{ii} = (\sigma_{ii,ls})$ where $\sigma_{ii,ls} = cov(\varepsilon_{ilt}, \varepsilon_{ist})$, or written more compactly, $\varepsilon_{it} \sim iid(0, \Sigma_{ii})$. The assumption that the industry-specific variance-covariance matrices are time invariant can be relaxed, but for the analysis of annual observations, this time invariant assumption may not be overly restrictive. This industry-specific model can now be consistently estimated separately, treating d_t and x^*_{it} as weakly exogenous $I(1)$ with respect to the parameters of this model.

The weak exogeneity assumption in the context of cointegrating models implies no long-run feedbacks from x_{it} to x^*_{it}, without necessarily ruling out lagged short-run feedbacks between the two sets of variables.[7] In this case x_{it} is said to be *long run forcing* x^*_{it}, and implies that the error correction terms of the individual industry VECMs do not enter in the marginal model of x^*_{it} (see DdPS). The weak exogeneity of these variables can then be tested in the context of each of the industry-specific models. Once the individual industry models are estimated all the endogenous variables need to be solved for simultaneously.

All industry-specific models together with the relations linking the (weakly) exogenous variables of the industry-specific models to the variables in the rest of the model provide a complete system.

[7] Unlike DdPS, who establish the United States and a numeraire in their GVAR analysis, we abstain from doing so given that no one industry can be clearly considered ex-ante as maintaining a dominant position in US manufacturing.

However, due to data limitations for even moderate values of N, a full system estimation of the model may not be feasible. To sidestep this difficulty, we follow PSW and estimate the parameters of the cross-section-specific models separately, treating the foreign industry-specific variables as weakly exogenous on the grounds that industries are small relative to the size of the overall manufacturing sector.

Overall, the manufacturing-wide model, associated with the industry-specific models can now be given by:

$$Gx_t = a_o + a_1 t + Hx_{i,t-1} + \psi_0 d_t + \psi_1 d_{t-1} + \mu_0 m_t + \mu_1 m_{t-1} + \varepsilon_t$$

where a_o, a_1, ψ_0, ψ_1, μ_0, μ_1, G, H, and ε_t can be defined as: ($j = 0$ or 1)

$$a_j = \begin{pmatrix} a_{0j} \\ a_{1j} \\ \dots \\ a_{Nj} \end{pmatrix} \varepsilon_t = \begin{pmatrix} \varepsilon_{0t} \\ \varepsilon_{1t} \\ \dots \\ \varepsilon_{Nt} \end{pmatrix} \psi/\mu_j = \begin{pmatrix} \psi/\mu_{0j} \\ \psi/\mu_{1j} \\ \dots \\ \psi/\mu_{Nj} \end{pmatrix} G = \begin{pmatrix} A_0 W_0 \\ A_1 W_1 \\ \dots \\ A_N W_N \end{pmatrix} H = \begin{pmatrix} B_0 W_0 \\ B_1 W_1 \\ \dots \\ B_N W_N \end{pmatrix}$$

whereby W_i is a $(k_i \times k_i^*) \times k$ matrix of fixed constants defined in terms of the state-specific weights. W_i can be viewed as the link matrix that allows the state–specific models to be written in terms of the global variable vector x_t.

In general, such a GVAR model allows for interactions among the different industries through three separate but interrelated channels. First, there is a contemporaneous dependence of x_{it} on x_{it}^* and on its lagged values. Second, there is a dependence of the state-specific variables on common exogenous variables, such as oil and technology. Third, there is a nonzero contemporaneous dependence of shocks in industry i on the shocks in industry j, measured via the cross-industry covariances, Σ_{ij}.

3.2 The data

We analyse 12 US manufacturing sectors classified according to the "International Standard Industrial Classification" (ISIC) revision 3.[8] The frequency is annual, and spans the period 1977–2003 (i.e. a T dimension of 25 and an N dimension of 12). The endogenous sector-specific variables, x_{it}, included in the model are real compensation per employee ($COMP$), productivity ($PROD$), full-time equivalent employment ($EMPL$) and the capital stock (CAP). For each sector we assume that the sector-specific variables are related to an exogenous sector-specific variables (namely trade openness, $OPEN$[9]) and manufacturing-wide variables (measured as a sector-specific weighted average of the other sectors – henceforth star variables, x_{it}^*). A set of deterministic variables, such as time trends (t), is also included, along with common manufacturing-wide (weakly) exogenous variables (d_t), consisting of R&D expenditure per employee ($R\&D$), and the oil price (OIL). The sources and the construction of the data are discussed in more detail within Appendix B.

3.3 Specification issues and integration properties

For all industries, the sector-specific models therefore contain the four endogenous variables, their starred counterparts, trade openness as a sector-specific weakly exogenous variable, along with R&D and the real oil price as global, weakly exogenous variables. For each sector, we then estimate the

[8]A 13th sector under the ISIC Classification, "Coke, refined petroleum products and nuclear fuel", is excluded given that factors autonomous from those affecting other industries likely drive its evolution relative to the other sectors.

[9]Trade openness is measured as the ratio of the sum of sectoral exports and imports of goods to sectoral value added. Whilst alternative measures, such as tariffs, may also capture openness, industry-specific measures are not available for the full timespan of the dataset within the paper, but for the period in which there is overlap, appear to be highly correlated with the industry equivalents of the adopted measure of openness. Specifically, the average correlation coefficient between the sectoral openness variable and tariffs data (the most favoured nation definition) excluding the food sector is 73% and including the food sector 62%.

corresponding cointegrating VAR model and determine the rank of the cointegration space. Due to data limitations, we select the lag order of the sectoral and starred variables and set both equal to one.

Our working assumption in this modelling exercise is that the country-specific star variables are weakly exogenous I(1) variables, and that the parameters of the individual models are stable over time. These long-run forcing assumptions allow us to estimate and test the long run properties of the different country specific models separately and consistently. Both assumptions are needed for an initial implementation of the GVAR model (see DdPS). While the GVAR methodology can be applied to integrated variables, this assumption allows us to distinguish between short- and long-run relations and interpret the long-run relations as cointegrated. Formal unit root tests suggest that all variables analysed can be considered as I(1), once accounting for possible structural breaks and other possible one-off factors. Augmented Dickey Fuller tests suggest that the hypothesis of a unit root cannot be rejected for most variables for most individual industries – as well as for the panel as a whole.

Given this set-up the rank of the cointegrating space for each sector is computed using Johansen's trace and maximal eigenvalue statistics as set out in Pesaran, Shin, and Smith (2000) for models with weakly exogenous I(1) regressors, in the case where unrestricted constants and restricted trend coefficients are included in the individual country error correction models. In most cases, we find one cointegrating relationship except in the case of the textile sector where we find two. The cointegration results are based on the trace statistic (at the 95% critical value level) which is known to yield better small sample power results compared to the maximal eigenvalue statistic. Ultimately, results from the impulse response analysis in Section 4 along with an analysis of the GVAR's eigenvalues indicate stability of the system for all shocks considered.

4 Results

Below we present the results of the model in two steps. First, we analyse generalised impulse responses to several exogenous shocks along with spillovers from shocks to sector-specific endogenous variables of the system. Specifically, we present the impulse responses from shocks to (i) trade openness, (ii) R&D spending, and (iii) the oil price, and (iv) illustrate the strength of spillovers via shocks to employment in the textile sector along with productivity in the other transport sector. Second, we present contemporaneous effects of starred variables on their sector specific counterparts on the basis of impact elasticities.

4.1 Generalised impulse responses

In this section we make use of the Generalized Impulse Response Function (GIRF), as proposed by Koop, Pesaran, and Potter (1996) for non-linear models and developed further in Persaran and Shin (1998) for vector error-correcting models.[10] In the absence of strong a priori beliefs on ordering of the variables and/or sectors in the GVAR model, the GIRFs provide useful information with respect to changes in trade openness, R&D and employment. Although the approach is silent as to the specific structural factors behind the changes, the GIRFs can be quite informative about the dynamics of the transmission of shocks.

[10]The GIRF is an alternative to the Orthongonalised Impulse Responses (OIR) of Sims (1980). The OIR approach requires the impulse responses to be computed with respect to a set of orthogonalised shocks, whilst the GIR approach considers shocks to individual errors and integrates out the effects of the other shocks using the observed distribution of all the shocks without any orthogonalisation. Unlike the OIR, the GIRF is invariant to the ordering of the variables and the countries in the GVAR model, which is clearly an important consideration given various possible alternative orderings. Even if a suitable ordering of the variables in a given country model can be arrived at from economic theory or general *a priori* reasoning, it is not clear how to order sectors in the application of the OIR to the GVAR model.

To study the dynamic responses of the GVAR variables to exogenous shocks along with spillovers from idiosyncratic sector-specific shocks, we investigate the implications of the following innovations:

- The employment, real compensation and productivity impacts of a one standard error positive shock to *trade openness* in each of the US manufacturing sector industries;
- The employment and real compensation impacts of a one standard error positive shock to *R&D spending* in the US manufacturing sector;
- The employment and real compensation impacts of a one standard error positive shock to the *oil price*; and
- The *employment spillovers* emanating from two industry shocks, namely a a one standard error negative shock to employment in the textile sector along with a one standard error shock to productivity in the "other transport" sector.

Impulse responses are presented for twenty years following the imposition of a shock. Charts 2 to 5 display the bootstrap estimates of the GIRFs obtained using the sieve bootstrap procedure as reported in DdPS.

4.1.1 Shock to sector-specific trade openness

Chart 2 contains the GIRFs for the selected US manufacturing industries resulting from a positive one standard error shock to trade openness within that sector – with a one standard error positive shock resulting in a one percentage point increase in US manufacturing trade openness. The chart is comprised of three panels, with the results for: (a) employment, (b) real compensation and (c) productivity.

[INSERT CHART 2]

Concerning *employment*, an increase in sector trade openness has a mild negative or neutral impact on employment in the corresponding sector in most cases, though it is insignificant in several instances (see Chart 2, panel a). The average industry response is initially negative and small – with a decline in employment of around $\frac{1}{20}\%$ on impact– followed by a gradual neutralisation which brings the impact to near zero within a decade. In general, standard error bands indicate for a majority of sectors that the long-run employment impacts of such a shock is essentially absent. The dispersion of industry responses is relatively high, though heavily influenced by one clear outlier (other transport), where a positive employment impact reaching a maximum of around $\frac{1}{6}\%$ predominates. In the latter case, it is conceivable that openness has lowered the costs (e.g. via tariffs or regulatory barriers) or transport, thereby increasing its use. One key factor underpinning this development may be the evolution of the airline industry (representing the bulk of other transport) which appears to have benefited considerably from trade and is highly trade open. In general, whilst splitting production into stages (i.e. primary, secondary and tertiary production) cannot be achieved cleanly within the ISIC framework, it would appear that zero short- and longer-term impacts of openness are present for FTE employment within primary industries. The dynamics of system, whereby the initial impacts are generally highest and the effect of the shock decays through time, could be consistent with several factors, including adjustment costs in reallocating labour, frictions in varying the intensity of labour workforce in particular sectors, and a gradual loss of market share when faced with competition. Moreover, capital-labour substitution, particularly given with technology transfer associated with trade, may impart some equilibrium shifts as well as persistence in adjustment dynamics of employment to changes in openness.

Concerning *real compensation*, an openness shock appears to negatively impact all sectors considered with the only exception of machinery and equipment, where the impact is positive (see

Chart 2, panel b). The average industry response is initially negative, with a fall in real wages of just over 1% in absolute terms, followed initially by some amplification of the response prior to a very gradual neutralisation which brings the impact to near zero within two decades. In general, standard error bands indicate significant negative impacts of trade openness on compensation, with the only exception of paper (where the impact at all horizons is effectively insignificant). In the long run, confidence intervals obtained from the standard error bands indicate the effects of openness on compensation are neutralized for all sectors except for basic metals and other transport (where it is negative), along with machinery and equipment (where it is positive). The dispersion of industry responses is relatively low, with an initial fall in wages in 8 of the 12 industries amounting to around one percentage point. An examination of the dynamics of system indicates that, somewhat in contrast to the GIRFs for employment, a U-shaped profile in response of wages to the shock in several industries, possibly corresponding to some wage rigidity.

Analysing these results in the context of the literature in Section 2, the finding of a very limited employment response to an openness shock corroborates the basic thrust of the literature that the import competition effect is not the main driving force of manufacturing employment adjustments. At the same time, it does show that higher import competition appears to manifest itself through real wage adjustment.[11] Such a finding, whilst consistent with low real wage growth through the mid-1990s, would also be consistent with the predictions of the Stolper-Samuelson theory. As noted in Neary (2004), improved communications may have allowed large firms to fragment their operations, moving more unskilled-labor-intensive stages of production to countries where unskilled wages are low, so lowering unskilled wages in developed countries while simultaneously raising skilled wages in developing countries. Moreover, growing openness may be having an increasingly important effect on the wage formation process in the sectors analysed. This is confirmed by comparing the outcome of the GVAR over the sample period 1977-1999 with that of 1977-2003 whereby in the latter case the impulse responses to a one standard deviation shock in the US manufacturing trade openness appear to indicate a larger effect on real compensation.

Concerning the impacts of this shock on the *other endogenous variables* of the GVAR, trade openness appears to exert a positive pressure on productivity, positively impacting on all sectors considered (see Chart 2, panel c). The average industry response indicates a rapid impact of increased openness on productivity, with an initially strong impact of 0.2%, rising further to a peak of around 0.3% in the first two years after the shock.[12] Standard error bands indicate mainly significant positive impacts of trade openness on productivity, with the only exceptions of wood, non-metallic mineral products and machinery after over a decade. The dispersion of industry responses in terms of sign is minimal, though smaller responses appear to be generally present in primary industries such as rubber, food services and non-metallic mineral products. In general, the impulse responses support the view that trade competition induces firms to successfully introduce productivity-enhancing technologies. The finding of a positive productivity impact of increased trade openness is consistent with Lawrence (2000). The latter study finds that import competition has a positive impact on US total factor productivity, mainly in skill-intensive sectors and industries competing with developing countries. This may derive from defensive innovation or also reflect firm composition, whereby in response to greater foreign competition, profit margins fall as markups decline and average productivity rises as marginal firms exit the industry (see Chen, Imbs, and Scott (2004)). Concerning the GVAR findings for the sectoral capital stock, trade openness appears to exert a positive effect as with the productivity shock, potentially lending some support for the notion of international technology transfer or defensive innovation on the part of import-competing

[11] The finding of an initial negative impact on labour compensation is consistent with the findings reported in OECD (2005), where it is reported that large wage losses on the post-displacement job are a particularly important source of post-displacement earnings losses in the United States in contrast to Europe, where long-term unemployment and labour force withdrawal constitute a bigger source of earnings losses.

[12] This is somewhat stronger than the estimated impacts in Helbling, Jaumotte, and Sommer (2006) who, examining a panel of manufacturing industries in developed economies, find that a 1% increase in relative trade openness increases relative productivity by 0.12%.

firms.

4.1.2 Shock to US manufacturing sector research and development spending

Chart 3 contains the GIRFs of a one standard error negative shock to US manufacturing sector R&D – equivalent to an increase of around 5% in US manufacturing R&D spending per annum. The chart is comprised of two panels, with the results for: (a) employment and (b) real compensation.

[INSERT CHART 3]

Concerning *employment*, an R&D shock unambiguously leads to increases in all sectors considered (see Chart 3, panel a). The average response of all industries increases quite steadily from a zero response to a $1\frac{1}{4}\%$ positive impact after a decade. An analysis of standard error bands indicates that the impacts of the technology shock are significant for 8 of the 12 sectors considered; zero impacts are only present for wood, paper products, machinery and motor. The dispersion of the results within the cases where the shock produces significant positive impacts is rather low, with an impact in the vicinity of the above average impact for six industries, and with relatively stronger impacts on fabricated metals and other transport. An examination of the dynamics induced by the technological shock indicates that, with the exception of paper, after a small initial impact the effect gradually increases through time but generally takes less than a decade to reach its maximum impact. Such a finding could relate to adjustment costs, including the need for related investment in intangible capital, along with costs associated with rigidities in reallocating labour associated with the exploitation of new technologies.

Concerning *real compensation*, in contrast to the trade openness shock, an increase in R&D leads to an increase for all sectors except other transport, where it is near zero (see Chart 3, panel b). This general rise in real compensation following a period of technological progress is in line with theory as such a technology shock would be expected to increase skill premia embodied within in wages, with some frictions possibly implying sluggishness in adjustment. The average industry response is fairly high, moving from $2\frac{1}{2}\%$ to a peak of just over 3% after only two years. An analysis of standard error bands indicates a significant response to the shock for all industries except food and other transport. The dispersion of the results is rather high, with a weak impact of technology on wages for the two latter industries contrasting with a very strong positive impact for four industries (textiles, non-metallic mineral products, basic metals and motor) of well over 5%. Such a finding may possibly relate to differing skill content within the affected industries, notably heterogeneity in the adoption of new technologies or differing wage rigidities across affected industries. An analysis of the dynamics across all industries indicates a fairly rapid adjustment of compensation to technology shocks.

Concerning the impacts of this shock on the *other endogenous variables* of the GVAR, an R&D shock is, as in the case of the trade openness shock, also accompanied by an increase in productivity and capital stock.

4.1.3 Shock to the oil price

Chart 4 contains the GIRFs of a one standard error positive shock to the oil price – equivalent to an increase of around 20% in the oil price over one year. The chart is comprised of two panels, with the results for: (a) employment and (b) real compensation.

[INSERT CHART 4]

Concerning *employment*, an increase in the oil price initially depresses employment in all industries, with the exception of those with possible links to the oil price (chemical and other commodities such as basic metals and rubber), with a fairly heterogeneous long-term impact on industry employment (see Chart 4, panel a). The average response of all industries is an initial employment loss of around 0.4%, falling in absolute terms to zero after just over a decade. An analysis of standard error bands implies insignificant longer-run employment impacts of an oil shock for just over half of the industries. The dispersion of results is fairly low for most industries, where a negative impact predominates. An examination of the dynamics of the responses shows strong initial impacts for all industries except textiles; nonzero for all but four sectors.[13]

Concerning *real compensation*, an increase in the oil price depresses real compensation for all industries except the chemicals sector (see Chart 4, panel b). The average response of all industries is a fall in real wages of around 2%, similar in impact in both the short- and long-term. An analysis of standard error bands implies insignificant impacts in the long run for textiles, chemical, non-metallic mineral products and motor industries. The dispersion of responses is rather limited when excluding the positive impact within the chemical industry. The dynamics of the responses are quite varied, whilst the only non-contemporaneous impact is found in the paper industry.

Concerning the impacts of this shock on the *other endogenous variables* of the GVAR, the oil shock has a negative impact on productivity (on average a 20% shock lower productivity by 0.7%) and also on the capital stock (the same shock lowers the capital stock by about 1.2%).

4.1.4 Sectoral employment spillovers

In this subsection, we present sectoral employment spillovers resulting from two illustrative industry-specific shocks. First, we shock employment in the US textile sector, given a relatively high labour intensity within this sector along with its relatively elevated exposure to competitive pressures from emerging markets. Second, we shock productivity in the other transport sector, given its rather high capital content.

The GIRF results for employment of the negative shock to US textile employment is displayed in Chart 5. Overall, a one standard error shock to US textile sector employment, which amounts to a $2\frac{1}{2}$% fall in the textile sector employment in the long run, reduces employment in all other sectors, with a fairly homogeneous long-term impact on industry employment. The average response of all industries is an initial employment loss of around $\frac{2}{3}$% followed by a maximum impact in absolute terms of nearly 1% after 5 years. An inspection of the standard error bands, however, indicates that an insignificant impact cannot be ruled out in virtually all cases. Such a finding is hardly surprising against the backdrop of possibly limited linkages of the textile sector to other industries through the production chain, though capital transfer and other such channels may be at play. The dispersion of results declines steadily through time.

[INSERT CHART 5]

The GIRF results for employment of the positive unit shock to productivity in the "other transport" sector is displayed in Chart 6. Overall, a one standard error shock, with a maximum impact of $1\frac{3}{4}$% on employment in that sector, reduces employment in all other sectors. The average response of all industries is an initial employment gain of around $\frac{3}{4}$% which decays steadily to settle at $\frac{1}{2}$% over the first decade. An inspection of the standard error bands indicates significant results are present in all cases aside from non-metallic mineral products where a zero impact following a decade cannot be ruled out. A rather stable dispersion of results indicates that the employment spillovers are positively correlated with a productivity shock in one sector.

[INSERT CHART 6]

[13] Davis and Haltiwanger (2001) find using plant level data that oil price shocks triggered considerable job reallocation and net employment adjustments for U.S. manufacturing jobs from 1972 to 1988.

4.2 Contemporaneous effects of starred variables on their sector specific counterparts

Table 4 presents the contemporaneous effects of the starred variables on the employment of their sectoral counterparts with robust t-ratios, computed using White's heteroscedasticity-consistent variance estimator. These values can be interpreted as impact elasticities of starred variables on their industry counterparts' employment, or spillovers. Most of them are significant and have a positive sign. They are particularly informative as regards the linkages across sectors.

- Concerning employment, the elasticities vary across sectors by between 0.16 in other transport to 0.95% in fabricated metals. Focusing on the textile sector, representing approximately the average impact within this range, we can see that a 1% change in employment in the rest of the manufacturing sector, weighted by the importance of these sectors in the textile's sector output, leads to an increase of 0.5% in employment in the textile sector within the same year.

- Concerning the capital stock, interestingly we observe high and often significant elasticities, implying relatively strong co-movements across sectors regarding the capital stock formation, with the highest impacts in metals, motor, chemical and food.

- Concerning productivity and real compensation, elasticities are generally low and not significant. Especially on the wage side, this would suggest there is little contemporaneous 'contagion' across sectors as regards the wage formation process – indeed, the most significant impact elasticity is negative, for fabricated metals. This latter phenomenon may reflect a weak collective bargaining component of such industries over the period reviewed.

TABLE 4. Contemporaneous Effects on Employment of Starred Variables on the Sector-specific Counterparts

	employment	productivity	real comp.	capital stock
Food	0.36	0.08	-0.10	0.86
	(4.30)	(0.56)	(-1.23)	(18.59)
Textile	0.51	-0.04	0.03	0.28
	(3.32)	(-0.46)	(0.74)	(2.61)
Wood	0.56	0.07	0.01	0.02
	(3.96)	(0.91)	(0.13)	(0.09)
Paper	0.16	0.06	-0.01	0.91
	(3.79)	(1.10)	(-0.34)	(6.58)
Chemical	0.16	0.05	0.04	0.98
	(1.92)	(0.92)	(1.00)	(8.94)
Rubber	0.79	0.09	-0.06	0.19
	(5.51)	(0.70)	(-0.67)	(1.03)
Non-metallic	0.24	0.07	-0.21	0.62
	(5.21)	(0.28)	(-1.79)	(9.87)
Basic metals	0.51	-0.35	0.19	1.09
	(5.30)	(-1.89)	(1.26)	(7.34)
Fabricated metals	0.95	0.16	-0.25	0.24
	(3.76)	(1.23)	(-2.75)	(5.07)
Machinery	0.84	0.03	0.00	0.58
	(4.02)	(1.39)	(-0.06)	(8.04)
Motor	0.86	0.90	-0.09	0.95
	(4.65)	(10.68)	(-0.17)	(4.87)
Other transport	0.15	-1.00	0.60	0.05
	(1.59)	(-1.52)	(1.57)	(0.09)

Note: White's heteroscedastic robust t-ratios are given in round brackets.

5 Concluding Remarks

This paper sought to analyse the extent to which labour market developments in the US manufacturing sector over the last decades have derived from exogenous factors such as increasing sectoral trade openness along with technological change for the manufacturing sector as a whole. The empirical strategy adopted was an application of a GVAR approach, which allows for the analysis of the effects of specific exogenous shocks –notably sectoral trade openness, along with a common shock to technology (proxied by R&D spending) and the oil price– on the endogenous variables of the system (employment, real labour compensation, productivity and the capital stock) in 12 subsectors of US manufacturing, along with an illustrative assessment of employment spillovers from industry-specific shocks to employment and productivity.

Impact elasticities suggest strong intra-sectoral linkages for employment and capital stock formation, contrasting with weak linkages for what concerns real compensation and productivity. Results from impulse response analysis indicate that technological shocks seem to have a more important labour market impact in the manufacturing sector over the period considered than do shocks to trade openness, in keeping with the broad thrust of existing literature. An analysis of generalised impulse responses indicate that, whilst there is some heterogeneity in industry-specific impacts to sectoral trade openness and a common technology shock, trade openness on average negatively affects real compensation and has a negligible effect on employment, whilst technology appears to positively and significantly affect both real compensation and employment. In this sense, it would suggest that higher import competition for manufacturing industries has tended to manifest itself through real wage adjustment, an effect which appears to be growing through time. Increased trade openness is found to be associated with higher domestic productivity in the US manufacturing sector. Moreover, there is some evidence of positive employment spillovers from shocks to textile sector employment and productivity in the "other transport" sector. Impact elasticities indicate strong intra-sectoral linkages for employment and capital stock formation, contrasting with weak linkages for what concerns real compensation and productivity.

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Appendices

A Sectors covered

ISIC code	Industry name
15-16	Food products, beverages and tobacco
17-19	Textiles, textile products, leather and footwear
20	Wood and products of wood and cork
21-22	Pulp, paper, paper products, printing and publishing
23	Coke, refined petroleum products and nuclear fuel*
24	Chemicals and chemical products
25	Rubber and plastics products
26	Other non-metallic mineral products
27	Basic metals
28	Fabricated metal products, except machinery and equipment
29-33	Machinery and equipment
34	Motor vehicles, trailers and semi-trailers
35	Other transport equipment

* Not included in analysis (See footnote in Subsection 3.2).

B Data

PRODUCTIVITY
Definition: Value added per worker.
Units: Index, 2000=100. Value added divided by employment series (see definition below).
Source: OECD STAN Database for Industrial Analysis, Bureau of Economic Analysis and Bureau of Labor Statistics.

EMPLOYMENT
Definition: Total employees - Full Time Equivalent.
Units: Thousands of units.
Source: OECD STAN Database for Industrial Analysis (last update April 2005).

EXPORTS
Definition: Exports of goods.
Units: Index: 2000=100, current price export series are measured in millions USD and deflated using value added in current and constant prices per industry.
Source: OECD STAN Database for Industrial Analysis and Bureau of Economic Analysis.

IMPORTS
Definition: Imports of goods.
Units: Index: 2000=100, current price import series are measured in millions USD and deflated with the aid of value added in current and constant prices per industry.
Source: OECD STAN Database for Industrial Analysis and Bureau of Economic Analysis.

OPENNESS
Definition: Sum of exports and imports of goods by sector.
Units: Index (see exports and imports).
Source: OECD STAN Database for Industrial Analysis and Bureau of Economic Analysis.

OIL
Definition: West Texas Intermediate spot price deflated using the price index for personal consumption expenditures.
Units: US Dollars expressed in 2000Q1 prices.
Source: Dow Jones & Company (oil price), Bureau of Economic Analysis (price deflator).

COMPENSATION

Definition: Wages and salaries of employees paid by producers as well as supplements such as contributions to social security, private pensions, health insurance, life insurance and similar schemes.
Units: Index: 2000=100, nominal series are measured in millions USD and deflated with the aid of value added in current and constant prices per industry.
Source: OECD STAN Database for Industrial Analysis and Bureau of Labor Statistics.

RESEARCH AND DEVELOPMENT (R&D) SPENDING

Definition: Analytical Business Enterprise Research and Development.
Units: Millions of USD.
Source: OECD Research and Development Expenditure in Industry database (last update April 2005).

CAPITAL STOCK

Definition: An initial capital stock is calculated for 1975. For the years following investment series are accumulated and depreciated.
Source: OECD STAN Database for Industrial Analysis and Bureau of Economic Analysis.
Calculation: (see Griliches, 1979)

$$\begin{aligned} K_{1978} &= I_{1978} + (1-\delta)\lambda I_{1978} + +(1-\delta)^2\lambda^2 I_{1978} + \ldots \\ &= I_{1978}\left(\frac{1}{1-\lambda(1-\delta)}\right) \end{aligned}$$

with $\lambda = \frac{1}{1+\eta}$ and η is the mean annual growth rate of investments over the period 1970-1978. The depreciation rate δ is set to equal 13.33%.

C Aggregation weights

TABLE 9. Input-output table implied weights

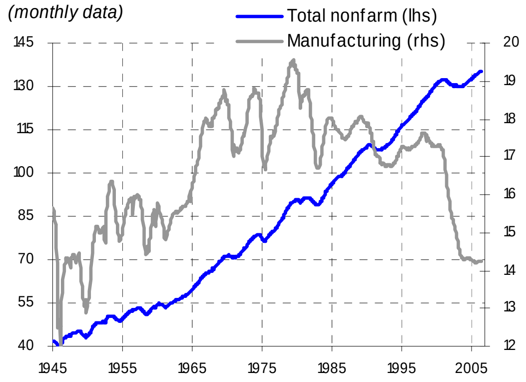
	15-16	17-19	20	21-22	24	25	26	27	28	29-33	34	35
15-16	0.00	10.43	2.93	5.46	5.14	1.13	1.23	1.01	0.57	4.48	0.50	0.50
17-19	1.84	0.00	3.64	15.89	3.12	6.62	2.75	0.94	0.63	6.33	4.54	1.89
20	2.43	3.46	0.00	14.35	2.23	1.09	3.59	2.57	1.12	8.05	1.08	0.87
21-22	23.75	23.60	7.82	0.00	21.19	9.36	17.80	7.02	4.97	43.87	4.07	3.46
24	21.59	3.61	20.12	1.15	0.00	57.19	25.41	12.28	9.18	0.71	8.98	7.67
25	12.86	21.57	7.58	0.70	17.04	0.00	7.79	4.68	3.34	0.61	8.80	5.07
26	4.73	4.06	7.52	0.03	4.18	2.52	0.00	10.03	2.53	0.04	2.99	1.77
27	5.49	0.08	7.51	0.49	7.28	4.17	10.15	0.00	60.78	4.12	27.20	16.97
28	13.16	0.58	16.77	25.95	14.40	5.77	10.62	24.90	0.00	8.23	16.61	20.85
29-33	10.74	28.64	19.52	31.34	21.73	10.54	15.94	31.81	14.34	0.00	24.84	38.38
34	2.91	3.95	6.03	4.63	3.10	1.37	4.06	3.86	2.22	23.53	0.00	2.57
35	0.51	0.02	0.58	0.02	0.59	0.25	0.67	0.90	0.31	0.02	0.39	0.00

Note: Rows and columns correspond to the ISIC revision 3 code of the relevant sector (see Appendix A for detail on the sectoral codes).

ANNEX OF CHARTS

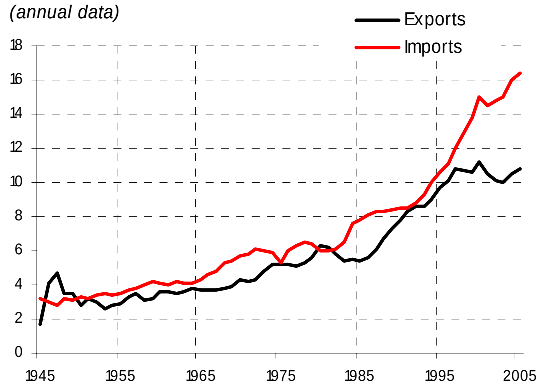
CHART 1. US employment, trade, productivity and real compensation

Chart 1a. US postwar payroll employment
millions of units (seas. adj.)



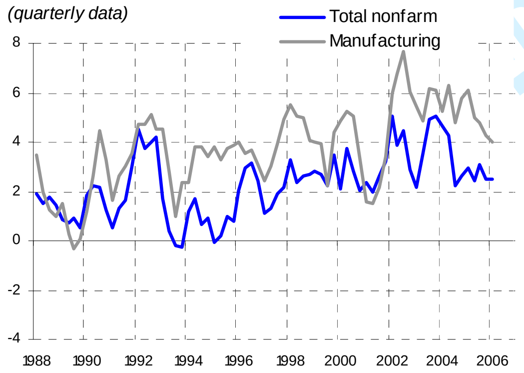
Source: Bureau of Labour Statistics.
Note: Last observation refers to July 2006.

Chart 1b. US real trade shares
% of real GDP



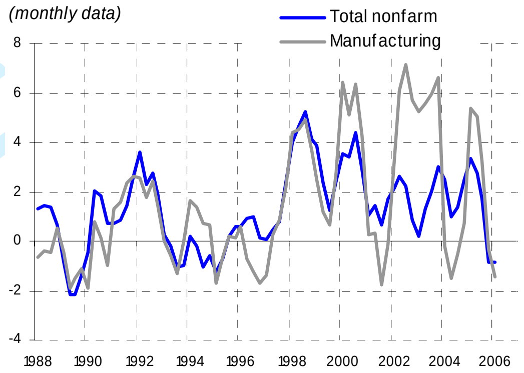
Source: Bureau of Labour Statistics.
Note: Last observation refers to 2005

Chart 1c. US output per hour
year-on-year growth, %



Source: Bureau of Labour Statistics.
Note: Last observation refers to 2006.Q1

Chart 1d. US real hourly compensation
year-on-year growth, %

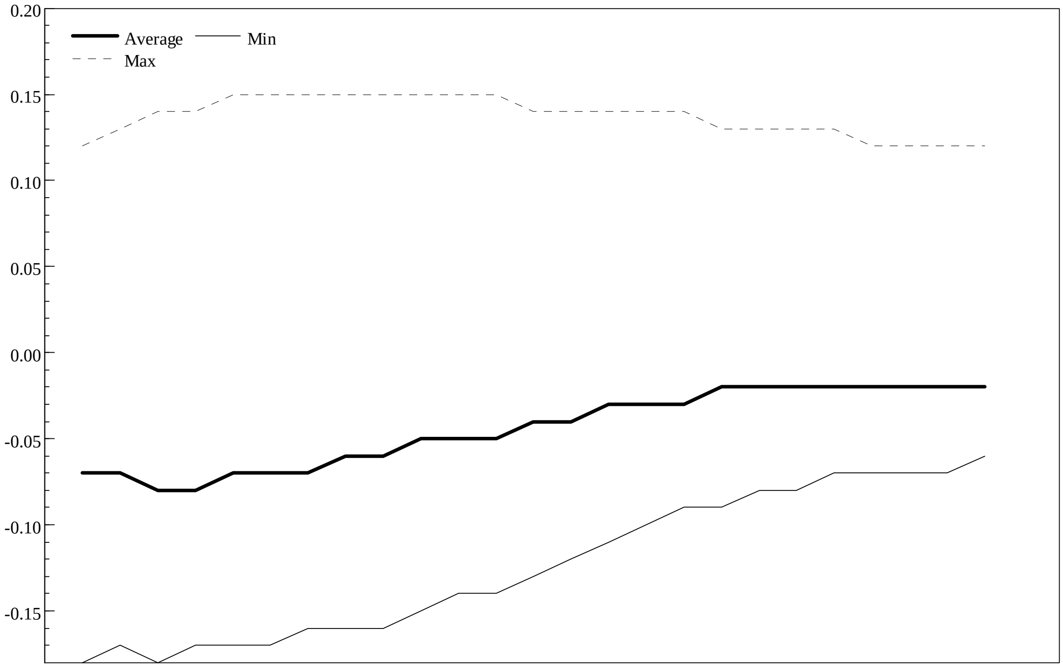


Source: Bureau of Labour Statistics.
Note: Last observation refers to 2006.Q1

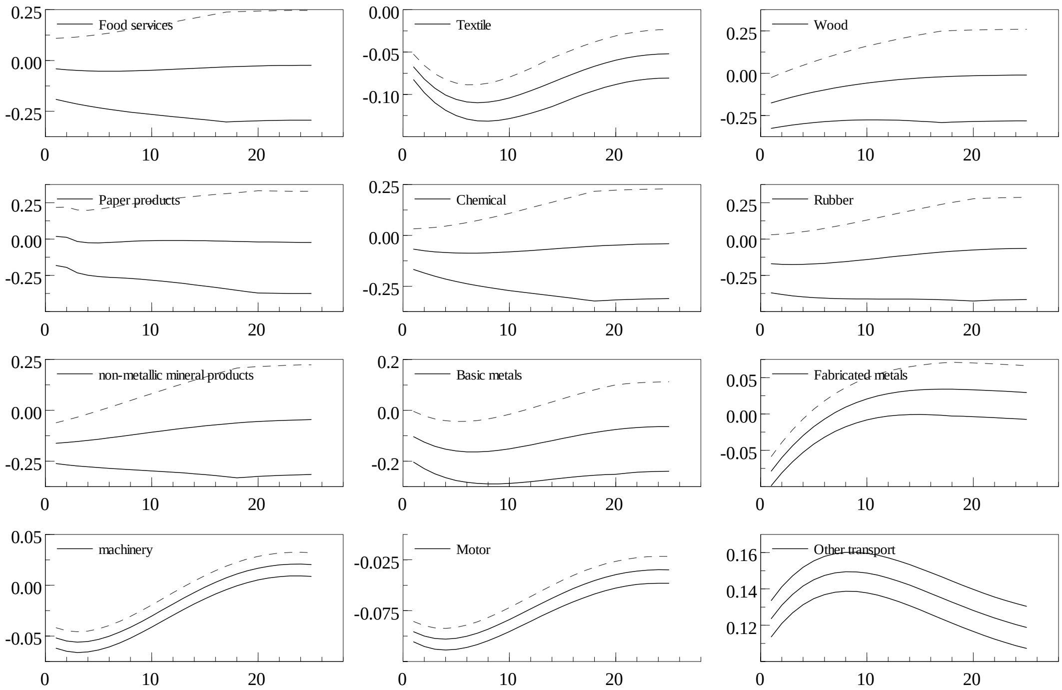
CHART 2. Impulse responses of a positive one standard deviation shock to US manufacturing ***trade openness*** (Bootstrap Mean Estimates)

a. Impact on full-time equivalent ***employment***

Range of industry responses



Individual industry responses

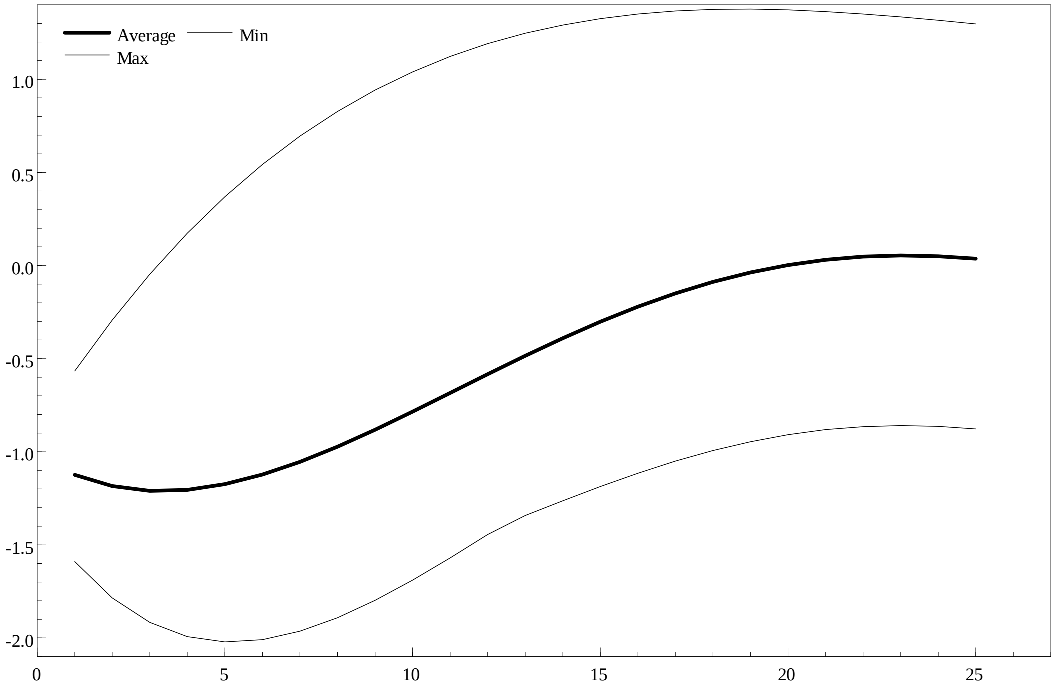


Source: Authors' calculations.

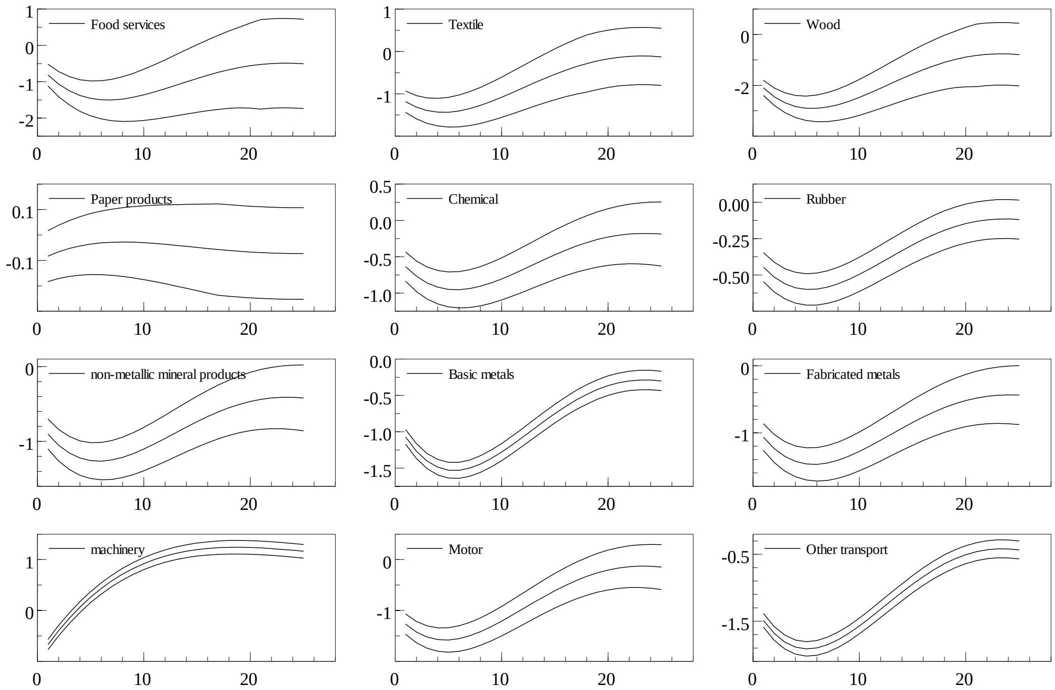
CHART 2(continued)

b. Impact on *real compensation per employee*

Range of industry responses



Individual industry responses

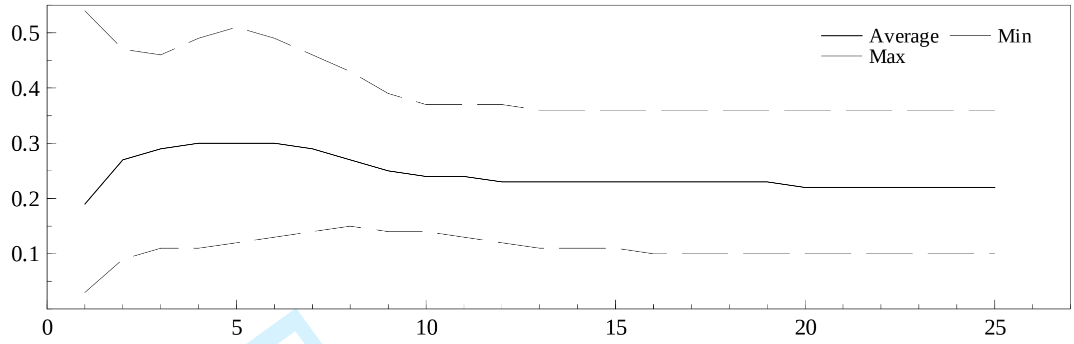


Source: Authors' calculations.

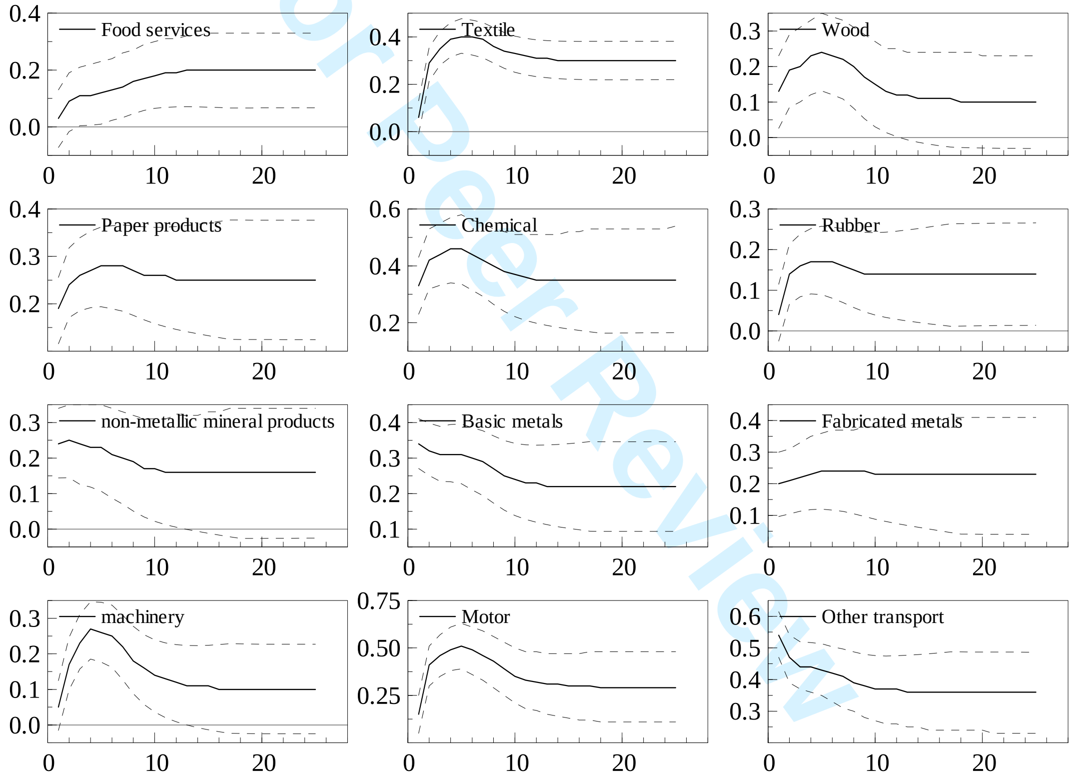
CHART 2(continued)

c. Impact on ***productivity***

Range of industry responses



Individual industry responses

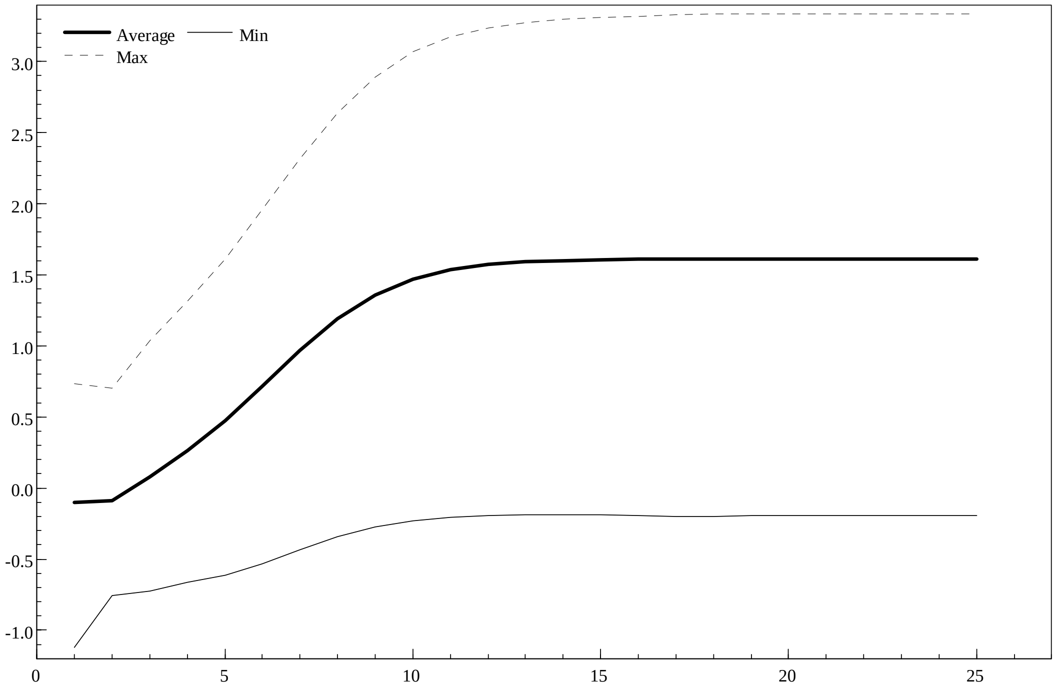


Source: Authors' calculations.

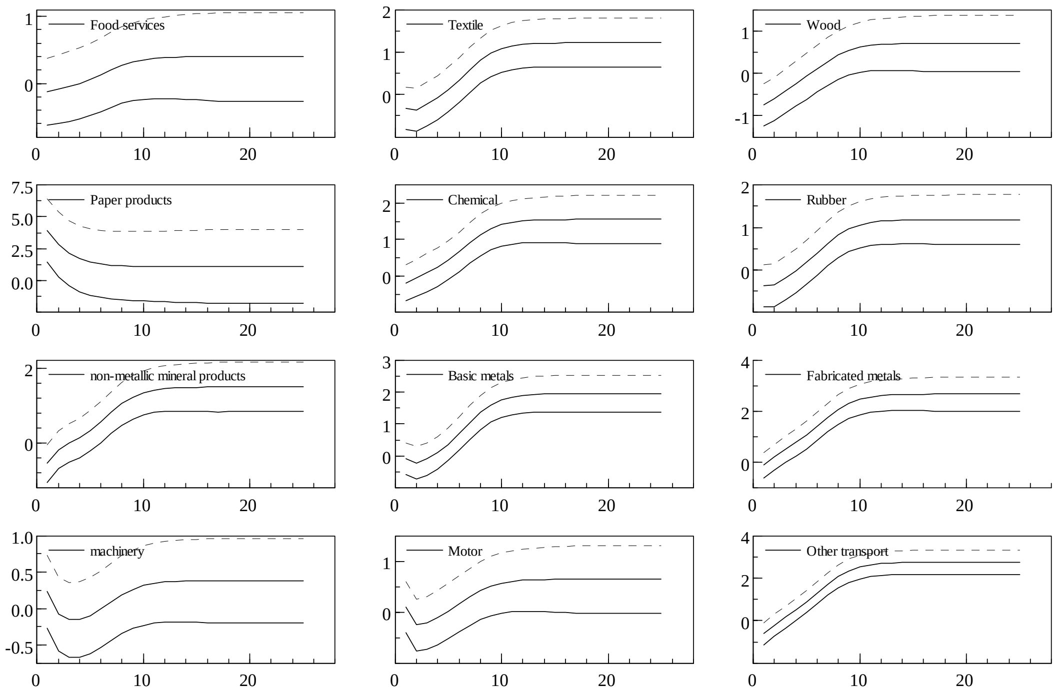
CHART 3. Impulse responses of a positive one standard deviation shock to US manufacturing *R&D* (Bootstrap Mean Estimates)

a. Impact on full-time equivalent ***employment***

Range of industry responses



Individual industry responses

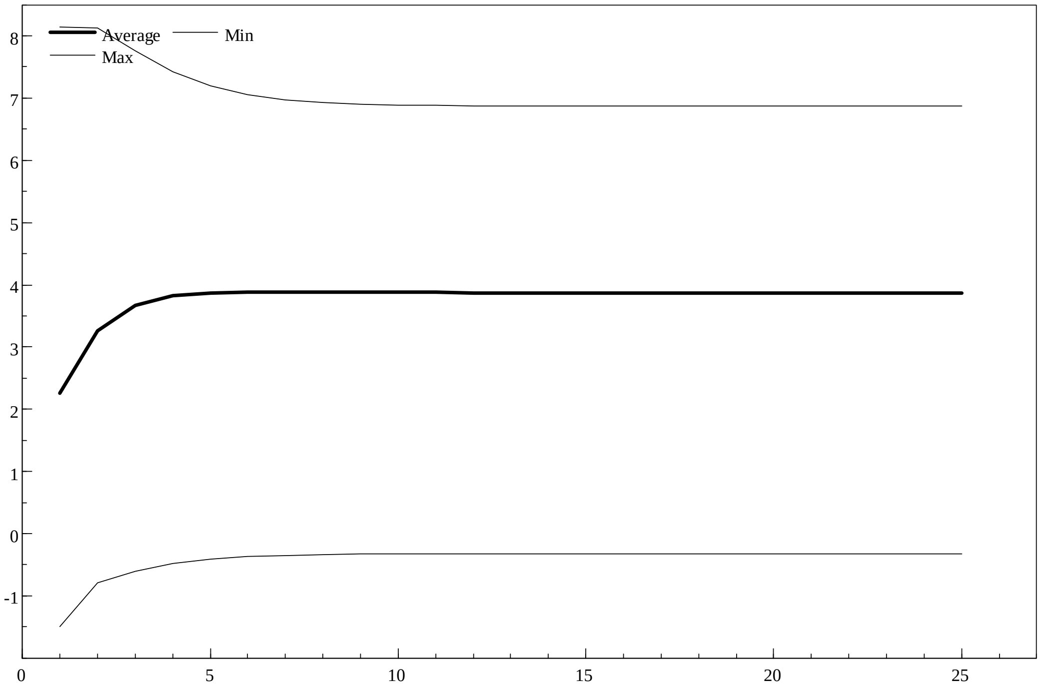


Source: Authors' calculations.

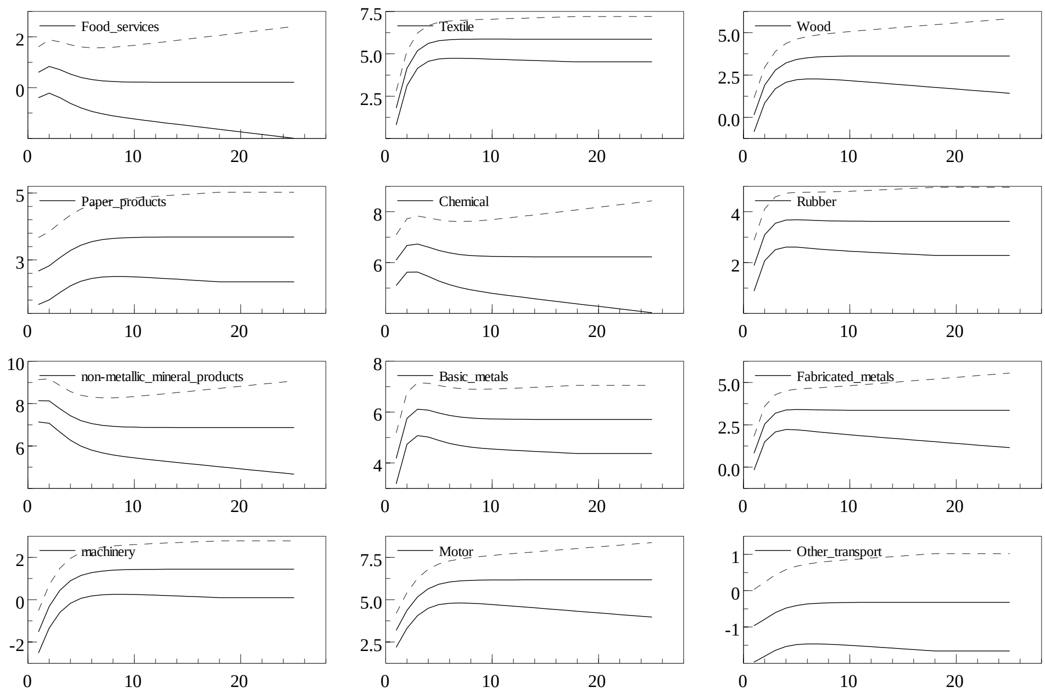
CHART 3(continued)

b. Impact on ***real compensation per employee***

Range of industry responses



Individual industry responses

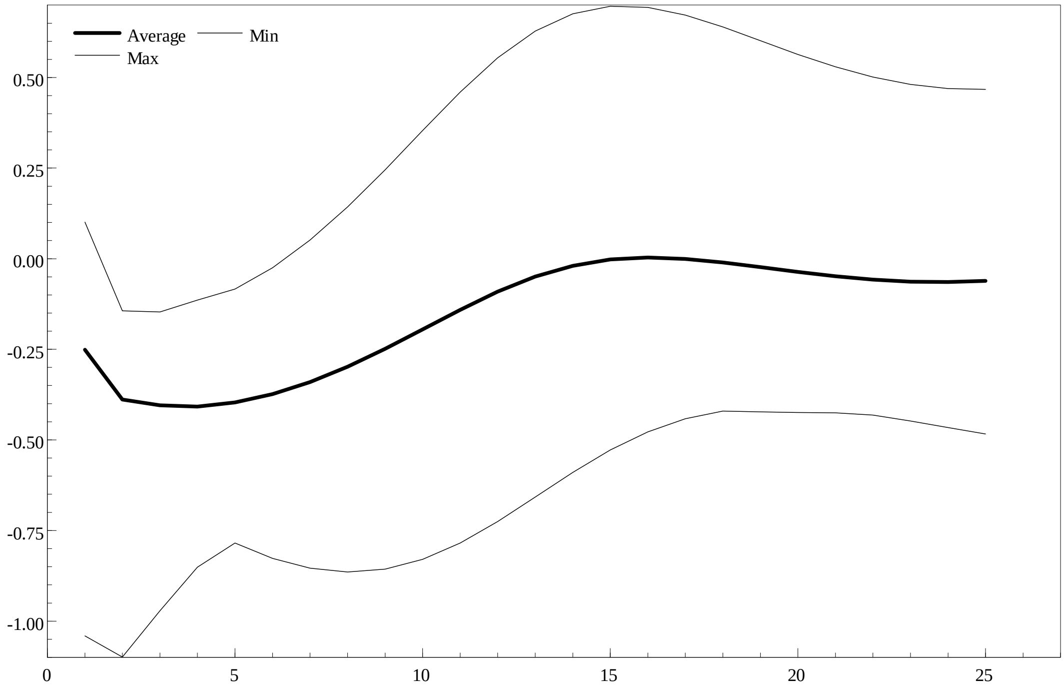


Source: Authors' calculations.

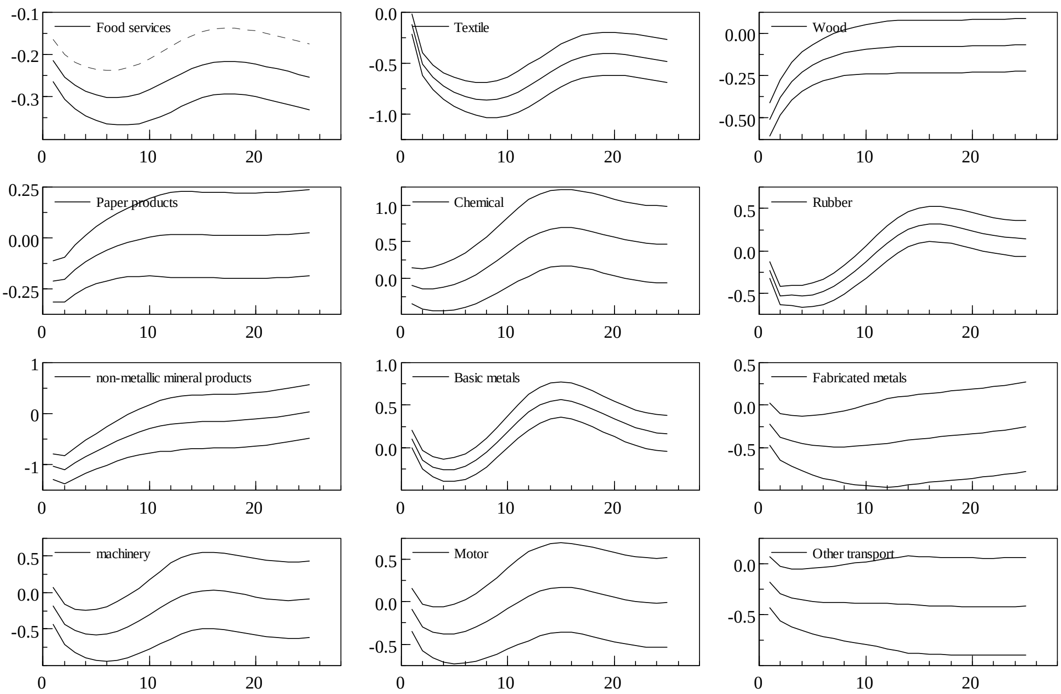
CHART 4. Impulse responses of a positive one standard deviation shock to the *oil price* (Bootstrap Mean Estimates)

a. Impact on full-time equivalent ***employment***

Range of industry responses



Individual industry responses

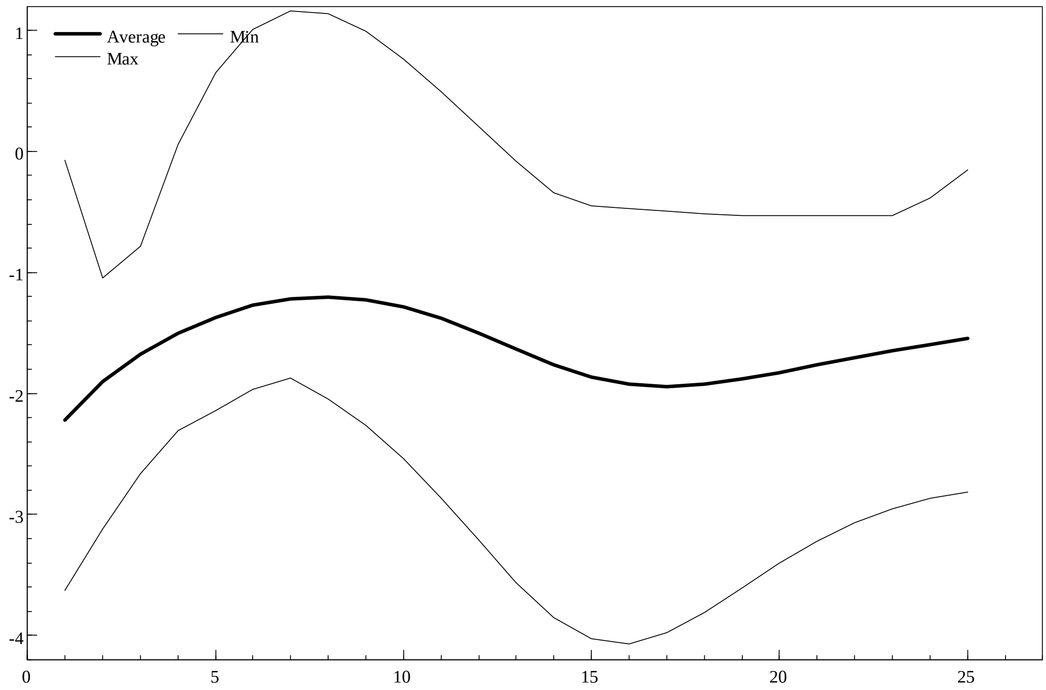


Source: Authors' calculations.

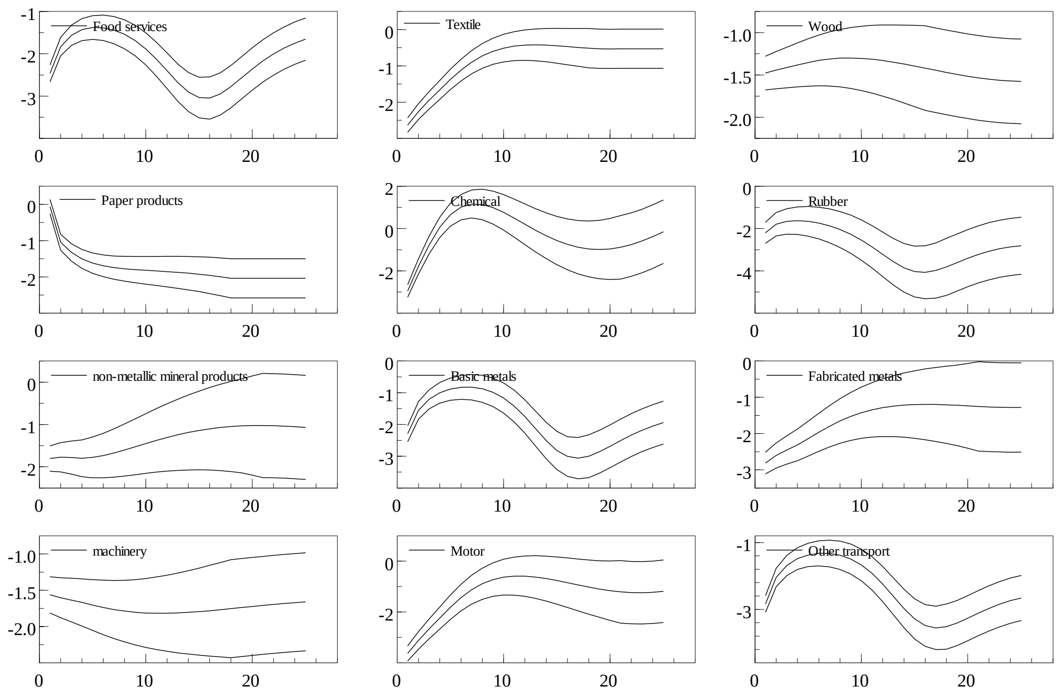
CHART 4(continued)

b. Impact on *real compensation per employee*

Range of industry responses



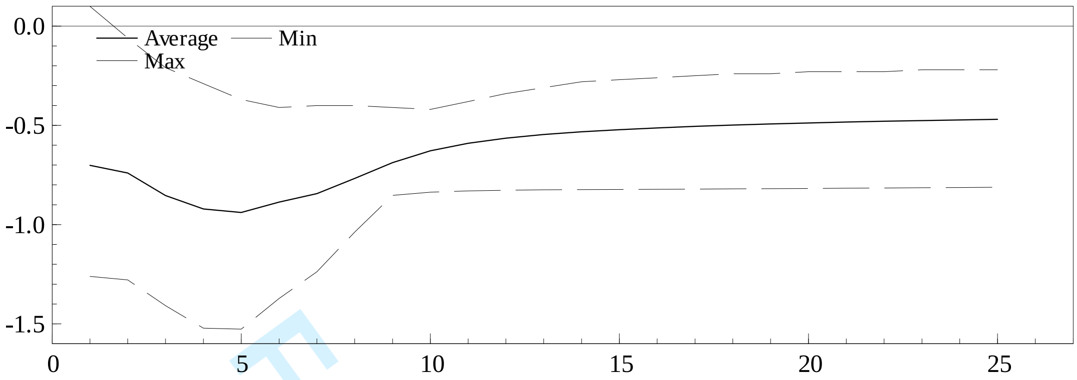
Individual industry responses



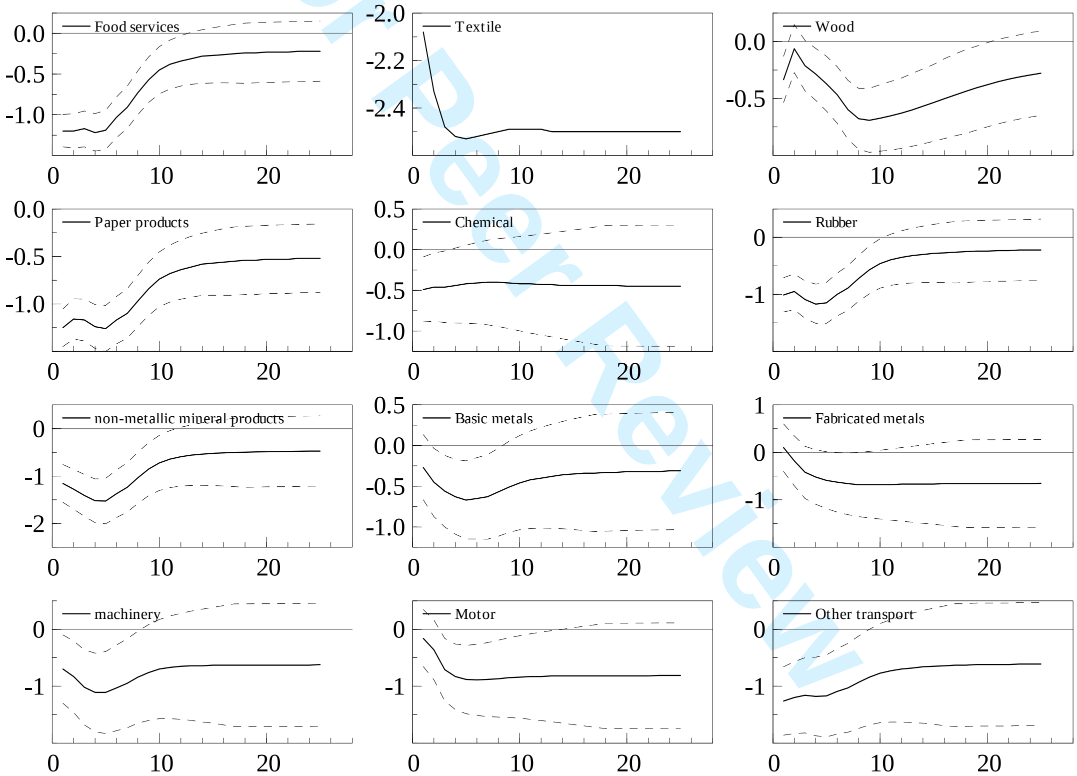
Source: Authors' calculations.

CHART 5. Impulse responses of a negative one standard deviation shock to US *employment in the textile* sector: Impact on *employment in other sectors* (Bootstrap Mean Estimates)

Range of industry responses



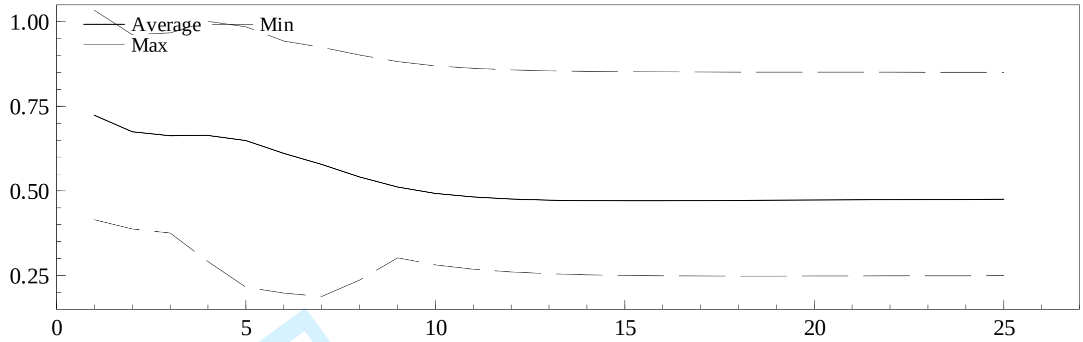
Individual industry responses



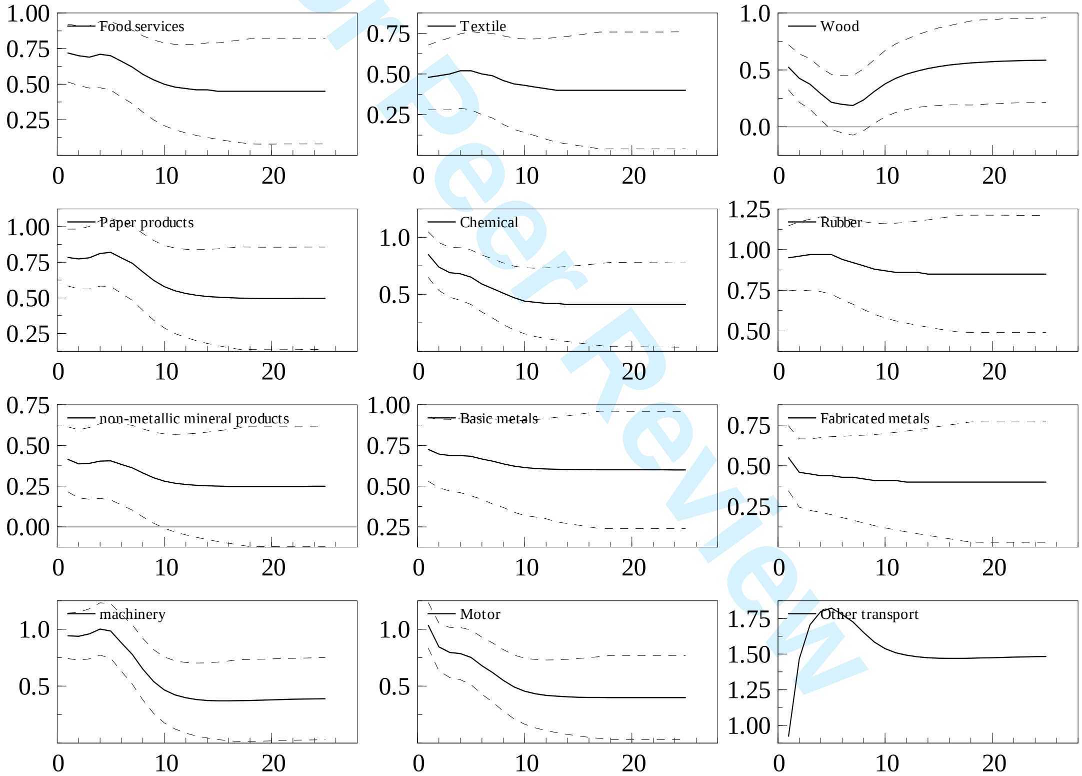
Source: Authors' calculations.

CHART 6. Impulse Responses of a positive one standard deviation shock to US *productivity in the "other transport" sector*. Impact on *employment in other sectors* (Bootstrap Mean Estimates)

Range of industry responses



Individual industry responses



Source: Authors' calculations.