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business cycle
dynamics**



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INTER-INDUSTRY TRADE AND BUSINESS CYCLE DYNAMICS

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ABSTRACT

Motivated by the increased importance of trade between industrialized and less-developed countries, we build a DSGE model featuring comparative advantage and inter-industry trade to analyze business cycle dynamics of industrialized countries. We show that productivity shocks lead to shifts in the relative demand of exporting and import-competing sectors, implying an important role for the mobility of workers across sectors. If workers are very mobile, then the aggregate implications of the two-sector model are similar to a one-sector model. If workers are very immobile, then the two-sector model features smaller responses in GDP to domestic shocks but larger responses to foreign shocks, implying larger comovement of GDP across countries.

Keywords: international business cycles; inter-industry trade; comparative advantage; wage inequality

JEL classification: E20, E25, F41, F44, F62

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1 Introduction

Figure 1 shows the share of two top US trading partners in total US trade. The figure illustrates that trade with China has been growing fast over the last couple of decades, while trade with Canada has been steadily declining. These trends are representative for other industrialized countries and mark a shift in the pattern of international trade since trade among industrialized countries, like the US and Canada, is primarily driven by intra-industry trade, while trade between industrialized and less-developed countries, like the US and China, is to a large degree inter-industry trade. This is illustrated by figure 2 showing the importance of intra-industry trade, as measured by the Grubel Lloyd index, for manufacturing trade between the US and Canada resp. China.¹ Two facts stand out: i) the Grubel Lloyd index is remarkably stable over time for both countries; ii) trade with China is to a much lesser extent based on intra-industry trade. Put differently, trade with China is to a much larger extent inter-industry trade.

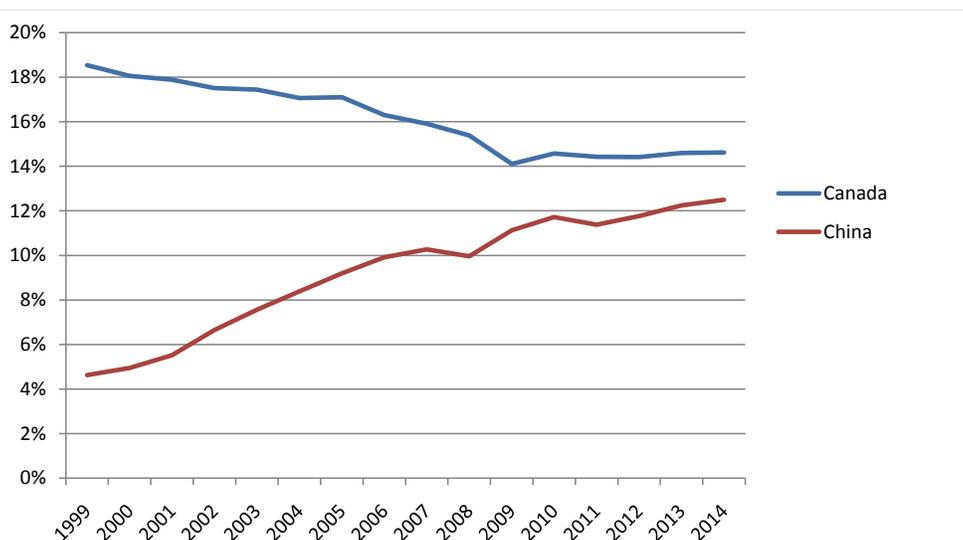


Figure 1: Trade shares of US with Canada and China

The potential consequences of this shift in the structure of international trade for business cycle dynamics are still under-explored, mainly due to the restriction of existing business cycle models to intra-industry trade. We aim to close this gap by developing a modern dynamic stochastic general equilibrium (DSGE) model that is based on comparative advantage as well as 'love of variety' and thus features both inter- and intra-industry trade. We find that the structure of international trade is potentially very important. Productivity shocks lead to shifts in the relative demand of exporting and import-competing sectors, implying an important role for the mobility of workers across sectors. If workers are very mobile then the aggregate implications of the two-sector model

¹The Grubel Lloyd index is defined as $GL_{it} = 1 - |Ex_{it} - Im_{it}| / (Ex_{it} + Im_{it})$ and lies between zero and one. It is the most popular measure of the importance of intra-industry trade and measures the share of intra-industry trade in total trade.

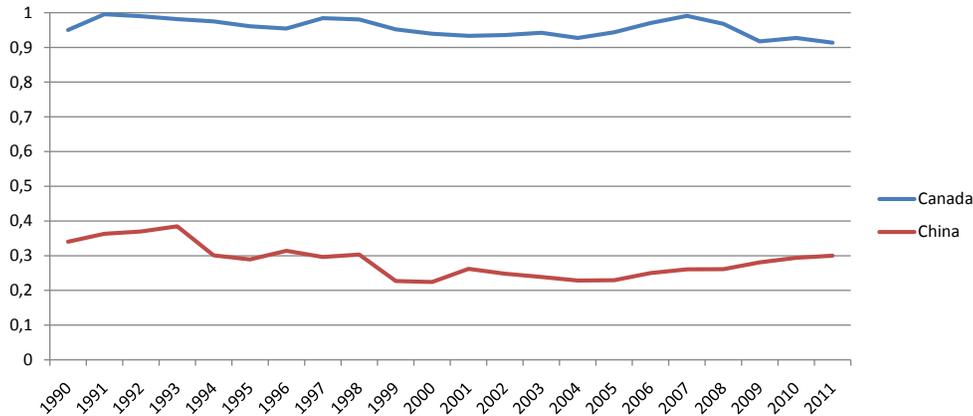


Figure 2: Grubel Lloyd index for manufacturing trade between the US and Canada resp. China

are very similar to a one-sector model. If workers are very immobile then the two-sector model features lower GDP volatility but a larger correlation of GDP across countries.

At the heart of our analysis lies the idea that sectors respond differently to aggregate productivity shocks, depending on whether they are exporting sectors (in which the US has a comparative advantage) or import-competing sectors (in which the US has a comparative disadvantage). To see whether this is indeed the case in the data, we regress a measure for aggregate productivity shocks on the output and revenue of exporting and import-competing sectors. Using US data, we find that there is indeed an economically and statistically significant difference in how strongly both types of sectors respond to aggregate productivity shocks: the response of output and revenue in import-competing sectors is on average roughly twice as strong as in exporting sectors.

We proceed by developing a model that can replicate this stylized fact. Our model is a dynamic version of the static model developed in Bernard et al. [2007] (BRS henceforth). BRS combine heterogeneous firms and endogenous firm entry a la Melitz [2003] with comparative advantage. Thus, they build a model that includes both inter- and intra-industry trade, which makes it suitable for our analysis.

The model we use is a dynamic version of BRS, along the lines of Ghironi and Melitz [2005] (GM henceforth), and is based on Lechthaler and Mileva [2013] and Lechthaler and Mileva [2014], who study the effects of trade liberalization on wage inequality. It is a model with two countries, two sectors and two factors of production, namely skilled and unskilled workers. The industrialized country has a relatively larger endowment of skilled workers and thus a comparative advantage in the skill-intensive sector. International trade induces both countries to specialize partly in producing their comparative advantage sector good. In contrast to Lechthaler and Mileva [2013], the model used here also features an intensive margin of labor supply (hours per worker) that can be adjusted at business cycle frequency as in most models of international macro.

We find that in response to temporary, negative shocks to aggregate productivity in the industrialized country, relative demand shifts from the import-competing sector towards the exporting sector, because the latter depends less on domestic demand. If workers are mobile across sectors

they follow the shift in demand and temporarily move to the exporting sector, implying a relative shift in production and revenue towards the exporting sector that is in line with our empirical analysis. If workers are immobile across sectors much of the adjustment is pushed into a shift in the relative price of both sectors. Interestingly, the shift in relative prices helps to cushion the effect of the productivity shock on domestic GDP. However, in this scenario the contraction in output in both sectors is roughly equal, in contrast to our empirical analysis. Thus our empirical results provide more support for the specification of the model with mobile workers, at least for the US economy.

Our model also has implications for wage inequality. The shift in relative demand towards the exporting sector that follows a decline in domestic productivity implies an increase in the relative demand for skilled workers which are used more intensively in the exporting sector. Consequently, the wage income of skilled workers goes up relative to that of unskilled workers and overall wage inequality increases.

Not only the effects of domestic shocks depend crucially on worker mobility, but also the effects of foreign shocks. Again worker immobility leads to stronger shifts in the relative price of both sectors, implying larger spillover effects. Comparing our two-sector model with a one-sector model that only features intra-industry trade, we find that under worker mobility the volatility of GDP in both models is remarkably similar. Under worker immobility, however, the two-sector model features lower volatility in GDP and larger business-cycle comovement across the two countries.

Thus our model predicts very different effects of changes in the structure of trade, depending on how mobile workers are across sectors. If workers are very mobile across sectors, the volatility of GDP and the cross-country correlation of GDP will not change by much while import-competing sectors and wage inequality become substantially more volatile. This is different for an economy in which workers are very immobile. In this case wage inequality and import-competing sectors are more stable, while the domestic economy is expected to react less to domestic shocks but more to foreign shocks. This result might imply an interesting divergence in the reaction of the US economy and European economies to increased trade with China, since European economies are known for more sclerotic labor markets and lower worker mobility.

Our paper lies in the tradition of open economy business cycle models, a literature that goes back to Backus et al. [1992], and more specifically to recent attempts to include endogenous firm entry as in Ghironi and Melitz [2005], or Cacciatore and Ghironi [2014]. Another recent paper related to ours is Caselli et al. [2015] who address the question whether trade liberalization increases or decreases the volatility of GDP, using a variant of the model in Eaton and Kortum [2002]. Their focus is on sector-specific vs. country-specific shocks, and they show that the effect of specialization on GDP volatility depends on the volatility of sector-specific shocks, on the covariance among sector-specific shocks, and on the covariance between sector-specific shocks and country-specific shocks. In contrast, we use a smaller model in the tradition of international macro models and focus on the endogenous shifts in specialization that follow shocks to aggregate

productivity. Our interest lies in the comparison of inter-industry trade and intra-industry trade and its implications for business cycle dynamics. To the best of our knowledge inter-industry trade of this kind has not been considered in the business cycle literature so far.

There is also a recent empirical literature related to our paper. An overview of this literature can be found in Fidrmuc and Korhonen [2015] who summarize previous research on China’s business cycle correlation with other countries with the help of meta-analysis techniques. For the US they report a mean correlation coefficient of 0.245 based on 24 surveyed papers. More than half of these papers are Chinese publications, which tend to report correlation coefficients that are about twice as high as those from other publications. Thus, the empirical literature on how China affects the business cycle of the US and other developed countries tends to report positive correlations but there is no consensus on the magnitude of this correlation. Nevertheless, these results are broadly in line with our model which produces a correlation between 0.13 and 0.3, depending on the specification.

The paper proceeds as follows. In the next section we develop our stylized facts that output and revenue of import-competing sectors respond much more strongly to shocks in domestic aggregate productivity than output and revenue of exporting sectors. In section 3 we develop a model that can explain this stylized fact. Section 4 discusses our calibration approach. Section 5 describes theoretical responses to both domestic and foreign shocks to aggregate productivity and the resulting business cycle statistics. Section 6 analyzes the robustness of our results to alternative specifications, including costly worker mobility, heterogenous firms and alternative structures of firm ownership. Section 7 concludes.

2 Aggregate productivity and sector responses in the data

The introduction motivated the analysis of inter-industry trade with the observation of the rising importance of China and other developing countries for the world economy and international trade. A central aspect of inter-industry trade is the distinction between comparative advantage sectors and comparative disadvantage sectors. It is to be expected that both types of sectors are affected differently by business cycle shocks, but in the end this is an empirical question. Thus in this section we use US data to assess the responsiveness of both types of sectors to changes in TFP growth. We find that comparative disadvantage sectors are considerably more responsive to domestic productivity shocks.²

To measure TFP growth we use an annual series constructed by the San Francisco Federal Reserve which calculates business sector TFP growth as output growth less the contribution of capital and labor.³ We then estimate the effect of aggregate TFP growth on the growth rate of

²Appendix 7 provides a more detailed description of the empirical strategy and the data used, as well as some robustness checks.

³The data and details on how it was constructed can be found at the San Francisco Fed website: <http://www.frbsf.org/economic-research/indicators-data/total-factor-productivity-tfp/>.

sector level revenue and output, where $\Delta y_{it} = \log(y_{it}) - \log(y_{it-1})$ is the growth rate of output in sector i at period t and $\Delta r_{it} = \log(r_{it}) - \log(r_{it-1})$ is the growth rate of revenue. We obtain data on sector output from the NBER-CES Manufacturing Industry Database. Output is measured as the value of shipments divided by a sector price deflator. Revenue is measured in real terms by dividing the value of shipments by the personal consumption expenditure price index obtained from the Saint Louis Federal Reserve website. The data is annual and runs from 1980 to 2006, and includes 19 three digit level manufacturing sectors based on the North American Industry Classification System (NAICS).⁴

In order to distinguish between the effects for comparative advantage and comparative disadvantage sectors, we use a measure of revealed comparative advantage (RCA) which takes account of exports and imports at the sector level. RCA is defined as the ratio of the export share of the sector in total manufacturing exports over the import share of the sector in total manufacturing imports ($RCA = \frac{Ex_{it}/Ex_{manuf,t}}{Im_{it}/Im_{manuf,t}}$), with $RCA > 1$ referring to comparative advantage sectors and $RCA < 1$ referring to comparative disadvantage sectors.⁵ We construct a dummy which takes the value of 0 if the sector has an RCA greater than 1 and 1 if the sector has an RCA lower than 1. Then we estimate a regression equation with the following specification:

$$\Delta x_{it} = \beta_0 + \beta_1 \Delta t f p_t + \beta_2 dummy_i + \beta_3 (\Delta t f p_t)(dummy_i) + u_{it}, \quad (1)$$

where Δx_{it} corresponds to either Δy_{it} , or Δr_{it} , and u_{it} is a random error. This is a pooled regression that can be estimated with ordinary least squares methods. The coefficient of interest is $\hat{\beta}_3$ which if positive and significant would indicate that the changes in aggregate productivity have larger impact on the growth rate of comparative disadvantage sectors than on the growth rate of comparative advantage sectors. We run two regressions one with output growth as the dependent variable and one with revenue growth as the dependent variable. We do this because we want to know whether the sectors experience differential responses due to a shift in quantities across sectors or due to a shift in the relative prices across sectors, or both.

Equations 2 and 3 show the estimated parameters with standard errors in parenthesis.

$$\Delta y_{it} = \begin{array}{cccc} 0.017 & + & 0.874 \Delta t f p_t & - & 0.027 dummy_i & + & 1.057 (\Delta t f p_t)(dummy_i) \\ (0.006)^{***} & & (0.28)^{***} & & (0.007)^{***} & & (0.361)^{***} \end{array} \quad (2)$$

⁴Details on aggregation from six to three digit level sectors as well as a list of the sectors included in the analysis can be found in the appendix.

⁵We prefer this measure over the more traditional measure of revealed comparative advantage introduced by Balassa because it not only takes account of the export structure of the sector but also of its import structure. In addition, data on US exports and imports at the NAICS industry classification is readily available at Peter Schott's website. In contrast the Balassa measure of RCA requires data on world export shares at the NAICs level which has to be converted from other industry classification systems. Nevertheless, in the Appendix we show that our results are robust with respect to this classification.

$$\Delta r_{it} = 0.001 + 0.98\Delta tfp_t - 0.019dummy_i + 1.066(\Delta tfp_t)(dummy_i) \quad (3)$$

(0.007) (0.322)*** (0.007)** (0.392)***

Notes: # of observations =513; sample =1980-2006; sectors =19; $R^2 = 0.101$ for equation 2, $R^2 = 0.101$ for equation 3. Standard errors are clustered by year to control for inter-sector correlation and heteroscedasticity in the residuals. “*” significance at the 10% level, “***” at the 5% level and “****” at the 1% level.

The estimated equations show that the aggregate productivity shock is an important driver of both sector-level output and sector-level revenue. The coefficient $\hat{\beta}_1$ is large (0.874 for output and 0.98 for revenue) and statistically significant at the 1%-level in both cases. The results also reveal that comparative disadvantage sectors are more responsive to productivity shocks than comparative advantage sectors both in terms of output and revenue: the coefficient $\hat{\beta}_3$ is large and statistically significant at the 1%-level in both cases. Our results suggest that in response to a 1% increase in aggregate productivity the output of comparative advantage sectors increases by 0.874% on average, while the output of comparative disadvantage sectors increases by 1.93%. In response to the same increase in aggregate productivity revenue in comparative advantage sectors increases by 0.98% while revenue of comparative disadvantage sectors increases by 2.05%.

The results from the two regressions imply a roughly equal relative response across sectors both in terms of revenue and output. In both specifications comparative disadvantage sectors are roughly twice more responsive to aggregate productivity changes than comparative advantage sectors. The fact that the relative response across sectors is equal for output and revenue indicates that the shift in revenue is driven by the shift in output and not by a shift in the relative price of both sectors.⁶ One implication of this result is that a decline in aggregate productivity leads to temporarily enhanced specialization of production in comparative advantage sectors. In the appendix we show that our results are robust to an alternative specification of revealed comparative advantage and alternative identifications of aggregate productivity.

Our empirical exercise demonstrates that there is a considerable difference in the extent to which comparative advantage sectors and comparative disadvantage sectors are affected by domestic shocks to aggregate productivity. In the following we develop a model that is able to explain this stylized fact and use the model to analyze its consequences for business cycle fluctuations.

3 Theoretical model

We build a dynamic stochastic general equilibrium model of two countries, Home (H) and Foreign (F). Each country produces two goods, good 1 and good 2, which are aggregated into a final consumption good using a Cobb Douglas technology. The production of each good requires two inputs, skilled and unskilled labor. The sector that produces good 1 is skill-intensive, i.e., the

⁶If the relative price of sectors changed substantially we would expect larger shifts in revenue than in output.

production of good 1 requires relatively more skilled labor than the production of good 2.

H has a comparative advantage in producing good 1 because it has a higher relative endowment with skilled workers. Similarly, F has a comparative advantage in sector 2 because it has a higher relative endowment with unskilled workers. We assume that unskilled workers are more abundant than skilled workers in both countries in order to generate a positive skill-premium.⁷ In the long run, workers are assumed to be perfectly mobile between sectors but not across countries. Concerning the short run, we use two polar cases to highlight the important role of worker mobility - full mobility in one case and full immobility in the other case. Additionally, we assume an intensive margin of labor supply in order to allow for endogenous changes in the labor input in response to business cycle shocks.

At the sector level the model features a continuum of firms, each selling a different variety under monopolistic competition. As in Ghironi and Melitz [2005] we assume that new firms have to pay a sunk entry cost to enter the market, thus endogenizing the number of firms and varieties. For our benchmark economy we assume that firms are homogenous, but in the robustness section we also consider the case of heterogeneous firm productivity. The bundle of varieties produced by firms is aggregated into a sector good using a CES technology. The economy is subject to country-specific shocks to aggregate productivity. In the following section we describe all the decision problems in H; equivalent equations hold for F.

3.1 Households

In our model there are two types of households, ones that comprise of skilled workers and ones that comprise of unskilled workers.⁸ In the following we describe the problem of a skilled worker's household, with analogous equations holding for an unskilled worker's household. The utility of a skilled worker's household is given by:

$$E_t \left\{ \sum_{k=0}^{\infty} \gamma^k \left[\frac{(C_{t+k}^S)^{1-\sigma}}{1-\sigma} S - \sum_{i=1,2} \frac{(H_{it+k}^S)^{1+v}}{1+v} S_{it} \right] \right\}, \quad (4)$$

where C_{t+k}^S is the consumption of each worker, H_{it+k}^S the hours supplied by each worker in sector i , S_{it} the number of workers in sector i , $S = S_{1t} + S_{2t}$ the total number of workers in the household, γ the subjective discount factor, σ the intertemporal elasticity of substitution, and v the inverse of the Frisch elasticity of labor supply. So every household member receives the same consumption, but labor supply might differ across sectors.

⁷What matters for comparative advantage are relative endowments, so skilled labor can be scarce in both countries.

⁸We assume two households and not one household, because this gives a more meaningful interpretation to wage inequality. We do not assume separate households for workers in different sectors, because then worker mobility across sectors would imply workers switching between households. In the robustness section we will discuss the case of separate households for both sectors for the case of worker immobility.

Every period the households face the following budget constraint written in terms of final consumption:

$$SC_t^S + A_t^S + Q_t A_{*,t}^S + \frac{\eta}{2}(A_t^S)^2 + Q_t \frac{\eta}{2}(A_{*,t}^S)^2 = \sum_{i=1,2} w_{it}^S H_{it}^S S_{it} + A_{t-1}^S(1+r_{t-1}) + Q_t A_{*,t-1}^S(1+r_{t-1}^*) + S\Pi_t + T_t^S \quad (5)$$

The left-hand side includes household expenditure on consumption SC_t^S , H bonds A_t^S and F bonds $A_{*,t}^S$. F bonds are in terms of the foreign consumption good and thus adjusted by the real exchange rate $Q_t \equiv e_t P_t^*/P_t$, defined as the relative price of F goods versus H goods. The nominal exchange rate e_t can be normalized to 1, since our model does not include any nominal rigidities. Note that households have to pay a quadratic adjustment cost for H bonds $\frac{\eta}{2}(A_t^S)^2$ and F bonds $Q_t \frac{\eta}{2}(A_{*,t}^S)^2$. These costs are paid to financial intermediaries whose only function is to collect these transaction fees and rebate them to the households in a lump-sum fashion. The purpose of these adjustment costs is to assure stationarity of the steady state (see GM for more details).

The right hand side of equation 5 includes the sources of income such as the wage income from both sectors $\sum_{i=1,2} w_{it}^S H_{it}^S S_{it}$, interest income on H bond holdings $A_{t-1}^S(1+r_{t-1})$ and F bond holdings in last period $Q_t A_{*,t-1}^S(1+r_{t-1}^*)$, profit transfers from owning firms Π_t (to be defined in more detail below) and the bond adjustment cost rebate T_t^S . r_{t-1} and r_{t-1}^* are the real interest rates on H and F bond holdings.

The household chooses how much to consume, how many hours to work in both sectors and how much H and F bonds to buy by optimizing its utility subject to the budget constraint. The optimization problem implies the following optimality conditions:

$$\frac{(H_{it}^S)^v}{(C_t^S)^{-\sigma}} = w_{it}^S \text{ for } i = 1, 2, \quad (6)$$

$$(1 + \eta A_t^S) = \gamma E_t \left[\left(\frac{C_{t+1}^S}{C_t^S} \right)^{-\sigma} (1 + r_t) \right], \quad (7)$$

$$(1 + \eta A_{*,t}^S) = \gamma E_t \left[\left(\frac{C_{t+1}^S}{C_t^S} \right)^{-\sigma} (1 + r_t^*) \frac{Q_{t+1}}{Q_t} \right]. \quad (8)$$

The first condition determines optimal labor supply by equating the marginal rate of substitution between leisure and consumption to the real wage. The other two conditions are the Euler equations that determine the optimal demand for H and F bonds, respectively.

As mentioned above we distinguish two specifications concerning the mobility of workers across sectors. In the first case, workers are fully mobile across sectors both in the short run and in the long run, without any restrictions. In the second case, workers are fully mobile in the long run but immobile in the short run.⁹ In the case of short-run mobility, the number of workers in each sector is pinned down by a further optimality condition which assures that the value generated

⁹In the robustness section we also consider the case of worker reallocation subject to movements costs.

by a worker is the same in each sector (following from maximizing utility with respect to S_{1t} and S_{2t}):

$$w_{1t}^S H_{1t}^S (C_t^S)^{-\sigma} - \frac{(H_{1t}^S)^{1+v}}{1+v} = w_{2t}^S H_{2t}^S (C_t^S)^{-\sigma} - \frac{(H_{2t}^S)^{1+v}}{1+v}. \quad (9)$$

Under short-run mobility equation 9 holds at any time. Under short-run immobility it still pins down the steady state (long-run) distribution of workers across sectors, but it no longer holds in the short run.

The composition of the aggregate consumption bundle is the same for skilled and unskilled households, only the quantity of consumed goods might differ across skill classes. Therefore, in the following we will omit the indices for the skill class of a household to avoid cumbersome notation. The aggregate consumption bundle C_t is a Cobb-Douglas composite of the goods produced in the two sectors:

$$C_t = C_{1t}^\alpha C_{2t}^{1-\alpha}, \quad (10)$$

where α is the share of good 1 in the consumption bundle for both H and F. We obtain relative demand functions for each good from the expenditure minimization problem of a household. The implied demand functions are:

$$C_{1t} = \alpha \frac{P_t}{P_{1t}} C_t \quad \text{and} \quad C_{2t} = (1 - \alpha) \frac{P_t}{P_{2t}} C_t, \quad (11)$$

where $P_t = \left(\frac{P_{1t}}{\alpha}\right)^\alpha \left(\frac{P_{2t}}{1-\alpha}\right)^{1-\alpha}$ is the price index that buys one unit of the aggregate consumption bundle C_t .

Each sector good is a consumption bundle aggregated over domestic and imported varieties in a Dixit-Stiglitz form:

$$C_{it} = \left[\int_0^1 c_{it}(k)^{\frac{\theta-1}{\theta}} dk \right]^{\frac{\theta}{\theta-1}}, \quad (12)$$

where $\theta > 1$ is the elasticity of substitution between goods. The consumption based price index for each sector is $P_{it} = \left[\int_0^1 p_{it}(k)^{1-\theta} dk \right]^{\frac{1}{1-\theta}}$ and the household demand for each good is

$$c_{it} = \left(\frac{p_{it}}{P_{it}} \right)^{-\theta} C_{it}. \quad (13)$$

It is useful to redefine the demand functions in terms of aggregate consumption units. To this end, let us define $\rho_{it} \equiv \frac{p_{it}}{P_t}$ and $\psi_{it} \equiv \frac{P_{it}}{P_t}$ as the relative prices for individual varieties and for the sector bundles, respectively. Then, we can rewrite the demand functions for goods and sector bundles as $c_{it} = \rho_{it}^{-\theta} C_{it}$ and $C_{it} = \alpha \psi_{it}^{-1} C_t$, respectively.

3.2 Production

There are two sectors of production in each country. Within each sector there is a continuum of firms, each producing a different variety. The number of firms and varieties is endogenous and determined by the entry of firms. Newly entering firms face a sunk entry cost f_e in effective labor units. For our benchmark we assume that firms are identical but in the robustness section we will consider heterogeneity with respect to firm productivity. To avoid cumbersome notation, we omit the index k pertaining to individual firms (varieties). The production technology is the same for all firms and is assumed to be Cobb-Douglas in the two inputs of production:

$$y_{it} = Z_t \left(S_{it} H_{it}^S \right)^{\beta_i} \left(L_{it} H_{it}^L \right)^{(1-\beta_i)} \quad (14)$$

where S_{it} and L_{it} are the numbers of skilled and unskilled workers used in a firm, whereas H_{it}^S and H_{it}^L are the hours worked per worker. As explained above we use the extensive margin of labor supply to model comparative advantage and the intensive margin of labor supply to model adjustments in labor supply in response to business cycle shocks. Z_t is time-varying aggregate productivity, which is the same in both sectors. Aggregate productivity follows an AR(1) process with autocorrelation ρ_z and is subject to i.i.d. shocks ε_z following a Normal distribution with mean 0 and standard deviation σ_z . β_i is the share of skilled labor required by a firm to produce one unit of output y_{it} in sector i . Sector 1 is assumed to be skill-intensive and sector 2 unskilled-intensive which implies that $1 > \beta_1 > \beta_2 > 0$. The labor market is assumed to be perfectly competitive implying that the hourly real wage of both skilled and unskilled workers equals their marginal products. Furthermore, workers are perfectly mobile across the firms in a specific sector implying that all firms within a sector pay the same wage. Consequently, relative labor demand can be described by the following condition:

$$\frac{w_{it}^S}{w_{it}^L} = \frac{\beta_i}{1 - \beta_i} \frac{L_{it} H_{it}^L}{S_{it} H_{it}^S}, \quad (15)$$

which says that the ratio of the skilled hourly real wage w_{it}^S to the unskilled hourly real wage w_{it}^L for sector i is equal to the ratio of the marginal contribution of each factor into producing one additional unit of output. Note that this condition implies that relative demand for labor is the same across all firms within a sector. This condition is valid for both sectors.

All firms are monopolistic competitors and face the residual demand curve, equation 13. They set prices as a proportional markup $\frac{\theta}{\theta-1}$ over marginal cost. Let $p_{d,it}(z)$ and $p_{x,it}(z)$ denote the nominal domestic and export prices of a H firm in sector i . We assume that the export prices are denominated in the currency of the export market. Prices in real terms are then given by:

$$\rho_{d,it} = \frac{p_{d,it}}{P_t} = \frac{\theta}{\theta-1} \frac{\left(w_{it}^S \right)^{\beta_i} \left(w_{it}^L \right)^{1-\beta_i}}{Z_t}, \rho_{x,it} = \frac{p_{x,it}}{P_t^*} = \frac{1}{Q_t} \tau_t \rho_{d,it}. \quad (16)$$

where $\tau_t \geq 1$ is the iceberg trade cost necessary to ship goods to the foreign country.

Profits, expressed in units of the aggregate consumption bundle of the firm's location are the sum of domestic $d_{d,it}$ and export profits $d_{x,it}$, such that $d_{it} = d_{d,it} + d_{x,it}$, and,

$$d_{d,it} = \frac{1}{\theta} \left(\frac{\rho_{d,it}}{\psi_{it}} \right)^{1-\theta} \alpha_i C_t, \quad d_{x,it} = \frac{Q_t}{\theta} \left(\frac{\rho_{x,it}}{\psi_{it}^*} \right)^{1-\theta} \alpha_i C_t^*. \quad (17)$$

3.3 Firm entry

We assume that all firms in a given country are owned by a mutual fund who invests in new firms on behalf of the entire population, collects all the profits and distributes the surplus of profits over firm investment in a lump-sum fashion.¹⁰ To set up a new firm the sunk entry cost $f_e (w_{it}^S)^{\beta_i} (w_{it}^L)^{1-\beta_i}$ has to be paid. Note that entry costs can differ between sectors due to different factor intensities and due to inter-sectoral wage differentials.

All firms are subject to exit shocks, which occur with probability $\delta \in (0, 1)$ at the end of each period. We assume that entrants at time t only start producing at time $t + 1$, which introduces a one-period time-to-build lag in the model. Thus, a proportion δ of new entrants will never produce. The number of existing firms is denoted by $N_{d,it}$ and the number of newly entering firms by $N_{e,it}$. Then the law of motion for the stock of producing firms can be written as:

$$N_{d,it} = (1 - \delta)(N_{d,it-1} + N_{e,t-1}). \quad (18)$$

The present discounted value of expected profits is:

$$v_{it} = E_t \sum_{k=t+1}^{\infty} \left[\gamma^{k-t} (1 - \delta)^{k-t} \left(\frac{C_k}{C_t} \right)^{-\sigma} d_{ik} \right]. \quad (19)$$

Firm profits are discounted using the aggregate stochastic discount factor adjusted for the probability of firm survival $1 - \delta$. Note that equation 19 can be written in recursive form as:

$$v_{it} = \gamma(1 - \delta) E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} (v_{it+1} + d_{it+1}) \right]. \quad (20)$$

Entry occurs until the value of a firm is equal to the entry cost:

$$v_{it} = f_e (w_{it}^S)^{\beta_i} (w_{it}^L)^{1-\beta_i}. \quad (21)$$

Finally, the total transfer of the mutual fund is given by profits minus investment in new firms:

$$(S + L) \Pi_t = d_{1t} N_{d,1t} + d_{2t} N_{d,2t} - v_{1t} N_{e,1t} - v_{2t} N_{e,2t} \quad (22)$$

¹⁰In the robustness section we will consider alternative cases of ownership structure.

3.4 Market Clearing Conditions, Aggregate Accounting and Trade

Market clearing requires that total production in each sector must equal total income so that:

$$N_{d,it} \left(\frac{\rho_{d,it}}{\psi_{it}} \right)^{1-\theta} \alpha_i C_t + Q_t N_{d,it} \left(\frac{\rho_{x,it}}{\psi_{it}^*} \right)^{1-\theta} \alpha_i C_t^* + v_{it} N_{e,it} = w_{it}^S S_{it} H_{it}^S + w_{it}^L L_{it} H_{it}^L + d_{it} N_{d,it}. \quad (23)$$

Total production of the sector includes the production of the sector good (both for the domestic and the foreign market) and the production of new firms. Total income generated by the sector includes wage earnings and profits.

The trade balance is defined as exports minus imports in both sectors:

$$tb_t = \sum_{i=1}^2 \left[Q_t N_{d,it} \left(\frac{\rho_{x,it}}{\psi_{it}^*} \right)^{1-\theta} \alpha_i C_t^* - N_{d,it}^* \left(\frac{\rho_{x,it}^*}{\psi_{it}} \right)^{1-\theta} \alpha_i C_t \right] \quad (24)$$

Let us define aggregate bond holdings in H as $A_t \equiv (A_t^S + A_t^L)$ and $A_{*,t} \equiv (A_{*,t}^S + A_{*,t}^L)$ for H and F bonds, respectively. Similarly, aggregate bond holdings in F are $A_t^* \equiv (A_t^{*S} + A_t^{*L})$ and $A_{*,t}^* \equiv (A_{*,t}^{*S} + A_{*,t}^{*L})$. In equilibrium, the international net supply of bonds is zero for H bonds such that $A_t + A_t^* = 0$ and for F bonds such that $A_{*,t} + A_{*,t}^* = 0$. Then net foreign assets evolve according to the following law of motion:

$$A_t + Q_t A_{*,t} = (1 + r_{t-1}) A_{t-1} + (1 + r_{t-1}^*) A_{*,t-1} Q_t + tb_t. \quad (25)$$

Finally, if workers are mobile between sectors, then, at each point of time the sum of workers employed in both sectors equals the exogenous worker endowment for skilled and unskilled worker respectively, such that $S = \sum_{i=1}^2 S_{it}$ and $L = \sum_{i=1}^2 L_{it}$. Equivalent equations hold for F.

4 Calibration

This section describes the calibration of the model that we use for the numerical simulations. Table 1 summarizes the calibration. In many aspects we follow GM. We interpret each period as a quarter, and set the household discount rate γ to 0.99, the standard choice for quarterly business cycle models. We set both the elasticity of intertemporal substitution, σ , and the inverse of the Frisch elasticity of labor supply v equal to 1, again standard choices for business cycle models. We set the elasticity of substitution between varieties to $\theta = 3.8$, based on the estimates from plant-level U.S. manufacturing data in Bernard et al. [2003]. We set the parameter for adjustment costs of international bond portfolios to $\eta = 0.01$.

Changing the sunk cost of firm entry f_e only re-scales the mass of firms in an industry. Thus, without loss of generality we can normalize it so that $f_e = 1$. We set the size of the exogenous firm exit probability to $\delta = 0.025$, to match the level of 10 percent job destruction per year in the US. These choices of parameter values are in line with GM.

To calculate the industry parameters α_i and β_i we use the NBER-CES Manufacturing Industry Database¹¹ which provides annual industry-level data from 1958-2009 on output, employment, payroll and other input costs, investment, capital stocks, TFP, and various industry-specific price indexes. We aggregate the data set to feature 19 3-digit NAICS industries and then classify these industries based on their revealed comparative advantage as in section 2. In order to calibrate the factor intensities of each sector, we calculate the wage share of production workers in the total payroll for comparative advantage sectors and for comparative disadvantage sectors. Production workers refers to blue-collar, unskilled workers. We take the period average from 1980 to 2009 and find that the implied wage share for skilled workers in comparative advantage sectors is $\beta_1 = 0.45$ and in comparative disadvantage sectors is $\beta_2 = 0.32$. Similarly, we calculate the average share of comparative advantage sectors in total manufacturing revenue to be 0.627 for 1980-2009. We calibrate $\alpha_1 = 0.6$.

In our calibration approach we assume that the Home and the Foreign economy are symmetric except for their relative endowments of skilled workers. We take this approach in order to isolate the role of comparative advantage and inter-industry trade for the business cycles of developed countries. Given the definition of skilled workers and unskilled workers in the NBER-CES data, we calibrate the endowments based on the ratio of production workers to managers in figure 4 in Ebenstein et al. [2011]. For the US this ratio is 4 to 1 in 1990 and 3 to 1 in 2005. For China the ratio is 8 to 1 in 1990 and 11 to 1 in 2005. Taking the average over the two available years and for a total population of 2000 workers in both countries these ratios imply that $S = 444$ and $L = 1356$ for the Home country and $S^* = 191$ and $L^* = 1809$ for the Foreign country. These endowments imply that the US has a higher relative endowment of skilled workers than China and thus comparative advantage in producing skill-intensive goods.

The persistence parameters for both productivity shocks are ρ_z are 0.95 and the standard deviation of the shocks are $\sigma_z = \sigma_{z^*} = 0.01$.

Finally, we calibrate the iceberg trade costs for both countries to deliver a share of total trade in Home GDP of 0.62. This corresponds to the average share of total manufacturing trade in manufacturing value added for the US over the period 1980-2009. This share implies trade costs of $\tau = \tau^* = 1.35$. This is close to the value of trade costs used in GM. For the autarky scenario we set the iceberg transport costs to $\tau = \tau^* = 10$.

A detailed description of a one sector version of the model with intra-industry trade can be found in GM. We have simplified their model by assuming that firms have homogeneous productivity. The parametrization is identical to the two-sector model except for the exogenous labor supply which is set such that Home's GDP in the one-sector model equals Home's GDP in the two-sector model.

¹¹The data can be accessed at <http://www.nber.org/nberces/>.

Table 1: Calibration table

Parameter	Description	Value
α	share of exporting sector in total revenue	0.6
γ	household discount factor	0.99
σ	elasticity of intertemporal substitution	1
$1/\nu$	Frisch elasticity of labor supply	1
η	adjustment cost of international bond trading	0.01
θ	elasticity of substitution between varieties	3.8
δ	probability of firm exit	0.025
f_e	fixed entry cost	1
β_1	skilled labor intensity parameter in exporting sector	0.45
β_2	skilled labor intensity parameter in import-competing sector	0.32
L/S	ratio of unskilled to skilled workers for Home	3.5/1
L^*/S^*	ratio of unskilled to skilled workers for Foreign	9.5/1
ρ_Z	persistence of productivity shocks	0.95
σ_Z	standard deviation of productivity shocks	0.01
τ	iceberg trade cost under trade	1.35
τ	iceberg trade cost under autarky	10

5 Aggregate Productivity shocks

In this section we discuss the reaction of our model economy in response to two standard business cycle shocks, a temporary productivity shock at Home and a temporary productivity shock at Foreign. In each case aggregate productivity is assumed to decrease on impact by 1% and then to slowly converge back to its steady state level with an autocorrelation of 0.95. We assume that the productivity shock affects both sectors equally, i.e., it is not sector-specific. The analysis of sector-specific shocks is left for future research.

Before starting the discussion of these shocks, let us briefly discuss the steady state of this economy. As pointed out in section 4, we calibrate the model such that Home is relatively more abundant in skilled workers than Foreign, which means that the share of skilled workers to unskilled workers is higher at Home than at Foreign. This implies that at the steady state international trade leads to specialization of production. Home concentrates on the production of the skill-intensive good while Foreign concentrates on the production of the unskilled-intensive good.

At the aggregate level trade is balanced, but at the sector level it is not. In the following discussion of the results, we call the sector, in which a country specializes, its exporting sector because in that sector it produces more than it consumes, and exports the difference. We call the other sector the import-competing sector because in it the country consumes more than it produces, and imports the difference. Each country finances the trade deficit in its import-competing sector with the trade surplus in the exporting sector. This specialization pattern is important for our analysis, because it responds to business cycle shocks (in line with the empirical results in section 2).

5.1 Aggregate productivity shock at Home

5.1.1 Mobile workers

We start our discussion with our baseline case where workers are assumed to be fully mobile across sectors (but not across skill classes).¹² This implies that equation 9 holds at any time, stating that workers of a given skill class have to generate the same utility in both sectors - only then is the household indifferent between employing a worker in one sector or the other. As a result, wages and hours worked (and thus disutility of labor) are equalized across sectors.

Figure 3 shows the development of selected variables at Home in response to the drop in aggregate productivity. A negative productivity shock leads to a contraction in output because production becomes less efficient and real marginal costs $((w_{it}^S)^{\beta_i} (w_{it}^L)^{1-\beta_i} / Z_t)$ rise. Output contracts in both sectors but the contraction is much larger in the import-competing sector than in the exporting sector, so that output and revenue become more concentrated in the exporting sector. Thus, the temporary fall in Home productivity leads to a temporary increase in specialization. Note that, this is very much in line with the stylized facts developed in section 2, where we show empirically that in the US comparative disadvantage sectors are significantly more responsive to changes in aggregate productivity than comparative advantage sectors. According to the empirical analysis, the reaction of import-competing sectors to shocks in aggregate productivity is around twice as strong as the reaction of exporting sectors in the year that the shock hits. Our simulation matches this result surprisingly well. In the fourth quarter after the 1% percent decline in productivity our model predicts that both production and revenue will decline about 2.5 times more strongly in the import competing sector than in exporting sector.

The shift in specialization is driven by movements in relative demand and relative prices. As figure 3 shows the fall in productivity leads to an increase in Home's terms of trade. The terms of trade increase because the fall in productivity makes Home production less efficient. Marginal costs increase and thus the price of its exports increase relative to the price of its imports.

As in the standard Heckscher-Ohlin model an increase in the terms of trade translates into an increase in specialization. Our model is more complicated since it incorporates both inter- and intra-industry trade, but the basic mechanism remains intact. In the standard Heckscher-Ohlin model the exporting sector only exports and does not import, while the import-competing sector only imports and does not export. This is different in our model due to the co-existence of comparative advantage and love of variety, but it is still the case that exports are more concentrated in the exporting sector.¹³ Since exports are concentrated in the exporting sector, this sector depends relatively more on foreign demand and relatively less on domestic demand. To the contrary, the import-competing sector depends relatively more on domestic demand.¹⁴ Thus, the

¹²In the robustness section we provide empirical evidence that workers indeed move across sectors in line with the predictions of our model, although the flows across sectors are relatively small

¹³In steady state the exports of exporting sector make up 89.6% of total exports while the imports of the exporting sector make up only 21% of total imports.

¹⁴To be precise, in steady state the share of domestic demand in total revenue is 25% higher in the import-

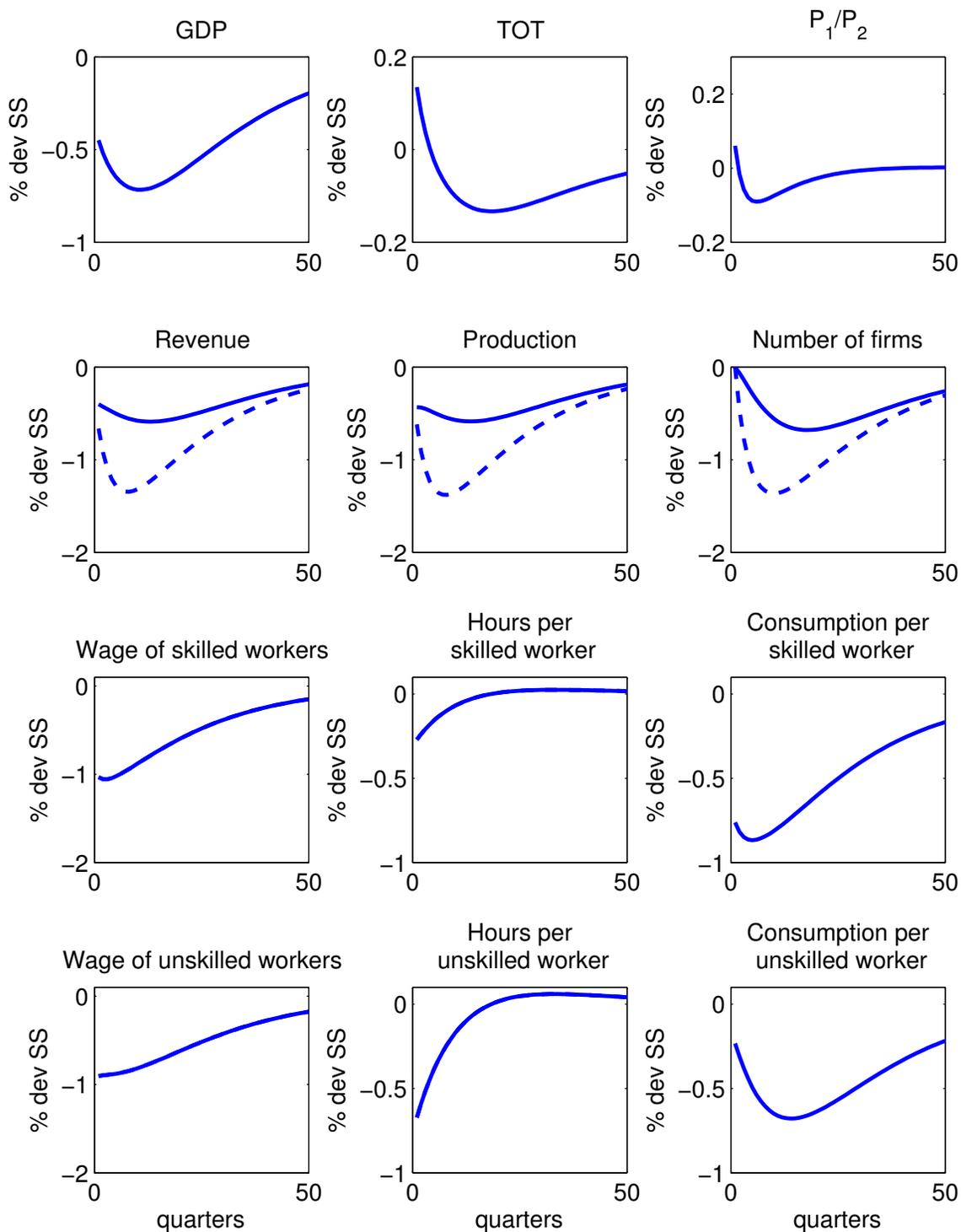


Figure 3: Full mobility of workers.

Impulse responses to a decline in domestic aggregate productivity. Variables are measured in %-deviations from steady state. Solid lines either refer to aggregate variables (first row) or sector 1, the exporting sector, (all other rows) while dashed lines refer to sector 2, the import-competing sector.

import-competing sector faces a relatively larger decline in demand. Relative demand and the relative price of the two sectors switch in favor of the exporting sector.

Naturally, the shift in relative demand has implications for the allocation of production factors. The drop in aggregate productivity reduces firm profits and thus investment in new firms. As a consequence, the number of firms goes down in both sectors, but it goes down much more in the import-competing sector due to the enhanced specialization of production in the exporting sector.

Labor inputs are similarly affected. Because of reduced productivity, demand for labor in the whole economy goes down. However, since relative product demand shifts towards the exporting sector, the demand for labor in the exporting sector goes down relatively less than the demand for labor in the import competing sector. The general decline in labor demand is reflected in a decrease in the hours worked per worker, while the shift in relative labor demand across sectors is reflected in the (free) movement of workers from the import-competing sector to the exporting sector. The full mobility of workers arbitrages away any sector differences in hours worked and wages.

As production factors and production shift more and more towards the exporting sector, the trend in prices is reversed so that the terms of trade decrease and the relative price of the import competing sector increases. The sector shifts in production factors and production peak and then slowly recede, converging back to the old steady state levels.

Figure 3 also shows that the hours worked go down more for unskilled workers than for skilled workers.¹⁵ In our model this is explained by the distribution of profits from the mutual fund. In response to the negative productivity shock, the mutual fund reduces investments in new firms, and therefore can redistribute more profits to the households, even though firm profits actually go down. Thus, the transfers of the mutual fund are counter-cyclical and stabilize consumption. The cyclicity of consumption is important for the cyclicity of the labor supply because labor supply is determined by both the real wage and the marginal utility from consumption (see equation 6). Due to the stabilizing effects of the mutual fund, consumption goes down by less, the marginal utility from consumption goes up by less, and thus labor supply goes down by more.

For unskilled workers the stabilizing effect of the mutual fund is more important, because unskilled workers have a lower wage income and thus the transfers of the mutual fund make up a bigger portion of their income. The marginal utility from consumption increases by less for unskilled than for skilled workers and therefore they reduce their labor supply more in response to the drop in the real wage.¹⁶

competing sector than in the exporting sector.

¹⁵This is in line with the data. We calculated measures of hours worked by high-skilled and low-skilled workers based on data provided by the “WORLD KLEMS consortium” for the period 1960-2010. The standard deviation of the HP filtered series for hours worked is 0.009 for low-skilled workers and 0.006 for high-skilled workers (HP filtering parameter $\lambda = 100$). Both series appear to be pro-cyclical. More details are available upon request.

¹⁶In the robustness section we discuss the case when the mutual fund distributes its profits only to the skilled households, based on the argument that it is primarily richer households that participate in capital markets. In that case the labor supply of unskilled workers is acyclical because their consumption is very responsive to productivity shocks, which is in contrast to what is found in the data. Aggregate dynamics remain unaltered.

5.1.2 Immobile workers

In the discussion so far we have assumed that workers are freely mobile across sectors. While we provide empirical evidence in the robustness section that workers move across sectors in line with the patterns predicted by our model, we also show that the movements of workers across sectors are relatively small. Thus, in order to further our understanding of the role of worker mobility we assume here the opposite extreme case of full worker immobility. Figure 4 shows the results. The impulse responses under perfect mobility of workers are still shown in the graphs as a reference point. The blue lines show the scenario under mobile workers and the red lines the scenario under immobile workers.

Figure 4 reveals that worker mobility is critical for the magnitude of the response to productivity shocks. Workers can no longer move across sectors, but in principle the intensive margin of labor supply, hours worked, can be used to compensate for the immobility of workers. However, this adjustment mechanism is more costly, because households prefer equal hours worked across its members. Thus this adjustment mechanism is used relatively little, implying a significantly reduced specialization pattern compared to the case of free worker mobility.¹⁷

The import-competing sector still contracts by more than the exporting sector but the difference is small. Although the mobility of firms is unchanged, this reduced specialization pattern is carried over to the number of firms. The reason is that the reduced movement of workers across sectors increases the entry cost in the exporting sector relative to the import-competing sector, since the entry cost depends on the wages in a given sector. This reduces the incentives of new firms to enter the exporting sector even though profits there are still higher than in the import-competing sector.

Note, however, that the shift in relative demand is still in place. It is still the case that the terms of trade increase and that the demand for the import-competing sector good is reduced by more than the demand for the exporting sector good. Since supply cannot keep track of the shift in relative demand, relative prices must react much more. This is reflected in the relative price of the exporting sector and the import-competing sector, which not only increases by much more on impact than in the model with full worker mobility, but is also much more persistent.

This has important implications for revenue, which, in contrast to production, is based on market prices. The shift in relative prices towards the exporting sector, pushes up the revenues in the exporting sector relative to the import-competing sector. So the specialization pattern in sector revenue is much stronger than the specialization pattern in sector output. Comparing revenue across the two scenarios with and without worker mobility reveals that the weakened response in relative production combined with the stronger shift in relative prices under worker immobility leads to a smaller reduction in the revenue of the import-competing sector, while the reduction in the revenue of the exporting sector is about the same. Thus in a sense the shift in

¹⁷The reduced specialization pattern is not solely due to households trying to smooth labor supply across sectors. This is demonstrated in the robustness section where we discuss the case of separate households for both sectors.

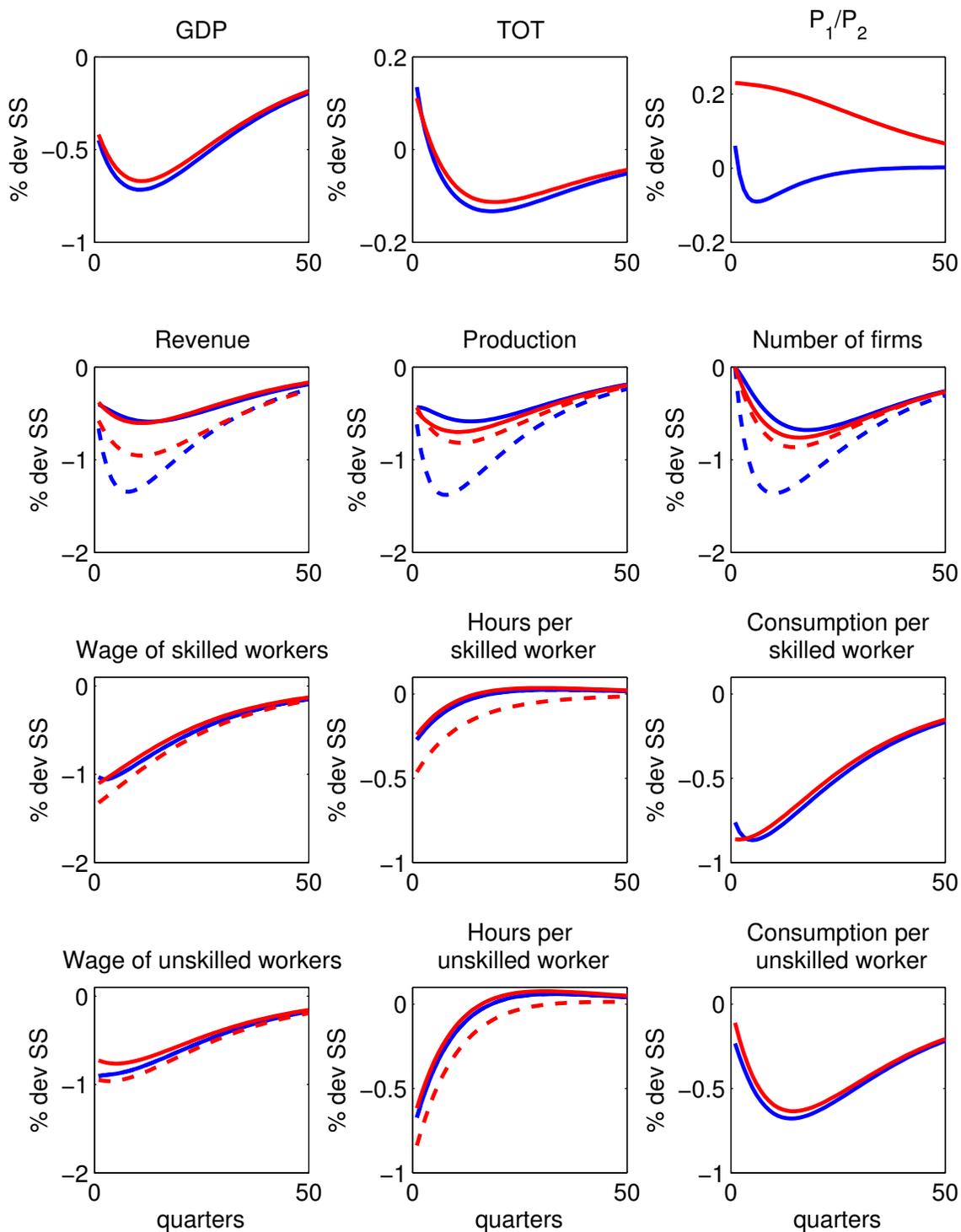


Figure 4: Immobility of workers.

Impulse responses to a decline in domestic aggregate productivity. Variables are measured in %-deviations from steady state. Blue lines refer to full mobility and red lines refer to no mobility. Solid lines either refer to aggregate variables (first row) or sector 1, (all other rows) while dashed lines refer to sector 2.

relative prices under worker immobility helps to stabilize revenue. This is what explains the lower response of GDP to domestic productivity shocks in the specification without worker mobility.

To summarize, we find that the exporting sector and the import-competing sector respond differently to shocks in aggregate productivity due to shifts in relative prices (both international and across sectors). In a sense negative productivity shocks lead to a temporary strengthening of sector specialization, because exporting sectors contract by less. This is in line with our empirical analysis which yielded the exact same result. The strength of the specialization pattern depends importantly on the mobility of workers across sectors. If workers are completely immobile, the specialization pattern in sector output is significantly reduced. Our empirical analysis yields quantitatively important differences across exporting and import-competing sectors. Thus the specification with mobile workers yields results more in line with the US data. It remains for future research whether the same holds true for more inflexible European economies.

5.1.3 Inequality

One of the advantages of our model, in deviating from the standard representative household framework, is that it allows us to discuss inequality across various margins. Figure 5 shows the development of wage and income differences across sectors, across skill classes and in the whole economy both for the scenario with mobile workers and the one with immobile workers. For a precise definition of these inequality measures, see the Appendix.

Note that sectoral wage differences only arise in the scenario with immobile workers. The shift in relative demand for both sectors that follows a decrease in aggregate productivity, raises the relative demand for labor in the exporting sector. If workers are immobile this is reflected in an increase in the wage of the exporting sector relative to the import-competing sector. If workers are mobile this is reflected in the movement of workers from the import-competing sector to exporting sector that arbitrages away the sectoral wage differential.

The aggregate productivity shock also has consequences for the wage inequality between skilled workers and unskilled workers. As explained above, the drop in aggregate productivity leads to a shift in relative demand from the import-competing sector to the exporting sector. Since the exporting sector is skill-intensive this also implies relatively more demand for skilled workers than for unskilled workers.¹⁸ As a consequence the share of total wage income (the wage times hours worked) that goes to skilled workers increases temporarily. Note, however, that there is a large difference between the effect under worker mobility and worker immobility. To fully exploit the shift in relative demand towards skilled workers, the sector input shares of skilled and unskilled labor need to adjust, which can be achieved more easily under worker mobility. With immobile workers the potential cannot be exploited fully and the relative income of skilled workers increases only little compared to the mobility case.

¹⁸The demand for skilled workers goes down but it goes down relatively less than for unskilled workers, so that the relative demand for skilled workers increases.

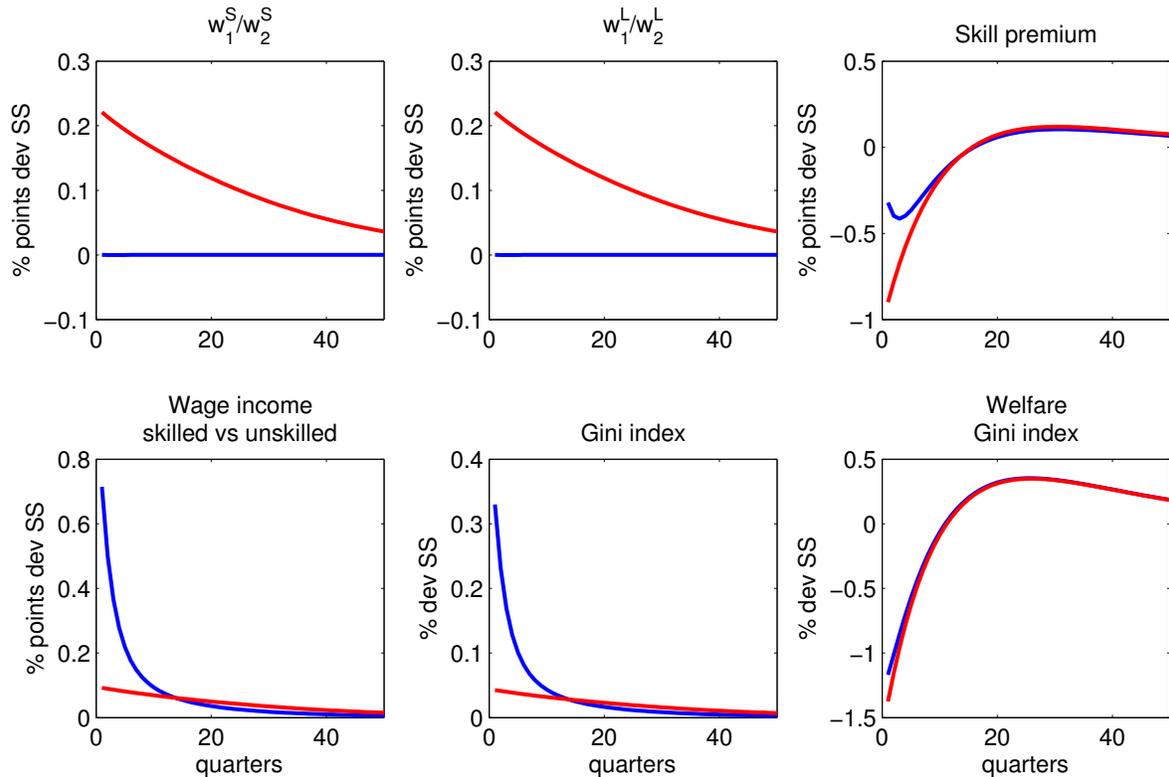


Figure 5: Inequality.

Impulse responses to a decline in domestic aggregate productivity. Blue lines refer to full mobility and red lines refer to no mobility.

Figure 5 also reports the skill premium. The skill premium goes down which seems to contradict the argument above. Note, however, that this can be explained by the stronger reduction in hours worked of unskilled workers. This has the effect of making unskilled workers relatively scarcer and that pushes down the skill premium. Note that the effect is much larger when workers are immobile. Again this is explained by the fact that worker mobility is necessary to exploit the shift in relative labor demand.

These developments are reflected in overall wage inequality measured by the Gini coefficient, which is based on the deviation of income from a totally equal distribution. The Gini coefficient goes up in both scenarios, but does so much more in the scenario with mobile workers. Overall wage inequality is largely driven by the relative income of skilled and unskilled workers. The increase in sectoral wage inequality under worker immobility only plays a minor role for overall wage inequality.

Let us stress again, that this increase in wage inequality is driven to a large extent by the different responses of skilled and unskilled workers: Unskilled workers reduce their labor supply by more than skilled workers. This reduces their income by more and wage inequality goes up. Since in return to this unskilled workers can enjoy more leisure, wage inequality is only an imperfect measure of welfare inequality in this setting. To this end figure 5 also shows a Gini of 'utility inequality' that is constructed in the exact same way as the income Gini, but based on the total period utility of a worker rather than just his income. This makes a large difference, the inequality

of utility actually goes down in response to the aggregate productivity shock reflecting the larger increase in leisure for unskilled workers.

5.2 Productivity shocks at Foreign

Figure 6 shows the effects of a temporary productivity shock at Foreign for the economy at Home. The figure shows that international spillovers also depend importantly on worker mobility. If workers are immobile, then the international spillovers are much larger. The reason for the larger spillover effect lies in the shift in the relative price between the exporting sector and the import-competing sector, which, not surprisingly, moves in the exact opposite direction to that of the domestic productivity shock. The terms of trade of Home go down because Home's imports (which are Foreign's exports) are produced less efficiently and thus become relatively more expensive. Since Home's import-competing sector depends less on foreign demand its price goes up relative to the exporting sector. Again this development is much more persistent when workers are immobile across sectors.

The shift in relative demand and relative prices raises revenue in the import-competing sector and lowers revenue in the exporting sector. If workers are mobile this implies a movement of workers from the exporting sector to the import-competing sector that reduces the decline in GDP relative to the case where workers are immobile. If workers are immobile across sectors, this adjustment is hindered, the expansion in the import-competing sector is subdued and as a consequence GDP drops by more relative to the case where workers are mobile.

Finally, figure 6 reports some measures of inequality. These develop in the opposite direction compared to the domestic shock. The shift in relative demand towards the import-competing sector implies that wages in the import-competing sector go up relative to those in the exporting sector (if workers are immobile), and that the demand for unskilled workers rises. This implies that the skill premium and the relative wage income that goes to skilled workers (not depicted) decrease. Overall wage inequality is largely driven by the inequality between skilled and unskilled workers and therefore decreases, even though inter-sector inequality increases. Since in response to the foreign productivity shock hours worked respond relatively little, our welfare-Gini coefficient moves similarly to the income-Gini coefficient.

5.3 Business cycle statistics

This section presents business cycle statistics of our model in response to aggregate productivity shocks and discusses the importance of inter-industry trade and trade costs. In order to do so we compare the two specifications of the model discussed above with the same model under autarky, and with a one-sector version of the model (basically the GM-model without firm heterogeneity).¹⁹

¹⁹The size of the one-sector model is calibrated in such a way that its steady state GDP is the same as Home's steady state GDP in the two-sector model under trade. The autarky version of the two-sector model uses the same calibration as the trade version, with the only difference of prohibitively high trade costs, which implies a lower

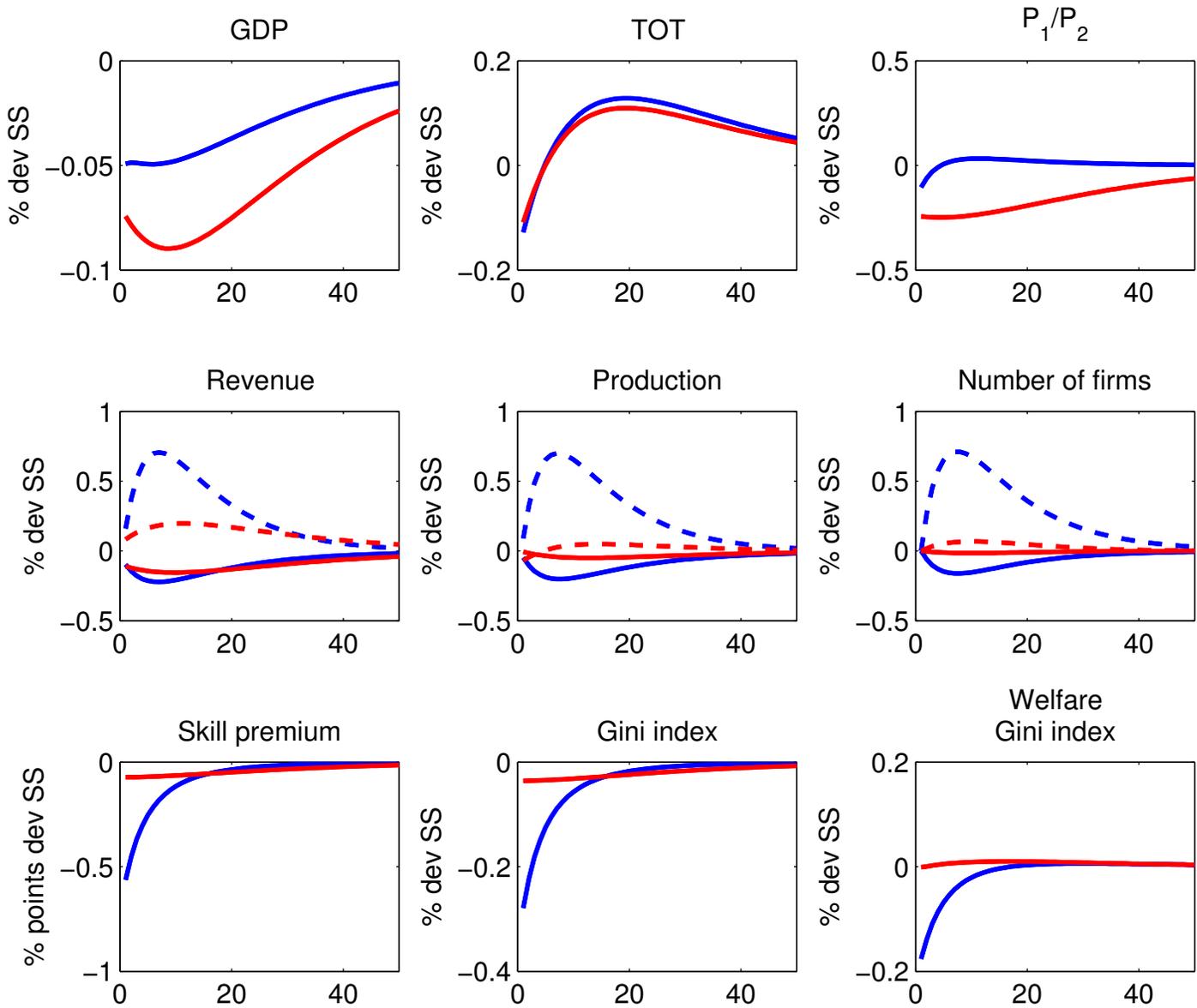


Figure 6: Foreign productivity shock.

Impulse responses to a decline in foreign aggregate productivity. Variables are measured in %-deviations from steady state. Blue lines refer to full mobility and red lines refer to no mobility. Solid lines either refer to aggregate variables (first and third row) or sector 1, (second row) while dashed lines refer to sector 2.

The latter model represents the standard approach in international macro which neglects the role of inter-industry trade. To concentrate on the endogenous mechanisms of the model we assume that there are no cross-country spillovers in technology and that the technology shocks of the two countries are not correlated with each other. We use the same shock distribution as specified above.

Table 2: Business cycle statistics.

FM: model with full worker mobility; NM: model without worker mobility.

	GDP	P_1/P_2	H_1^S	H_2^S	H_1^L	H_2^L	y_1	y_2	$Gini$ <i>index</i>	$Avg.$ <i>utility</i>	GDP/GDP^*
2 sectors	Relative standard deviation										Correlation
FM, trade	3.73	0.34	0.55	0.55	1.37	1.37	3.3	6.66	0.69	1.56	0.14
	Relative standard deviation										
2 sectors	3.93	0.2	0.59	0.59	1.3	1.3	3.89	4.01	0.11	1.69	
FM, autarky	Relative standard deviation relative to benchmark										
	1.05	0.59	1.08	1.08	0.95	0.95	1.18	0.6	0.17	1.09	
	Relative standard deviation										Correlation
2 sectors	3.51	1.72	0.51	1.37	1.26	1.96	3.68	4.17	0.25	1.48	0.3
NM, trade	Relative standard deviation relative to benchmark										
	0.94	5.03	0.93	2.48	0.92	1.43	1.12	0.63	0.36	0.95	
	Relative standard deviation										Correlation
1 sectors	3.71									1.08	0.13
trade	Relative standard deviation relative to benchmark										
	0.99									0.7	

Table 2 illustrates the results. Several features stand out. First, international trade reduces GDP volatility. Although international trade exposes an economy to foreign shocks, in all models simulated the reduced responsiveness to domestic shocks more than compensates for this. The reduced volatility in GDP also translates into reduced volatility in average utility (the weighted average of the utility of both households).

Second, as already suggested above, the mobility of workers is very important in the two-sector model. Worker immobility reduces sectoral shifts in production and implies stronger movements in the relative price of both sectors goods. As we have seen, this implies lower responsiveness of GDP to domestic shocks but larger responsiveness to foreign shocks. This has two important implications for GDP volatility. On the one hand, worker immobility reduces the volatility of GDP, on the other hand it increases the correlation between GDP in both countries. Note, however, that the reduced volatility in GDP comes at the cost of a large divergence in the hours worked across the two sectors (while households would prefer perfect comovement). This effect somewhat diminishes the effect of reduced volatility in GDP on the volatility of utility, but the latter is still substantially lower under worker immobility.

steady state GDP.

Third, looking at GDP the distinction between inter-industry trade and intra-industry trade only seems to matter in the case of worker immobility. Under worker mobility the volatility of GDP and the cross-country correlation of GDP is virtually the same in the one-sector model and the two-sector model. In both cases the cross-country correlation of GDP is around 0.13.²⁰ However, there are still two notable and large differences between the two-sector model and the one-sector model. First, utility is substantially more volatile in the two-sector model. This result is explained by the structure of both models. The two-sector model features large differences in the response of the intensive margin of skilled and unskilled workers which by construction cannot emerge in the one-sector model. Second, inequality fluctuates in the two-sector model, which cannot happen in the one-sector model due to the representative household assumption.

Fourth, in the two-sector model there is large heterogeneity across the two sectors and in how much they are affected by the possibility to trade internationally. Under autarky the volatility of both sectors is basically the same. That is because under autarky there is no possibility to specialize or de-specialize in response to shocks. Therefore, both sectors move in unison in response to aggregate shocks. This is different under international trade. As we have seen above, under trade the exporting sector contracts much less than the import-competing sector in response to domestic shocks. The exporting sector is more exposed to foreign shocks, but this is more than offset by the lower vulnerability in response to domestic shocks. As a result the volatility of the exporting sector is reduced by the possibility to trade, while the volatility of the import-competing sector is increased. This results in a large difference of the relative standard deviations of both sectors, with the one of the import-competing sector being about twice as high as the one of the exporting sector in the full-mobility model.

Finally, there is very large divergence in the volatility of inequality. As discussed above, international trade is necessary for sectoral shifts in production in response to productivity shocks. These sectoral shifts do not only reduce the volatility of GDP they also bring along shifts in inequality. Thus in the trade versions of the two-sector model the volatility of the Gini is much higher than in the autarky version of the same model. Again worker mobility plays an important role. The volatility of the Gini in the model with immobile workers is only about one third of its volatility in the model with mobile workers. Again this is so because worker mobility allows to take full advantage of the shifts in relative demand. Thus, our model predicts substantial changes in the dynamics of inequality over the business cycle, no matter how mobile workers are across sectors.

Naturally, the openness to trade plays a crucial role in determining business cycle comovement. To further highlight this, figure 7 shows the volatility of GDP at Home and the correlation between the GDP of both countries for different levels of iceberg trade costs, which are the most

²⁰Backus et al. [1992] point out the inability of standard RBC models to generate positive cross-country correlation of GDP. GM show that a one sector model with intra-industry trade resolves this puzzle and implies positive comovement across countries. Our results indicate that the two-sector model with inter-industry trade is able to generate a cross-country correlation very similar to the one-sector model, and potentially even a larger one.

prominent measure of openness to trade in theoretical trade models. The figure compares our two specifications of the two-sector model and the one-sector model.

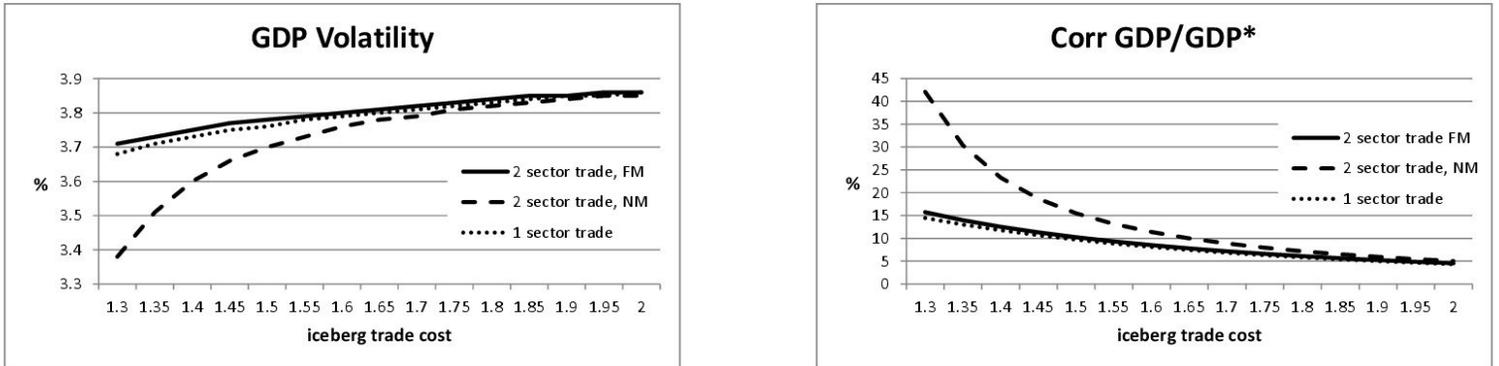


Figure 7: Effect of trade costs on volatility and correlation: 2 sector model vs. 1 sector model

Figure 7 reveals that for all models, higher openness to trade generally leads to lower GDP volatility and larger business cycle comovement across the two countries. However, the magnitude of these effects rises much faster for the two-sector model without worker mobility, whereas the two-sector model with worker mobility is always very close to the one-sector model.

6 Robustness

In this section we present a number of robustness checks to further highlight certain aspects of the model. In our discussion so far we used the model with full mobility of workers as benchmark because that version of the model is closer to the results of our empirical analysis than the model with immobility of workers. In this section, we first present a simple extension of our model to allow for costly worker mobility. In the following we discuss the role of firm entry, of firm heterogeneity, of firm ownership, of the Frisch elasticity of labor supply, of the intertemporal elasticity of substitution and of the household structure. Table 3 reports selected business cycle statistics for the variety of models that we compare to our benchmark. For each model we report the relative standard deviation of the variable relative to our benchmark as well as the cross-country correlation of GDP. In the Appendix we also provide a table reporting standard deviations (not relative to the benchmark).

6.1 A model with costly worker mobility

So far we have discussed two polar cases concerning the mobility of workers across sectors. In this section we present a simple extension of the model that allows for the modelling of costly worker

mobility. We calibrate the movement cost based on empirical estimates using the same data as in section 2.

As in Dix-Carneiro [2014] we model the movement cost in terms of utility which has the advantage that it is not traded in the market. The utility function for skilled workers changes to:

$$E_t \left\{ \sum_{k=0}^{\infty} \gamma^k \left[\frac{(C_{t+k}^S)^{1-\sigma}}{1-\sigma} S - \sum_{i=1,2} \frac{(H_{it+k}^S)^{1+\nu}}{1+\nu} S_{it} - \frac{\nu}{2} (M_t^S)^2 \right] \right\},$$

with the two additional laws of motion:

$$\begin{aligned} S_{1t} &= S_{1t-1} + M_t^S \\ S_{2t} &= S_{2t-1} - M_t^S, \end{aligned} \tag{26}$$

where M_t^S is the number of workers moving from sector 2 to sector 1 and ν is a parameter determining the size of the movement cost. In steady state M_t^S is zero and no movement cost has to be paid. Out of steady state the convexity of the movement cost implies that the adjustment of workers across sectors is smoothed out over time. The first order condition associated with the choice of M_t^S is

$$\nu M_t^S = \mu_{1t}^S - \mu_{2t}^S,$$

where μ_{it}^s is the shadow value of a skilled worker in sector i . An identical problem holds for the unskilled household.

To calibrate the parameter ν we first estimate how strongly the employment in import-competing sectors and exporting sectors responds to shocks in domestic aggregate productivity. We use the same data and a similar approach as in section 2 (for more details see the appendix). In line with previous results, we find that the share of workers employed in exporting sectors increases in response to negative shocks to domestic aggregate productivity, while the share of workers employed in import-competing sectors decreases. Thus workers temporarily move from import-competing sectors to exporting sectors. Note, however, the movement is relatively mild, the share of workers in the exporting sectors only increases by 0.4%.

We choose the parameter ν to match this pattern. Choosing $\nu = 0.014$ implies that the share of workers in the import-competing sector decreases by 0.4% during the first year after the shock hits. Results are illustrated in the first row of table 3. As expected the results of the model with costly mobility lie in between the model with free worker mobility and the model without worker mobility. However, although the movement of workers across sectors is relatively small, the results look remarkably similar to the model with free mobility of workers. For example, the volatility of GDP is reduced only by 1%. The largest difference is in terms of inequality. The volatility of the Gini coefficient is cut by half and thus closer to the model without worker

mobility. It is important to note that under costly mobility the sectoral specialization pattern is still intact. Thus, we conclude that the results of the model with full mobility are largely robust to the introduction of mobility costs.

Table 3: Model comparison

	Relative standard deviation relative to benchmark										Correlation
	GDP	P_1/P_2	H_1^S	H_2^S	H_1^L	H_2^L	y_1	y_2	$Gini$ <i>index</i>	$Avg.$ <i>utility</i>	GDP/GDP^*
Model with costly worker mobility	0.99	1.47	0.98	1.17	0.95	1.15	1.04	0.84	0.5	1	0.16
Model with no firm entry	0.87	2.09	0.33	0.33	0.32	0.32	0.97	0.64	0.29	1.1	0.24
Model with heterogeneous firms	1.02	0.83	1.02	1.02	0.97	0.97	1.03	0.8	0.75	1.04	0.08
Model where only skilled workers own firms	0.93	1.07	2.02	2.02	0	0	1.06	0.61	0.36	1.21	0.13
Model where skilled workers own larger share of firms	1	0.56	1.87	1.87	0.76	0.76	1.04	0.83	0.5	1.03	0.14
Model with Frisch elasticity of 2	1.07	1.44	1.66	1.66	1.64	1.64	1.06	1.19	1.43	1.2	0.14
Model with intertemporal substitution elasticity of 2	0.64	1.41	2.02	2.02	0.93	0.93	0.59	1.44	1.16	1.29	0.1
Model with sector specific households	0.91	7.72	1	1.04	0.98	1.02	1.16	0.53	0.14	0.86	0.39

6.2 The role of firm entry and firm heterogeneity

Our baseline model features endogenous firm entry, but not firm heterogeneity. Table 3 provides selected business cycle statistics for equivalent versions of the model with i) an exogenous number of firms (row 2) and ii) firm heterogeneity additionally to endogenous firm entry as in GM (row 3).

The flexibility of firm adjustment is very important for the degree of sectoral specialization and with it for the volatility of GDP and inequality. In the scenario without firm entry, the number of firms in each sector cannot react to shocks and thus the reallocation of production is

hampered, and, consequently, the volatility of the import-competing sector (which is generally more responsive to domestic shocks) is considerably reduced. More of the adjustment to the shock is in terms of prices rather than quantities, so that the relative price across sectors is twice as volatile as in the baseline model. In line with our discussion above this reduces the volatility of GDP and inequality, and increases the correlation of GDP across the two countries.

Endogenous firm heterogeneity instead allows for more flexibility because the share of exporting firms and thus the average productivity of exporting firms can adjust in response to shocks. As a result, the volatility of the relative sector-price is reduced, the volatility of GDP is increased and the correlation of GDP across the two countries is reduced.

6.3 The role of firm ownership

For our baseline model we have assumed that firm ownership is spread equally across all workers. This assumption has the implication that the total income of unskilled workers is relatively more stable than the total income of skilled workers because the transfers from the mutual fund are countercyclical and make up a larger share of unskilled workers income. This assumption might be criticized on the ground that skilled workers are typically more active in capital markets. Therefore, this section provides two alternative specifications with respect to the assumption of firm ownership.

In the first alternative we assume that it is only the skilled workers that participate in the capital market, i.e., only skilled workers hold shares in the mutual funds and, thus, indirect ownership in the firms. As demonstrated by row 4 in table 3, this has huge implications for the volatility of hours worked. Most notably, the hours worked by unskilled workers are constant. This is the case because wage income is now the only source of income for unskilled workers and thus consumption moves in unison with the wage. Under our specification of preferences (with unit elasticity of labor supply and unit elasticity of intertemporal substitution), the decrease in the wage is fully compensated by an increase in the marginal utility from consumption (see equation 6), so that unskilled workers do not have an incentive to adjust their labor supply. This is in contrast with the data that shows large variability in hours worked for unskilled workers (see footnote 15). We thus reject this alternative as unrealistic.

In the second alternative we use a middle-road in between the approaches used so far by assuming that skilled workers own a larger share of the mutual fund than unskilled workers, but that they do not own it exclusively. More specifically, we assume that the share of ownership of a household in the mutual fund corresponds to the share of wage income of the household in total wage income. This choice is motivated by the idea that a higher wage income allows for larger investments in capital markets. Results are shown in row 5 in table 3. Compared to our baseline, the larger ownership of firms by skilled workers, coupled with countercyclical transfers from the fund, implies more stable total income for skilled workers. As a result their consumption, and with it their marginal utility from consumption, fluctuates by less. This makes the labor supply

more dependent on the wage, which increases the incentives to adjust the labor supply in response to shocks. For unskilled workers the exact opposite holds, so that the hours worked become less volatile relative to the baseline. In this scenario the volatility of hours worked is very similar for skilled and unskilled workers, but still slightly more volatile for unskilled workers which is in line with the data (see footnote 15).

This changed behavior in relative labor supply works to stabilize the output of the import-competing sector relative to the baseline but it is still the case that the import competing sector is more volatile than the exporting sector. The effects for GDP are only minor, both the volatility of GDP and the correlation of GDP across countries is virtually unchanged. However, the consequences for inequality are quite substantial. The volatility of the Gini is cut by half, because the income of unskilled workers is less volatile.

6.4 The role of preferences

For our baseline we have assumed that the elasticity of intertemporal substitution and the Frisch elasticity of labor supply are both equal to 1. Here we provide robustness with respect to both elasticities, assuming that they take the value 2 instead of 1, implying $\sigma = 2$ and $\nu = 0.5$. Rows 6 and 7 in table 3 illustrate the results. As seen from equation 6, a decrease in ν makes labor supply more responsive to changes in the wage. This implies that hours worked of both skilled and unskilled workers become more volatile relative to the baseline, which translates into more volatile GDP and inequality. The correlation of GDP across countries does not change by much.

The increase in σ makes fluctuations in consumption more relevant for the intensive margin of labor supply. Since the consumption of skilled workers fluctuates relatively more than the consumption of unskilled workers, the change in σ matters more for the hours worked of skilled workers which become considerably more volatile. The increased flexibility of the intensive margin of labor supply enhances the scope for (de-)specialization in response to productivity shocks with the result that the import-competing sector becomes more volatile while the exporting sector becomes less volatile. The stabilizing effect of potential shifts in the production structure is increased so that the volatility of GDP drops by one third.

The reduced volatility in GDP translates into a reduced volatility of consumption, which explains why the volatility of the hours worked by unskilled workers actually decreases. On the one hand, the increase in σ raises the responsiveness of hours worked to changes in consumption. On the other hand, consumption becomes less volatile. For unskilled workers the second effect dominates, so that hours worked become less volatile, too.

6.5 Four households

In section 5.1.1 we have argued that the intensive margin of labor supply could be used to compensate for limited mobility at the extensive margin, but that this option is not used much because

the households prefer hours worked to not differ too much across sectors. This poses the question how the model would react in the case of separate households for both sectors. This assumption is not feasible for the model under worker mobility because then workers that switch sectors would also switch families (with different endowments), but it is feasible if workers are immobile across sectors.

Thus in the section we discuss the situation of four separate households, one for skilled workers in the exporting sector, one for skilled workers in the import-competing sector and the same for unskilled workers. Row 8 in table 3 shows the results. Instead of stronger usage of the intensive margin of labor supply, it is actually used less. The reason is that the split household structure offers less insurance against wage differentials across sectors. As a consequence, consumption is driven more by changes in wages, reducing the incentives to adjust hours worked (because marginal utility of consumption and wages exhibit strong co-movement). This leads to volatilities in hours worked that are actually closer to the model under full mobility than to the model under immobility.

Thus in the four-household structure not only is the extensive margin of labor supply shut off, but also the adjustment along the intensive margin reduced. Consequently, the movements in the relative price of both sectors are enhanced. This brings along enhanced stabilization of GDP and an enhanced correlation of GDP across the two countries.

7 Conclusion

Motivated by the sharply rising trade between developed and developing countries over the last two decades, we analyze how the structure of trade, inter-industry vs. intra-industry trade, affects business cycle fluctuations. We start out by showing empirically that import-competing sectors react more strongly to domestic shocks than exporting sectors. We proceed by building a DSGE model which features inter-industry as well as intra-industry trade. It is a model with two countries, two sectors and two factors of production, skilled and unskilled workers. The industrialized country has a relatively larger endowment of skilled workers and thus a comparative advantage in the skill-intensive sector. The model also features an intensive margin of labor supply (hours per worker) that can be adjusted at business cycle frequency as in most models of international macro.

We find that the mobility of factors across sectors in general, and the mobility of workers in particular, matters a lot for the effects that the change in the structure of trade might have on business cycles in developed countries. We have shown that in response to negative domestic productivity shocks relative demand shifts from the import-competing sectors to the exporting sectors. The economy can react to this shift in two different ways. If production factors are mobile, they will move temporarily to the exporting sector, thus, enhancing the specialization pattern. If production factors are immobile, the relative price of both sectors will shift very

persistently in favor of the exporting sector.

The implications for aggregate fluctuations are very different in both cases. If production factors are mobile, the aggregate outcomes of the two-sector model look a lot like the aggregate outcomes of a one-sector model. If production factors are immobile, the two-sector model shows considerably lower GDP volatility and a larger correlation of GDP across countries.

Thus our analysis suggests different reactions of economies depending on how mobile production factors are across countries. Our analysis has focused on the US economy which is well known for its flexibility. It remains for future research to explore more deeply the effects in more rigid economies like those in Europe.

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Appendix A Measures for wage inequality

In order to analyze the effect of the business cycle on various sources of inequality, we define a number of wage inequality measures. First, we define two measures of wage inequality across sectors. They measure the relative percentage difference across sectoral wages for skilled and unskilled workers

$$\begin{aligned} IndexS_t &= \left(\frac{w_{1t}^S}{w_{2t}^S} - 1 \right) 100, \\ IndexL_t &= \left(\frac{w_{1t}^L}{w_{2t}^L} - 1 \right) 100. \end{aligned}$$

Note that these indices are zero at the steady state, due to long run mobility across sectors. However, they might be different from zero out of the steady state. It is one of the advantages of our dynamic model that it can capture these temporary increases in inequality.

To measure wage inequality across the skill classes we define a skill premium for each sector and an average skill premium. The skill premium for sector i is defined as the percentage difference between the wage of skilled and unskilled workers

$$Skill_{it} = \left(\frac{w_{it}^S}{w_{it}^L} - 1 \right) 100.$$

To define the average skill premium for each country, we use the average wage of skilled workers, $w_t^S = \frac{S_{1t}}{S} w_{1t}^S + \frac{S_{2t}}{S} w_{2t}^S$, and the average wage of unskilled workers, $w_t^L = \frac{L_{1t}}{L} w_{1t}^L + \frac{L_{2t}}{L} w_{2t}^L$ to obtain

$$Skill_t = \left(\frac{w_t^S}{w_t^L} - 1 \right) 100.$$

Note that the average wage in country H is $w_t = \frac{S_{1t}}{S+L} w_{1t}^S + \frac{S_{2t}}{S+L} w_{2t}^S + \frac{L_{1t}}{S+L} w_{1t}^L + \frac{L_{2t}}{S+L} w_{2t}^L$. Note also that the above measures of the skill premium are based on hourly wages. However, to capture what happens to income inequality we can define the skill premium based on wage income:

$$Skill_{it}^I = \left(\frac{w_{it}^S H_{it}^S}{w_{it}^L H_{it}^L} - 1 \right) 100. \quad (27)$$

For the average skilled premium, we define the average wage income for skilled workers as $w_t^{IS} = \frac{S_{1t}}{S} w_{1t}^S H_{1t}^S + \frac{S_{2t}}{S} w_{2t}^S H_{2t}^S$, and for unskilled workers $w_t^{IL} = \frac{L_{1t}}{L} w_{1t}^L H_{1t}^L + \frac{L_{2t}}{L} w_{2t}^L H_{2t}^L$, to get:

$$Skill_t^I = \left(\frac{w_t^{IS}}{w_t^{IL}} - 1 \right) 100. \quad (28)$$

Finally, we measure aggregate wage inequality for each country by constructing a theoretical Gini index, which is a standard measure of inequality. The Gini index measures the extent to which the distribution of wages among the different groups of workers within each country deviates from

a perfectly equal distribution. A Gini index of 0 means perfect equality, while an index of 1 means perfect inequality. The Gini coefficient is defined as half the relative mean difference of a wage distribution. The Gini coefficient for country H is based on wage income with the average wage income $w_t^I = \frac{S_{1t}}{S+L}w_{1t}^S H_{1t}^S + \frac{S_{2t}}{S+L}w_{2t}^S H_{2t}^S + \frac{L_{1t}}{S+L}w_{1t}^L H_{1t}^L + \frac{L_{2t}}{S+L}w_{2t}^L H_{2t}^L$:

$$\begin{aligned} Gini_t &= \frac{1}{2w_t^I} \frac{1}{(S+L)^2} (2S_{1t}S_{2t} |w_{1t}^S H_{1t}^S - w_{2t}^S H_{2t}^S| + 2L_{1t}L_{2t} |w_{1t}^L H_{1t}^L - w_{2t}^L H_{2t}^L| \\ &+ 2S_{1t}L_{1t} |w_{1t}^S H_{1t}^S - w_{1t}^L H_{1t}^L| + 2S_{2t}L_{2t} |w_{2t}^S H_{2t}^S - w_{2t}^L H_{2t}^L| + 2S_{1t}L_{2t} |w_{1t}^S H_{1t}^S - w_{2t}^L H_{2t}^L| \\ &+ 2S_{2t}L_{1t} |w_{2t}^S H_{2t}^S - w_{1t}^L H_{1t}^L|). \end{aligned}$$

Finally, we define a Gini index that captures welfare inequality, based on the period utility functions of workers defined as $u_{it}^S = \log(C_t^S) - H_{it}^{S(1+v)}/(1+v)$ and $u_{it}^L = \log(C_t^L) - H_{it}^{L(1+v)}/(1+v)$ for skilled and unskilled workers, respectively. The average utility per worker is $u_t = \frac{S_{1t}}{S+L}u_{1t}^S + \frac{S_{2t}}{S+L}u_{2t}^S + \frac{L_{1t}}{S+L}u_{1t}^L + \frac{L_{2t}}{S+L}u_{2t}^L$. We define the welfare Gini as:

$$\begin{aligned} Gini_t^W &= \frac{1}{2u_t} \frac{1}{(S+L)^2} (2S_{1t}S_{2t} |u_{1t}^S - u_{2t}^S| + 2L_{1t}L_{2t} |u_{1t}^L - u_{2t}^L| \\ &+ 2S_{1t}L_{1t} |u_{1t}^S - u_{1t}^L| + 2S_{2t}L_{2t} |u_{2t}^S - u_{2t}^L| + 2S_{1t}L_{2t} |u_{1t}^S - u_{2t}^L| + 2S_{2t}L_{1t} |u_{2t}^S - u_{1t}^L|). \end{aligned}$$

Appendix B Robustness

Robustness table with statistics not relative to benchmark

Table 4: Model comparison

	Relative standard deviation										Correlation
	GDP	P_1/P_2	H_1^S	H_2^S	H_1^L	H_2^L	y_1	y_2	$Gini$ <i>index</i>	$Avg.$ <i>utility</i>	GDP/GDP^*
Model with costly worker mobility	3.69	0.5	0.54	0.64	1.31	1.58	3.42	5.56	0.34	1.56	0.16
Model with no firm entry	3.25	0.71	0.18	0.18	0.43	0.43	3.21	4.23	0.2	1.71	0.24
Model with heterogeneous firms	3.82	0.28	0.56	0.56	1.33	1.33	3.41	5.32	0.51	1.62	0.08
Model where only skilled workers own firms	3.48	0.37	1.11	1.11	0	0	3.51	4.08	0.24	1.89	0.13
Model where skilled workers own larger share of firms	3.72	0.19	1.03	1.03	1.04	1.04	3.42	5.55	0.34	1.6	0.14
Model with Frisch elasticity of 2	4	0.49	0.92	0.92	2.25	2.25	3.48	7.91	0.98	1.87	0.14
Model with intertemporal substitution elasticity of 2	2.39	0.48	1.11	1.11	1.28	1.28	1.94	9.56	0.79	2.01	0.1
Model with sector-specific households	3.41	2.63	0.55	0.57	1.35	1.39	3.84	3.55	0.1	1.35	0.39

Calibration of model with costly mobility of workers

In this part of the appendix we describe the calibration approach of the model with costly mobility of workers described in the robustness section. We calibrate the parameter ν referring to the cost of worker mobility across sectors to target the employment growth of import-competing sectors in response to a decline in aggregate productivity.

In order to estimate by how much employment growth declines in response to a decrease in domestic aggregate productivity, we use a similar estimating equation as 31 but with sector employment growth as the dependent variable. We define employment growth in each sector as

$\Delta emp_{it} = \ln(emp_{it}) - \ln(emp_{it-1})$. We use the dataset constructed for the analysis in section 2, where emp_t refers to the total number of workers in sector i in period t . The data sample still includes 19 manufacturing sector and spans the period 1980-2006. The equation below shows the estimated parameters with standard errors in parenthesis:

$$\Delta emp_{it} = \begin{matrix} 0.008 \\ (0.003)^{***} \end{matrix} + \begin{matrix} 0.991\Delta emp_t \\ (0.027)^{***} \end{matrix} - \begin{matrix} 0.377\Delta tfp_t \\ (0.127)^{***} \end{matrix} - \begin{matrix} 0.017dummy_i \\ (0.006)^{***} \end{matrix} + \begin{matrix} 0.75(\Delta tfp_t)(dummy_i) \\ (0.303)^{**} \end{matrix} \quad (29)$$

Notes: # of observations =513; sample =1980-2006; sectors =19; $R^2 = 0.36$. Standard errors are clustered by year to control for inter-sector correlation and heteroscedasticity in the residuals. “*” significance at the 10% level, “**” at the 5% level and “***” at the 1% level.

Note that in our model sector employment varies over time while total employment in each country is stable. However, this is not the case in the data. Thus, we include Δemp_t on the right hand side of equation 29 in order to control for changes in sectoral employment that arise from changes in total manufacturing employment that might occur over time and are not captured by our model or driven by changes in aggregate productivity.

Equation 29 implies that a 1% decline in productivity results in an approximate 0.4% increase in employment growth in exporting sectors and a 0.4% employment decline in the import-competing sectors in the same year that productivity declines.

Appendix C: Details on the empirical analysis

In this appendix we describe the empirical analysis conducted in section 2 in more detail and provide some robustness checks.

Sector-level data

The data on sector output and sector revenue used in the analysis in section 2 was retrieved from the NBER-CES Manufacturing Industry Database. This data base contains annual industry-level data from 1958-2009 on output, employment, payroll and other input costs, investment, capital stocks, TFP, and various industry-specific price indexes. The version that was used in the analysis contains data on 473 six-digit 1997 NAICS industries. For the purposes of our analysis the data was aggregated to the three-digit sector level, resulting in a data-set with 19 manufacturing sectors for the period 1980-2006. The sectors included in the analysis are the following: Food, beverage, and tobacco (NAICS = 311,2); Textiles and products (NAICS = 313,4); Apparel and leather goods (NAICS = 315,6); Wood product (NAICS = 321); Paper (NAICS = 322); Printing and related support activities (NAICS = 323); Petroleum and coal products (NAICS = 324); Chemical (NAICS = 325); Plastics and rubber products (NAICS = 326); Nonmetallic mineral

product (NAICS = 327); Primary metal (NAICS = 331); Fabricated metal product (NAICS = 332); Machinery (NAICS = 333); Computer and electronic product (NAICS = 334); Electrical equipment, appliance, and component (NAICS = 335); Motor vehicles and parts (NAICS = 3361-3); Aerospace and miscellaneous transportation eq. (NAICS = 3364-9); Furniture and related product (NAICS = 337); Miscellaneous (NAICS = 339).

Sector output is measured by dividing the total value of shipments in each sector by a sector price index ($\text{output} = \text{VSHIP} / \text{PISHIP}$ where VSHIP is the database variable name of the value of shipments and PISHIP is the database variable name for the sector price index). The value of shipments is aggregated by summing up across all industries in each sector. The price index is aggregated by taking the weighted average across all industries in each sector with weights equal to the share of each industry in the total shipments for the sector.

Sector revenue is measured by dividing the total value of shipments by the personal consumption expenditure price index obtained from the Saint Louis Federal Reserve website.

In order to construct the sector level RCA index described in section 2 sector level data on exports and imports at the six-digit NAICS level was retrieved from Peter Schott's website. The data runs from 1989 to 2005. Both imports and exports are aggregated to the three-digit level sectors listed above by summing up across all industries within each sector. Then, the RCA measure is calculated at the sector level and averaged over the period 1989-2005. Based on this average RCA we constructed the dummy described in section 2. According to this classification we identified 9 comparative advantage sectors, including Aerospace and miscellaneous transportation eq. (NAICS = 3364-9); Chemical (NAICS = 325); Computer and electronic product (NAICS = 334); Food, beverage, and tobacco (NAICS = 311,2); Fabricated metal product (NAICS = 332); Machinery (NAICS = 333); Paper (NAICS = 322); Printing and related support activities (NAICS = 323); Plastics and rubber products (NAICS = 326); and 10 comparative disadvantage sectors, including Apparel and leather goods (NAICS = 315,6); Furniture and related product (NAICS = 337); Nonmetallic mineral product (NAICS = 327); Petroleum and coal products (NAICS = 324); Primary metal (NAICS = 331); Textiles and products (NAICS = 313,4); Wood product (NAICS = 321); Electrical equipment, appliance, and component (NAICS = 335); Miscellaneous (NAICS = 339); Motor vehicles and parts (NAICS = 3361-3).

Robustness check with alternative identification of aggregate productivity

The following analysis is based on Galí and Rabanal [2005] to identify aggregate productivity shocks and on Peersman and Smets [2005] to assess the effect of the identified productivity shocks on specific sectors. Peersman and Smets [2005] use a euro-area wide VAR model to identify a monetary shock and its historical contribution to the evolution of euro-area nominal interest rates. Then they regress the identified shock on industry level output within euro-area countries to analyze whether countries and industries react differently to monetary shocks. The advantage

of this methodology is that using a structural VAR based on aggregate variables, we can identify a productivity shock that is exogenous to sector output and revenue. Thus, we check whether our results in section 2 might be subject to endogeneity issues due to identifying changes in aggregate productivity using business sector TFP.

We use a standard methodology based on Galí and Rabanal [2005] to identify aggregate productivity shocks. In Galí and Rabanal [2005], the effects of technology shocks are identified and estimated using a structural VAR approach. In its simplest specification, which we follow here, the empirical model uses information on two variables: labor productivity (output per hour) and labor input (hours per capita), which we denote by z_t and h_t , respectively, both expressed in logs. Fluctuations in labor productivity growth (Δz_t) and labor input (h_t) are assumed to be a consequence of two types of shocks hitting the economy and propagating their effects over time. Formally, the following moving average (MA) representation is assumed:

$$\begin{bmatrix} \Delta z_t \\ h_t \end{bmatrix} = \begin{bmatrix} C^{11}(L) & C^{12}(L) \\ C^{21}(L) & C^{22}(L) \end{bmatrix} \begin{bmatrix} \varepsilon_t^z \\ \varepsilon_t^d \end{bmatrix} = C(L)\varepsilon_t, \quad (30)$$

where ε_t^z and ε_t^d are serially uncorrelated mutually orthogonal structural disturbances whose variance is normalized to unity. The polynomial $|C(z)|$ is assumed to have all its roots outside the unit circle. Estimates of the distributed lag polynomials $C^{ij}(L)$ are obtained by a suitable transformation of the estimated reduced form VAR for $[\Delta z_t, h_t]$ after imposing the long-run identifying restriction $C^{12}(L) = 0$. That restriction defines ε_t^z and ε_t^d as shocks with and without a permanent effect on labor productivity, respectively. Galí and Rabanal [2005] proposes to interpret ε_t^z , the shocks with permanent effects on productivity, as technology shocks. On the other hand, the shocks ε_t^d can potentially capture a variety of driving forces behind labor input (output) fluctuations that would not be expected to have permanent effects on labor productivity.

Note that we do not apply a first difference transformation to the labor input. This is in line with evidence from Christiano et al. [2003] who find that if they use the level of hours as opposed to the first difference in hours, then a positive technology shock as identified by Galí and Rabanal [2005] results in a rise in hours while it brings about a fall in hours in case of first difference specification. Some papers in the literature, including Galí and Rabanal [2005] themselves, treat the labor input as a non-stationary variable and apply first difference transformation to it. However, Christiano et al. [2003] “find that the odds overwhelmingly favor the level specification.” (p. 5). They explain the difference in their results by the fact that the papers treating labor input as a non-stationary series rely on univariate methods, while Christiano et al. [2003] rely on multivariate methods. Hansen [1995] shows that incorporating information from related time series has the potential to enormously increase the power of unit root tests. In addition to the evidence by Christiano et al. [2003] we would like to identify an empirical shock that closely follows the implied predictions of its theoretical counterpart: in our model a positive productivity shock implies a rise in hours.

We retrieve data on output per hour z_t and hours per capita h_t for the US from the Federal Reserve Economic Data (FRED) maintained by the Federal Reserve Bank of Saint Louis. Having estimated the structural VAR outlined above, we use historical decomposition to obtain a series ($shock_t$) which describes the historical contribution of our identified productivity shock to fluctuations in labor productivity growth Δz_t . Figure 8 shows a plot of the identified productivity shock (dashed line) against growth rate of aggregate TFP (solid line). The identified shock closely follows the growth rate of the TFP indicator suggesting that our regression results are robust to our definition of productivity shocks.

To further check the sensitivity of our regression results with respect to the identification of aggregate productivity we re-estimate 1 but substituting Δtfp_t with $shock_t$. Equations 31 and 32 show the estimated parameters with standard errors in parenthesis.

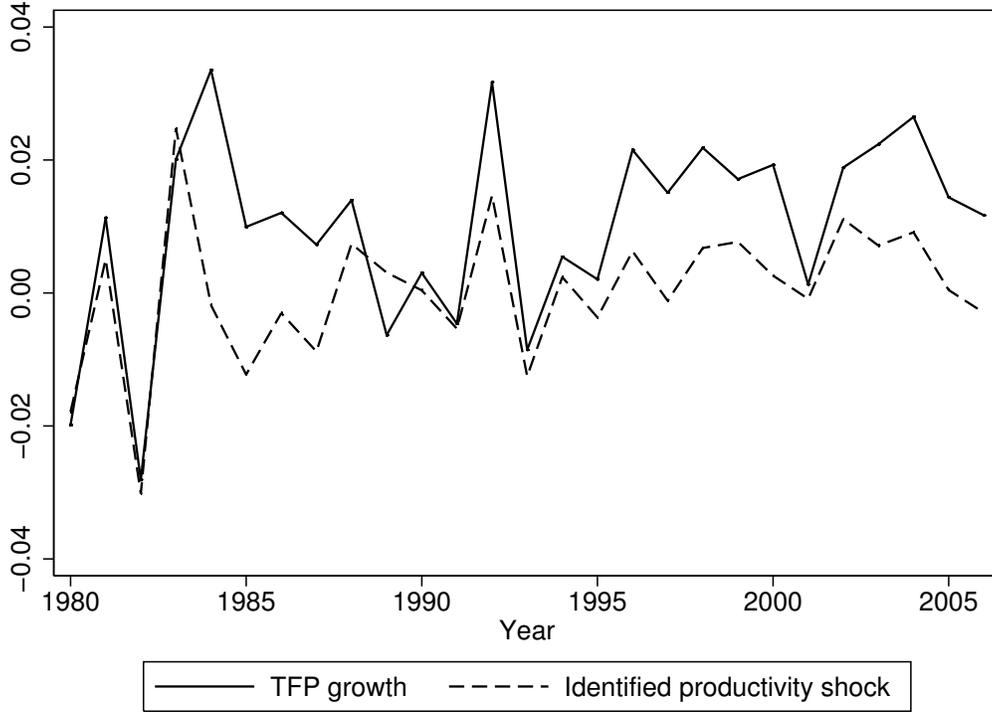


Figure 8: TFP growth vs. Identified shock series

$$\Delta y_{it} = \begin{matrix} 0.025 \\ (0.006)^{***} \end{matrix} + \begin{matrix} 0.397 shock_t \\ (0.481) \end{matrix} - \begin{matrix} 0.016 dummy_i \\ (0.004)^{***} \end{matrix} + \begin{matrix} 1.574(shock_t)(dummy_i) \\ (0.439)^{***} \end{matrix} \quad (31)$$

$$\Delta r_{it} = \begin{matrix} 0.01 \\ (0.007) \end{matrix} + \begin{matrix} 0.484 shock_t \\ (0.574)^{***} \end{matrix} - \begin{matrix} 0.009 dummy_i \\ (0.005)^* \end{matrix} + \begin{matrix} 1.668(shock_t)(dummy_i) \\ (0.421)^{***} \end{matrix} \quad (32)$$

Notes: # of observations =513; sample =1980-2006; sectors =19; $R^2 = 0.071$ for equation 31, $R^2 = 0.054$ for equation 32. Standard errors are clustered by year to control for inter-sector correlation and heteroscedasticity in the residuals. “*” significance at the 10% level, “**” at the 5% level and “***” at the 1% level.

The results described in section 2 are robust to the way we identify aggregate productivity shocks. An increase in aggregate productivity still has a positive impact on sector revenue and output although it is no longer significant. Most importantly, the coefficients in front of the interaction term are still positive and significant indicating that growth in comparative disadvantage sectors is more responsive to productivity shocks than the growth in comparative advantage sectors. The coefficients are bigger than in our baseline results. In the baseline the results suggest that comparative disadvantage sectors are about twice more responsive than comparative advantage sectors. The results reported above suggest that comparative disadvantage sectors are about five times more responsive in terms of output and four and a half times more responsive in terms of revenue. As in section 2, the similarity of the relative response in terms of revenue and output suggests that the shift in revenue is driven by a shift in output across sectors rather than a shift in relative prices.

Robustness check with alternative definition of RCA

Our preferred definition of RCA uses data on sector exports and imports. Another popular measure of RCA is based on an index introduced by Balassa which only considers the export structure of the sector. This index is the ratio of the share of exports of an industry or a commodity group in the total exports of a country to the share of world exports of that industry or commodity group to total world exports. A value larger than 1 reflects comparative advantage, while a value less than 1 reflects comparative disadvantage. We use this alternative measure of RCA to check the robustness results with respect to the definition of comparative advantage as well as to check whether the import structure of a sector matters for our results.

Data on Balassa-based RCA was obtained from the International Trade Competitiveness Database website (the <http://ref.sabanciuniv.edu/databases>) for 66 two digit level products based on the Standard International Trade Classification, Rev.3 (SITC3). The data is annual and encompasses the period 1990-2006. After taking the annual average, this RCA data was converted based on a concordance developed by Maskus [1991]²¹ from the two digit SITC, rev. 2 product classification to the three digit International Standard Industrial Classification of All Economic Activities, rev. 2 (ISIC2). The conversion resulted into RCA data for 20 manufacturing ISIC2 sectors. Finally, data for ISIC2 sectors was mapped into NAICS sectors. For some sectors this involved aggregating RCA data for ISIC2 sectors into a NAICS sector.²² For other sectors the mapping

²¹Source: Maskus, Keith E [1989]: "Comparing International Trade Data and Product and National Characteristics Data for the Analysis of Trade Models", pp.42, in: Hooper and Richardson, International Economics Transactions, Vol 55, The University of Chicago Press.

²²For example ISIC2 has separate sectors for Food, Beverages, and Tobacco products while NAICS has grouped Food, beverages and tobacco in one sector. In these cases, we simply took the average of RCA.

involved splitting one ISIC2 sector into smaller NAICS sectors and using the same RCA observation for both NAICS sectors.²³ The new classification implied some changes. Three comparative disadvantage sectors according to the previous classification became comparative advantage sectors, including Electrical equipment, appliance, and component (NAICS = 335); Miscellaneous (NAICS = 339); and Motor vehicles and parts (NAICS = 3361-3). Two comparative advantage sectors became comparative disadvantage sectors according to the new classification, including Fabricated metal product (NAICS = 332) and Plastics and rubber products (NAICS = 326). This resulted in 10 comparative advantage sectors and 9 comparative disadvantage sectors according to the new classification. After constructing our dummy variable based on this new classification, we re-estimated equation 1

Equations 33 and 34 show the estimated parameters with standard errors in parenthesis.

$$\Delta y_{it} = \begin{matrix} 0.013 \\ (0.006)** \end{matrix} + \begin{matrix} 1.194\Delta t f p_t \\ (0.294)*** \end{matrix} - \begin{matrix} 0.021dummy_i \\ (0.004)*** \end{matrix} + \begin{matrix} 0.497(\Delta t f p_t)(dummy_i) \\ (0.246)* \end{matrix} \quad (33)$$

$$\Delta r_{it} = \begin{matrix} -0.002 \\ (0.007) \end{matrix} + \begin{matrix} 1.215\Delta t f p_t \\ (0.3)*** \end{matrix} - \begin{matrix} 0.015dummy_i \\ (0.006)** \end{matrix} + \begin{matrix} 0.687(\Delta t f p_t)(dummy_i) \\ (0.407) \end{matrix} \quad (34)$$

Notes: # of observations =513; sample =1980-2006; sectors =19; $R^2 = 0.117$ for equation 33, $R^2 = 0.095$ for equation 34. Standard errors are clustered by year to control for inter-sector correlation and heteroscedasticity in the residuals. “*” significance at the 10% level, “**” at the 5% level and “***” at the 1% level.

The equations reported above indicate that our baseline results are robust to the way we classify sectors. The new results confirm that comparative disadvantage sectors are more responsive to aggregate shocks than comparative advantage sectors. The size of the relative response across sectors is still the same in terms of revenue and output which suggests that the shift in revenue is mostly driven by a shift in output across sectors than a shift in relative prices. The significance of this result is somewhat diminished. The coefficient in front of the interaction term in the revenue regression is no longer significant and the coefficient in the output regression is only significant at the ten percent level. This suggests that the import structure of the sector is important in order to understand why comparative disadvantage sectors are more responsive than comparative advantage sectors to changes in aggregate productivity.

²³For example, we have NAICS data for two transportation sectors Motor vehicles and parts and Aerospace and miscellaneous transportation equipment, while ISIC2 just has a sector called Transportation. In that case, we used the same RCA observation of ISIC2 transportation for the two separate NAICS sectors.